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Full Length Article

Navigating the complexities of healthcare costs in Bangladesh: A closer look at environmental quality, economic growth, energy use, industrialization, urbanization, and forest area

Asif Raihan [a,*], Mohammad Ridwan [b], Syed Masiur Rahman [a,c,d], Tapan Sarker [e]

[a] Applied Research Center for Environment and Marine Studies, King Fahd University of Petroleum & Minerals, Dhahran, 31261, Saudi Arabia
[b] Department of Economics, Noakhali Science and Technology University, Noakhali, 3814, Bangladesh
[c] Department of Civil and Environmental Engineering, King Fahd University of Petroleum & Minerals, Dhahran, 31261, Saudi Arabia
[d] Interdisciplinary Research Center for Construction and Building Materials, King Fahd University of Petroleum & Minerals, Dhahran, 31261, Saudi Arabia
[e] School of Business, University of Southern Queensland, QLD, 4300, Australia

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ABSTRACT

Bangladesh is grappling with the challenge of balancing public health with pollution reduction. The current research seeks to analyze the relationships between ecological indicators and health expenditure and to provide policy suggestions to enhance environmental conditions and minimize healthcare costs. The investigation explored various elements, such as carbon dioxide (CO_2) emissions, gross domestic product (GDP), the use of fossil fuels and renewable energy sources, industrialization, urbanization, and forest areas. The dynamic ordinary least squares (DOLS) approach was used to explore time series data from 2000 to 2022, and the results revealed that every 1 % increase in CO_2, GDP, industrialization, urbanization, and consumption of fossil fuels increased long-term health expenditures by 1.45 %, 0.38 %, 1.39 %, 0.91 %, and 1.04 %, respectively. Instead, a 1 % expansion in forest area and renewable energy use would reduce health expenditures by 1.91 % and 0.48 %, respectively. To test the robustness of the model, canonical cointegrating regression (CCR) and fully modified ordinary least squares (FMOLS) estimation techniques were incorporated. The findings offer policy recommendations for Bangladesh to reduce pollution and ensure the sustainability of the environment and healthcare facilities. These outcomes are valuable for generating a preventive health plan to combat the growing health effects of environmental pollution in Bangladesh.

Abbreviations

ADF	Augmented Dickey-Fuller
AMG	Augmented mean group
ARDL	AutoRegressive distributed lag
CCEMG	Common correlated effect mean group
CCR	Canonical cointegrating regression
CO_2	Carbon dioxide
CUSUM	Cumulative sum of recursive residuals
DF-GLS	Dickey-Fuller generalized least squares
DOLS	Dynamic ordinary least squares
EKC	Environmental Kuznets Curve
FA	Forest area
FFE	Fossil fuel energy use
FMOLS	Fully modified ordinary least squares
GDP	Gross domestic product
HE	Health expenditure
IND	Industrialization
GMM	Generalized method of moments
NOx	Nitrogen oxides
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary least squares
P-P	Phillips-Perron
PM2.5	Particulate matter 2.5
RNE	Renewable energy use
SDGs	Sustainable development goals
SO_2	Sulfur dioxide
URB	Urbanization
USD	United States dollar
WDI	World Development Indicator
WHO	World Health Organization

* Corresponding author.
E-mail address: asif.raihan@kfupm.edu.sa (A. Raihan).

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1. Introduction

Carbon dioxide (CO_2) emissions from deforestation and the use of nonrenewable energy are responsible for most of the warming and resulting climatic changes that the world has experienced in the 21st century (Begum et al., 2025). It is believed that a continuous increase in CO_2 emissions would have catastrophic repercussions on the planet's climate, severely impacting civilization and human health (Raihan et al., 2023a). Global health spending has been steadily increasing over the years, reflecting the growing demand for healthcare services, medical advancements, and the need to address public health challenges worldwide. Recent projections by the World Health Organization (WHO) reported that the global expenditure on health was approximately USD 9.7 trillion in 2022, representing approximately 10 % of the global GDP. The increasing healthcare costs pose a risk to efforts to provide healthcare to all individuals. To address the health hazards caused by environmental deterioration, several countries have recognized the importance of restructuring their healthcare systems (Xiu et al., 2022). Like many other emerging nations, Bangladesh aspires to enhance its healthcare system, but the growing expense of healthcare is significantly draining national economies (Raihan et al., 2022a). Owing to high levels of pollution and rapid population growth in Bangladesh, the country's environment is rapidly degrading (Akter et al., 2024). In 2022, Bangladesh's fossil CO_2 emissions rose by 3.57 % compared with those in 2021, totaling 109 million tons. Over the past five years, the average annual growth rate of CO_2 emissions has been approximately 3.1 % (World Bank, 2025). Bangladesh has become one of the seven economies most susceptible to economic instability and public health hazards connected with climate change, as confirmed by the Global Climate Risk Index 2021. Enhancing environmental conditions by reducing pollution and acclimating to climate change has emerged at the top of the agenda as a means of ensuring responsible growth and health security (Rahman et al., 2024).

The Sustainable Development Goals (SDGs) were formulated by the United Nations with the overarching objective of enhancing global well-being by 2030. It is argued that health transcends national boundaries and socioeconomic conditions to have major implications for advancement over time. For emerging nations with rapid population growth, there is an immediate need to increase living standards (Huo et al., 2023). More people believe that natural resources such as trees, land, air, and groundwater are under high pressure. Furthermore, evidence suggests that elevated air pollution levels increase the severity of contagious diseases such as dengue fever, tuberculosis, cholera, and malaria, which increases healthcare expenses (Liao et al., 2024). However, health is a key determinant of overall quality of life, and CO_2 emissions have an impact on public healthcare. Prolonged exposure to CO_2 can lead to headaches, drowsiness, anxiety, stinging or pin-and-needle sensations, difficulty breathing, perspiration, fatigue, a rapid pulse, an increase in blood pressure, hypoxia, asphyxiation, and convulsions, among other symptoms. Therefore, scholars and politicians have focused on the correlation between environmental damage and high medical expenses.

Economic research from both developing and developed countries has focused increasingly on the links among GDP expansion, environmental damage, and health expenditure in the last 20 years. Bangladesh's economy is growing at the fifth-fastest pace worldwide and the second-fastest pace in South Asia (World Bank, 2025). With a GDP of USD 6.29 billion in 1972, Bangladesh is expected to generate USD 460.13 billion in 2022 (World Bank, 2025). Consequently, Bangladesh relies heavily on fossil fuels to operate its industrial sector, key infrastructure, and transportation systems. Air pollution and toxic waste disposal have increased due to economic expansion, which is harmful to human health (Akasha et al., 2024). The growth of urbanization and industrialization in Bangladesh has increased the use of fossil fuels, environmental degradation, and health risks. Moreover, the highly harmful gases generated by industry contaminate the air, harming human health and decreasing productivity at work. In contrast, increasing industrialization, urbanization, and economic development are leading to greener, more frequent, and more efficient adoption in urban settings and public healthcare facilities. There is a growing interest in how GDP growth, urbanization, and industrialization impact healthcare expenditures in Bangladesh because of the profound impact these factors have on the country's ecology and public health. Furthermore, concerns about energy shortages, climate change, destruction of the environment, and threats to public health have increased the value of sustainable power (Iyke, 2024). Worldwide, people are beginning to notice the negative consequences of fossil fuels on the planet and public health; thus, businesses are starting to look for alternatives. One of these alternatives is renewable energy. Sustainable energy from renewable resources has the potential to keep the world's economy, ecosystems, and populations healthy in the long run (Raihan & Tuspekova, 2022). Bangladesh has enacted regulations to encourage the development of this sector with various renewable energy resources. However, insufficient research has examined how renewable energy might improve ecological conditions and, by extension, public health in Bangladesh.

Bangladesh is highly susceptible to natural calamities such as floods and landslides. Deforestation is another important source of environmental degradation in Bangladesh (Sarkar & Mukul, 2024). Forests are being cleared at an alarming rate to make way for buildings, farms, highways, and other necessities, such as development, urbanization, settlements, industrialization, agriculture, and mining. Changes in land use, such as rapid urbanization and forest cover loss, can lead to significant CO_2 emissions. These emissions can generate numerous health complications among people in different economies, increasing healthcare expenses (Slathia et al., 2024). Trees absorb CO_2 from the atmosphere and store it as biomass, reducing the rate of global warming and increasing biodiversity, health, and air quality (Raihan et al., 2023b). To improve the environment, more trees should be planted to reduce the amount of CO_2 released into the air, thus benefiting people's health. If investments in forests and reforestation are encouraged, many health issues can be resolved, and healthcare costs can be reduced. Lower levels of CO_2 emissions in the atmosphere have positive health effects (Pradhan et al., 2024). However, the importance of forests has been neglected in health and environmental studies, particularly in Bangladesh. Therefore, it is necessary to assess the scope of forests to improve public health in Bangladesh.

Healthcare concerns and expenditures are increasing in both developed and emerging nations. Bangladesh is pivotal to the discourse on healthcare expenditure due to its status as a densely populated, lower-middle-income country that has achieved significant health benefits despite limited resources. Its healthcare system operates under significant financial constraints, with low per capita health spending and a heavy reliance on out-of-pocket expenses, making it a critical case for understanding how effective health interventions can be sustained in resource-scarce settings. Examining the determinants of healthcare expenditure in Bangladesh offers unique insights into the interplay of socioeconomic factors, such as income levels, energy consumption, urbanization, industrialization, and environmental quality, in shaping healthcare costs. These factors provide valuable lessons on how countries with similar socioeconomic contexts can optimize health spending, prioritize policy interventions, and balance equity with efficiency in healthcare delivery. Bangladesh should find a solution to the challenging paradox of improving public health while reducing environmental pollution. For a country such as Bangladesh, which is in the midst of rapid economic development, it is crucial to design a preventative health plan to mitigate the growing health risks posed by environmental pollution. Environmental risk factors play a crucial role in health issues and are the primary cause of rising healthcare costs. If the nation hopes to balance environmental destruction, healthcare protection, climate change mitigation, and sustainable development,

policymakers should be aware of this.

Understanding the multifaceted relationship between environmental, economic, and developmental factors and health expenditure is imperative for formulating effective and sustainable public health policies in Bangladesh. As a lower-middle-income country experiencing rapid economic growth, Bangladesh is facing escalating environmental degradation stemming from intensified CO_2 emissions, fossil fuel dependency, industrialization, and unplanned urban expansion. These phenomena exacerbate public health risks, increase the burden of disease, and consequently increase healthcare costs. Simultaneously, underexplored mitigating factors—such as the expansion of forest cover and the integration of renewable energy—have the potential to offset environmental damage and reduce healthcare expenditures by improving air quality and ecosystem resilience. Given the intricate interlinkages among these variables, a comprehensive empirical assessment is essential to understand their collective and individual impact on health expenditure. Such analysis can inform evidence-based strategies that promote economic development while safeguarding environmental integrity and public health, thus ensuring a more sustainable trajectory for Bangladesh's healthcare system.

Few studies have used macroeconomic approaches to examine the connection between environmental conditions and health expenses, even though there is growing scientific enthusiasm in this field. Past econometric studies did not look at how environmental factors affect public healthcare; instead, they focused on how various socioeconomic and environmental factors, such as energy use and GDP growth, impact CO_2 emissions (Bekun, 2022, 2024). Although few studies have examined the effects of GDP expansion, energy utilization, and CO_2 emissions on health expenditures (Karaaslan & Çamkaya, 2022; Slathia et al., 2024), there is still a gap in the literature concerning the impacts of other ecological indicators, such as urbanization, industrialization, and forest area, on health expenditures. Therefore, to fill this gap in the existing work, the present study seeks to concisely observe the complex links between health expenditure and its determinants in Bangladesh. The research question is as follows: What are the actual impacts of CO_2 emissions, GDP growth, industrialization, urbanization, fossil fuel usage, clean power, and forest areas on health expenditures in Bangladesh?

The current paper adds numerous contributions to the ongoing research and policymaking process by providing valuable insights into healthcare costs in Bangladesh. One of the key contributions of this study is its detailed analysis of the role of environmental quality in shaping healthcare costs. It emphasizes how deteriorating environmental conditions from intensifying emissions, energy use, urbanization, industrialization, and economic growth can contribute to rising healthcare expenses due to an increase in health issues. By examining the consequences of factors for healthcare, this research sheds light on the long-term economic burden of ecological damage to healthcare systems in Bangladesh. Additionally, the study discusses how rapid economic development in Bangladesh has led to both positive and negative impacts on healthcare expenses. While economic growth can enable greater access to healthcare services and improvements in healthcare infrastructure, it can also lead to increased demand for healthcare as a result of higher living standards and alterations in disease types. The study highlights the necessity of sustainable development that does not exacerbate healthcare costs or compromise environmental quality.

Furthermore, this research takes a comprehensive approach, acknowledging the interdependence of various factors influencing healthcare expenses, in contrast to previous studies that have typically concentrated on individual aspects. This study is unique from other studies, such as Yang and Usman (2021), who have shown that a country's low-carbon policy has led to an improvement in its emissions, and Qu et al. (2023), who have identified the substantial influence of health expenditure and GDP expansion on CO_2 release. The incorporation of ecosystem condition indicators in the present study demonstrates a sophisticated comprehension of the complex dynamics involved. This study provides significant contributions to understanding the relationships among various economic, environmental, and social factors and their impacts on healthcare costs in Bangladesh. The marginal contribution of this study lies in its integrated and country-specific analysis of health expenditure determinants in Bangladesh, which remains underexplored in the literature. Unlike prior studies that often isolate the effects of economic growth, CO_2 emissions, or energy consumption, this study adopts a multidimensional framework that simultaneously investigates the roles of CO_2 emissions, fossil fuel usage, renewable energy consumption, industrialization, urbanization, and forest area in shaping healthcare expenditure. By doing so, it bridges a significant empirical gap in health economics, particularly for lower-middle-income countries undergoing rapid development. Additionally, this study is among the first to quantify the health cost-reducing potential of forest expansion and renewable energy in Bangladesh, offering a novel perspective on the ecological determinants of healthcare costs. The use of the DOLS, complemented by FMOLS and CCR robustness checks, adds further methodological rigor. These analytical advancements generate nuanced insights for policymakers seeking to reconcile economic growth with environmental protection and sustainable healthcare financing. The study highlights the intricate linkages between healthcare expenditure and broader socioeconomic development in the country.

The analysis of energy use, industrialization, and urbanization presents another valuable contribution. The study examines how these factors contribute to the rising costs of healthcare in urban areas. Industrialization and urbanization often result in increased pollution and lifestyle-related diseases, which can significantly strain the healthcare system. Energy consumption is also linked with environmental degradation, further increasing healthcare expenditures. The study highlights the need for innovative strategies that address energy use, manufacturing operations, and urban development to reduce the healthcare burden. The unique feature of this analysis is that it assesses the influence of renewable energy, fossil fuels, industrialization, and forest areas on health expenses. Finding a link between the use of fossil fuels, green power, excessive industrialization, the existence of forests, and healthcare costs is a revolutionary effort. Moreover, although Ampon-Wireko et al. (2023) considered energy use as an indicator of health costs in their research, this research compared the costs of healthcare in Bangladesh utilizing both traditional fossil fuels and renewable energy sources to gain a greater grasp of the role that both play in the country's overall healthcare expenditures. Considering both traditional fossil fuels and renewable energy sources is important when investigating the determinants of healthcare costs in Bangladesh, as energy types influence environmental quality, which directly impacts public health and associated medical expenses. Additionally, the role of forested areas is explored, with studies discussing how forests and urban green spaces can improve the environment and public health while reducing health expenditures. Although recent studies in the area of health economics (Ampon-Wireko et al., 2023; Slathia et al., 2024) have analyzed the influences of GDP expansion and CO_2 release on health expenditure, limited research has focused on the impacts of forests and green spaces on health spending. Consequently, the novelty of this paper lies in its contribution to the health economics literature by exploring the nexus between forested areas and health expenditure via several econometric techniques. Overall, the study provides a nuanced comprehension of how environmental, energy, and economic factors interconnect and affect healthcare costs in Bangladesh.

Finally, the results of this investigation offer more detailed and actionable information to decision-makers in Bangladesh about healthcare improvement and pollution reduction. It stresses the need for a more comprehensive view of healthcare regulations, taking into account not only hospitals but also the broader context of urbanization, ecological damage, and financial stability. It also indicates how the decarbonization policy of Bangladesh, aimed at meeting the terms of the Paris Agreement and the SDGs, will help improve national health

expenditures and fulfill energy transition planning, which aims to focus 40 % of its energy on renewable energy by 2041. This paper may be applied to analyze environmental policies and generate modern legislation to help Bangladesh prepare for future scenarios of global warming. Stronger policies and operational efforts to minimize the destructive impact of temperature increases could be relevant in the spheres of public health, responsible growth, and ecosystem protection. In addition, the findings of this paper can be used in other developing nations to develop programmes to adjust and reduce the consequences of global climate change on the health of their citizens. The practical significance of this study lies in its potential to guide policymakers in Bangladesh and comparable developing nations toward integrated environmental and health planning. By empirically quantifying how environmental degradation—driven by CO_2 emissions, fossil fuel use, deforestation, and industrialization—raises healthcare expenditures, this study provides actionable evidence that environmental and public health policies must not operate in silos. These findings suggest that investments in renewable energy and forest conservation are not only environmentally beneficial but also economically prudent strategies for controlling rising health costs. The results offer a replicable framework for countries facing the dual burden of rapid urbanization and ecological stress, particularly in South Asia, Sub-Saharan Africa, and Latin America. For such nations, adopting sustainable energy transitions, protecting forest cover, and managing industrial emissions can simultaneously improve public health outcomes and fiscal sustainability in healthcare. Thus, this study contributes to the global discourse on sustainable development by demonstrating that improving environmental quality is a strategic pathway for achieving health equity and economic resilience.

2. Literature review

Numerous studies have shown that developing nations face enormous difficulties in achieving a sustainable economic development rate (Asghar et al., 2024; Cai et al., 2024; Hunjra et al., 2024; Idroes et al., 2024; Raihan et al., 2025; Wu et al., 2024). Many studies emphasize that developing nations often prioritize rapid industrialization and poverty reduction, which can lead to resource overexploitation, deforestation, and increased carbon emissions (Anas et al., 2024; Chen et al., 2024; Oke et al., 2025; Zhang et al., 2022). Structural constraints, such as limited financial resources, weak regulatory frameworks, and reliance on environmentally harmful sectors such as mining and agriculture, further complicate the transition to sustainable practices (Islam & Ali, 2024; Liu, 2025; Raihan et al., 2024; Udeagha & Ngepah, 2023). The literature also underscores the unequal historical responsibility for climate change, which puts developing nations in a difficult position, as they push for growth while being disproportionately affected by environmental degradation (Green & Healy, 2022; Mohanty, 2025; Nguyen et al., 2023; Raihan & Bari, 2024). Numerous studies suggest that achieving this balance requires integrated policy approaches that promote green technologies, capacity building, and international financial support to enable sustainable development without stalling economic progress (Herrador & Van, 2024; Raihan, 2024; Singh & Ballini, 2025; Soputra, 2025).

Many scholars in developing countries have long discussed health expenditure indicators (Demir, Demir, Karaduman, & Cetin, 2023). The relationship between health expenditure and its main determinants provides useful information for lawmakers. In every country, health is an important aspect of the development strategy since it may influence an increase in life expectancy at birth (Jaba et al., 2014) and overall well-being (Mushkin, 1962). In this respect, credible econometric techniques need to examine the effects of a variety of socioeconomic drivers, such as economic growth, pollution, energy consumption, urbanization, industrialization, free trade, and population. A growing economy is highlighted as the core factor of health expenditures (Yang & Usman, 2021; Shahzad et al., 2020; Apergis et al., 2020). Other possible determinants of health spending include CO_2 emissions (Apergis et al., 2018; Chaabouni et al., 2016), urbanization (Ahmad et al., 2021), and renewable energy (Ullah, Rehman, Khan, Shah, & Khan, 2020).

A study by Shahzad et al. (2020) demonstrated that in Pakistan, GDP expansion had a positive influence on health spending from 1995 to 2017. Apergis et al. (2020) reported that an increase in GDP and health expenditures had a positive relationship in 178 countries from 1995 to 2017. In addition, the panel OLS approach of Yetim et al. (2021) revealed that economic growth increased health expenditures from 2000 to 2017 in 36 OECD countries. Yang and Usman (2021) revealed that GDP development contributed positively to health costs in the long run using 1995–2018 data from the AMG and CCEMG estimators. Unlike these studies, Wang et al. (2019) determined that the long-term outcomes of the ARDL model in Pakistan reveal a negative impact of monetary expansion on health expenditures from 1995 to 2017.

Similarly, Chaabouni et al. (2016) studied the connection between CO_2 emissions, health spending, and economic growth on the basis of other indicators in 51 countries, which were divided into low-income, low-middle-income, and high-middle-income countries. The results of the estimation in the long run demonstrated that CO_2 emissions prompt health spending. In their study, Usman et al. (2019) explored the associations among air pollution, economic and non-economic aspects, and health spending between 1994 and 2017 in 13 emerging economies. They found that CO_2 emissions and the environment index have a positive effect on government health expenditures and a negative effect on expenditures on privately financed health in the long term.

Furthermore, Ahmad et al. (2021) introduced urbanization as one of the possible indicators of health expenditure in China. The authors used panel GMM and reported that urbanization leads to higher public expenditure in the country. Ullah et al. (2020) reported that clean energy consumption provides a healthy environment. The authors used a simultaneous equation model to estimate the impact of green power on public health in Pakistan, and the results revealed that sustainable energy is negatively related to health expenditure, confirming their hypothesis. Shahzad et al. (2020) used a similar indicator and tested it for Pakistan from 1995 to 2017, and the results revealed that renewable energy has an opposing link with health expenditures, suggesting that greater use of eco-friendly energy can minimize environmental pollution and thus reduce the cost of medicines associated with health expenditures.

In addition to the above indicators, some previous studies have considered population aging (Zweifel et al., 1999; Hogan, Lunney, Gabel, & Lynn, 2001), healthcare technology (Bodenheimer, 2005), and many others. However, the different health expenditure indicators used in previous studies could lead to different results depending on the stage of development the country is in or the country's health policy. Some studies have examined how changes in GDP, power consumption, and CO_2 affect health care costs, but few have examined how changes in urbanization, industrialization, and forest area affect these same costs (Slathia et al., 2024).

Moreover, previous research has frequently examined healthcare spending on a global scale or concentrated on a specific set of factors, overlooking the distinct socioeconomic and environmental factors in developing countries such as Bangladesh. Consequently, there is a research gap in the exploration of other possible health expenditure indicators via econometric techniques that adopt the latest time series data in the context of developing countries, which could contribute more knowledge in this field. Consequently, the present paper seeks to overcome a notable lack of existing research by exploring the complex connections between healthcare expenses and multiple environmental, economic, and energy-related factors within the particular context of Bangladesh.

In Bangladesh, rapid economic growth often comes at the cost of ecosystem damage, such as increased air and water pollution, deforestation, and industrial waste (Raihan et al., 2022b). This environmental harm directly contributes to an increase in health problems such as respiratory diseases, waterborne illnesses, and malnutrition, leading to

increased health expenditures at both the household and national levels (Ofremu et al., 2024). Thus, while economic growth increases income and development, it also indirectly drives healthcare costs by deteriorating environmental quality and public health (Yacour et al., 2024). Historically, the literature on healthcare costs in Bangladesh has not fully explored the impacts of environmental quality, urbanization, industrialization, and energy use as key factors. This study seeks to address this gap by including carbon emissions, GDP growth, industrialization, urbanization, fossil fuel and renewable energy consumption, and forest area as factors to be considered. This comprehensive consideration of various factors demonstrates a forward-thinking and sophisticated approach, recognizing that health outcomes are affected by several ecological and developmental factors.

In addition, analyzing health expenditure as an endogenous factor provides a unique perspective on the current body of research. While some studies have focused on health effects (Polcyn et al., 2023), the precise monetary effects of environmental and social variables on Bangladesh's healthcare system have received less attention. While Ampon-Wireko et al. (2023) examined energy use as an indicator of health expenditure, the present study compares healthcare costs in Bangladesh based on fossil fuels and renewable energy to better understand how energy types, through their impact on environmental quality, affect public health and medical expenses. This research acknowledges the importance of comprehending the economic aspects of healthcare costs and offers a more comprehensive perspective on the factors that impact healthcare expenditures in the country.

While prior studies have examined the relationships between health expenditures and variables such as GDP growth, CO_2 emissions, and energy consumption, they often suffer from conceptual and methodological limitations that restrict their applicability to developing countries such as Bangladesh. Specifically, much of the literature either analyzes health spending in high-income contexts or treats environmental and economic determinants in isolation, overlooking the integrated nature of ecosystem degradation, urban dynamics, and healthcare burdens. Moreover, there is a tendency to exclude critical ecological variables such as forest cover and the dichotomy of renewable versus nonrenewable energy use, both of which play significant roles in shaping environmental health outcomes. These gaps have resulted in an incomplete understanding of the systemic drivers of health costs in lower-middle-income economies undergoing rapid industrial and demographic transitions. In response, the present study introduces a novel, multidimensional approach that jointly examines CO_2 emissions, GDP growth, fossil fuel and renewable energy use, industrialization, urbanization, and forest area as determinants of health expenditure in Bangladesh. By applying a robust methodological framework—incorporating DOLS, FMOLS, and CCR estimations—this research not only addresses omitted-variable bias but also captures the long-run dynamics of environmental–health linkages with greater precision. Thus, the paper advances the literature by offering a holistic and context-sensitive model that can inform both national and cross-country policy discourse on sustainable healthcare and environmental management.

3. Theoretical framework and hypothesis development

In theory, health spending is connected to unfavorable environmental circumstances resulting from air pollution and trash generation, which are tied to carbon emissions, heightened reliance on fossil fuel energy, rapid economic expansion, urbanization, and industrialization. Following Abbas et al.'s (2022) frameworks, which suggest that socioeconomic risk factors (e.g., socioeconomic conditions, out-of-pocket expenditures, and the population growth rate) and state capacity determinants (e.g., resources/public finance, institutional governance, and decision-making/powerhouse) lead to health quality and access, the present research assesses the implications of ecological indicators for the health cost of Bangladesh. The research chose health expenditure as the endogenous factor to emphasize the main focus on the financial burden that healthcare services impose on the nation's economy. To simplify the intricacies, this investigation includes various parameters, such as CO_2 release, GDP growth, industrialization, urbanization, fossil fuel and sustainable energy use, and forest area, as components that help explain the situation.

CO_2 emission is an important factor to consider when assessing environmental quality. This study highlights crucial aspects of the probable consequences of pollution for healthcare expenses. The adoption of GDP growth in this paper provides a comprehensive view of a country's economic well-being. This information helps us understand how fluctuations in financial conditions can impact healthcare expenditures. The correlation between industrialization and urbanization and their impact on healthcare demands and environmental degradation should be carefully considered. This in-depth understanding is crucial for making well-informed policies and promoting sustainable development in Bangladesh, as the interplay of CO_2 emissions, industrialization, and urbanization significantly impacts healthcare expenditure. Rapid industrialization and urbanization have driven economic growth, but they have also led to higher CO_2 emissions through increased energy consumption, vehicular pollution, and factory outputs. This environmental degradation contributes to air and water pollution, which in turn increases the prevalence of health problems such as respiratory diseases, cardiovascular conditions, and waterborne illnesses. Urban areas, which are often densely populated and lack adequate infrastructure, exacerbate these health risks, placing additional pressure on healthcare systems. As a result, both public and private healthcare expenditures are increasing to address the growing burden of disease, invest in pollution-related health interventions, and expand medical services to meet the demands of a rapidly urbanizing population. Thus, the intertwined effects of CO_2 emissions, industrial growth, and urbanization directly drive healthcare costs by worsening environmental health conditions in Bangladesh.

In addition, a country's energy profile is strongly affected by the use of renewable energy and fossil fuels, which in turn affects public health and the ecosystem. Increased production and consumption of energy are associated with rapid economic expansion, urbanization, and industrialization; nevertheless, a higher portion of clean power in total energy usage helps to lower the pollution that arises from nonrenewable energy sources (Raihan, 2023). By promoting cleaner energy consumption, Bangladesh can create a healthier environment that indirectly helps manage healthcare costs while improving quality of life. Thus, this investigation attempted to ascertain the financial benefits of using renewable energy. Additionally, increased forest cover is beneficial to both ecological health and human well-being. In addition, incorporating forest areas into the model would provide valuable insights into the correlations among biodiversity, ecosystem health, and healthcare costs. Consequently, forest areas may stand in for other, more basic causes when attempting to explain the implications of environmental indicators for health costs.

The core research question addressed in this work was as follows: do CO_2 emissions, economic growth, fossil fuel, renewable energy, urban, industrialization, and the area of forests affect health expenditures in Bangladesh? According to the insights provided in the introduction and literature review chapters, this study anticipates that CO_2 emissions, GDP expansion, fossil fuel, urbanization, and industrialization will have positive effects on health expenditures, and that renewable energy and forest areas will have negative effects on health expenditures. The empirical study tests the following hypotheses on the basis of the relationships between the explanatory and dependent variables.

Higher CO_2 emissions are often associated with air pollution and environmental degradation, which have direct and indirect effects on public health. In developing countries such as Bangladesh, increased CO_2 emissions worsen air quality, contributing to respiratory diseases, cardiovascular issues, and other health issues. According to the Environmental Kuznets Curve (EKC) hypothesis, at lower income levels,

environmental degradation (and thus CO_2 emissions) increases with economic activities, thereby increasing the disease burden and health costs. Research by Socol et al. (2023) and others supports the claim that rising emissions increase public and private health costs due to the treatment of chronic diseases, hospital admissions, and preventive health measures. In Bangladesh, frequent air quality crises in urban areas such as Dhaka lead to increased health-related spending.

H1. There is a positive and significant relationship between CO_2 emissions and health expenditure.

As economies grow, disposable income increases, leading to greater demand for better healthcare services and technologies. According to Wagner's Law, public expenditure (including health) increases as national income increases. Economic growth also facilitates more government revenue, enabling greater public investment in healthcare infrastructure. Several studies, including those by Slathia et al. (2024), indicate a favorable link between GDP expansion and health expenditure. In Bangladesh, despite economic growth lifting many out of poverty, it has also driven lifestyle changes and urbanization, leading to noncommunicable diseases that require increased health spending.

H2. There is a positive and significant relationship between economic growth and health expenditure.

Fossil fuel adoption is a major contributor to air pollution, which deteriorates environmental quality and public health. Prolonged exposure to pollutants from fossil fuels increases the prevalence of diseases, thus increasing healthcare costs. The pollution haven hypothesis also suggests that developing economies that rely on fossil fuels may suffer higher health costs due to weak environmental regulations. Empirical studies, such as those by Yang (2025), have shown that higher fossil fuel consumption leads to health burdens due to pollution-related diseases. In Bangladesh, energy production is still heavily dependent on fossil fuels such as coal and natural gas, exacerbating health risks and expenses.

H3. There is a positive and significant relationship between fossil fuel energy use and health expenditure.

Renewable energy sources reduce dependency on fossil fuels and minimize harmful emissions, leading to better air quality and reduced health risks. Ecological modernization theory supports the idea that technological shifts toward cleaner energy improve environmental and health outcomes, thus reducing health expenditures. Countries investing in renewable energy have reported reduced pollution-related health costs. Although Bangladesh's renewable energy share is still small, initiatives such as solar home systems have contributed to better indoor air quality, reducing diseases linked to traditional biomass use.

H4. There is a negative and significant relationship between renewable energy usage and health expenditure.

Industrialization in developing countries such as Bangladesh, while beneficial for economic growth, often comes with environmental costs such as air and water pollution, which influence public health. Structural change theory indicates that as economies move toward industry, health burdens shift from infectious to chronic diseases linked to environmental exposure, thus increasing healthcare costs. Empirical studies have shown that industrial pollutants contribute to higher rates of occupational diseases and public health challenges (Xu et al., 2022). In Bangladesh, industries such as textiles and leather contribute significantly to pollution, leading to increased government and household health expenditures.

H5. There is a positive and significant relationship between industrialization and health expenditure.

Urbanization often leads to overcrowding, inadequate sanitation, and increased pollution levels, which increase the incidence of infectious diseases and chronic health problems. The urban penalty hypothesis suggests that rapid urbanization in developing countries often outpaces infrastructure development, thereby increasing health burdens and spending. Rahaman et al. (2023) reported that urban areas in Bangladesh, especially Dhaka, face high healthcare costs driven by diseases linked to poor urban living conditions. Studies by Nguyen--Phung and Le (2024), Shao et al. (2022), and others highlight how rapid urbanization is tied to health challenges that increase health expenditures.

H6. There is a positive and significant relationship between urbanization and health expenditure.

Forests provide ecosystem services such as air purification, climate regulation, and recreational spaces, all of which contribute to better public health. The Biophilia Hypothesis emphasizes the health benefits of natural environments, which can reduce stress and disease incidence, ultimately decreasing healthcare costs. Empirical research shows that greater forest coverage is correlated with lower incidences of respiratory diseases and mental health issues (Yang & Jiang, 2023). In Bangladesh, forest areas such as the Sundarbans play a role in air purification and protecting communities from extreme climate events, indirectly reducing health expenditures. Studies such as Buckley and Chauvenet (2022) have validated the cost-saving health impacts of preserving green spaces.

H7. There is a negative and significant relationship between forest area and health expenditure.

4. Methodology

4.1. Data

The present investigation seeks to analyze long-term trends and patterns in health expenditure in relation to various environmental factors by utilizing annual data from the World Development Indicator (WDI). The explained variable in this study was health expenditure, while the explanatory variables were CO_2 emissions, GDP growth, industrialization, urbanization, fossil fuel and renewable energy consumption, and forest area. This research incorporates a time series analysis spanning 2000–2022 to capture and comprehend the changing dynamics effectively over a significant period. The rationale for the time frame of the dataset is the unavailability of data on health expenditures beyond 2000 and after 2022. This period represents a crucial phase in Bangladesh's economic and environmental journey, characterized by notable changes in industrialization, urbanization, and energy usage. The variables were transformed to logarithms to ensure an even distribution of the data. Table 1 presents information on the factors.

Table 1
Variables' descriptions.

Variables	Description	Logarithmic forms	Units
HE	Health expenditure	LHE	Health expenditure (% of GDP)
CO_2	CO_2 emissions	LCO2	Kilotons (kt)
GDP	GDP	LGDP	Constant Bangladeshi taka
FFE	Fossil fuel energy use	LFFE	Percentage of total final energy use
RNE	Renewable energy use	LRNE	Percentage of total final energy use
IND	Industrialization	LIND	Industry value added (% of GDP)
URB	Urbanization	LURB	Number of urban populations
FA	Forest area	LFA	Square kilometers (sq. km)

4.2. Econometric model and analysis flowchart

The following equation presents the model constructed by treating the logarithmic version of the variables for the econometric analysis at time t:

$$LHE_t = \tau_0 + \tau_1 LCO2_{2t} + \tau_2 LGDP_t + \tau_3 LFFE_t + \tau_4 LRNE_t + \tau_5 LURB_t + \tau_6 LIND_t + \tau_7 LFA_t + \varepsilon_t \quad (1)$$

where τ_1, τ_2, τ_3, τ_4, τ_5, τ_6, and τ_7 represent the coefficients. In addition, ε_t and τ_0 denotes the error and intercept terms, respectively.

Fig. 1 displays the flow diagram of the analytical methods used to examine how environmental indicators dynamically affect health expenditure in Bangladesh. After choosing the range of data and building the econometric model, the stationarity of the data was tested via unit root tests. After establishing the stationarity of the data, the research estimates the long-run effects of the variables via DOLS regression. Moreover, the research used the FMOLS and CCR estimation specifications to check the back-longwise coefficients initialized by the DOLS estimation. Then, the paired Granger causality test was used to determine the linkages between the causal variables. Finally, the study provides policy implications, constraints, and recommendations for future research.

4.3. Stationarity check

A unit root test is necessary to prevent inaccurate regression estimation. First, it ensures that the series is stationary; hence, only stationary processes are employed when deriving the regression equation. Empiricism recognizes that the foundation for the integration technique must be established before addressing the issue of cointegration. When evaluating the order of integration, it is best to use multiple unit root tests because their effectiveness depends on the sample size. Three statistical approaches in the study analyzed the autoregressive unit root: the Dickey–Fuller generalized least squares test (DF-GLS), as proposed by Elliott et al. (1996); the Phillips–Perron test (P-P), which was established by Phillips and Perron (1988); and the augmented Dickey–Fuller test (ADF), which was created by Dickey and Fuller (1979). The DOLS approach was used in place of more conventional cointegration methods, and the unit root test was incorporated to ensure that no variables deviated from the integration sequence.

4.4. The DOLS cointegration regression

This study takes a broad dimension, aiming to investigate the interaction between healthcare expenditures and the environmental and economic aspects of Bangladesh. Dynamic ordinary least squares (DOLS) is a robust econometric technique developed by Stock and Watson (1993) to estimate long-term relationships in cointegrated time series models. Unlike traditional OLS, which may yield biased and inconsistent results when applied to nonstationary data, DOLS corrects for issues of endogeneity and serial correlation by incorporating leads and lags of the first differences of the regressors into the cointegrating regression. This adjustment ensures that the resulting estimators are both unbiased and efficient even for small samples. In the context of macroeconomic and environmental time series, DOLS is particularly advantageous because it accommodates regressors that are integrated of order one, I(1), and can be applied to systems with mixed integration orders provided that cointegration exists. By including lagged and leading values of the differenced explanatory variables, DOLS effectively controls for dynamic feedback effects and omitted variable bias, thereby capturing the true long-run elasticities of interest (Begum et al., 2020).

This method is especially appropriate for this study, which investigates the long-term impact of variables such as CO_2 emissions, GDP growth, fossil fuel and renewable energy usage, industrialization, urbanization, and forest area on health expenditures in Bangladesh. The country's macroeconomic indicators and environmental data are subject to structural shifts, measurement errors, and potential simultaneity

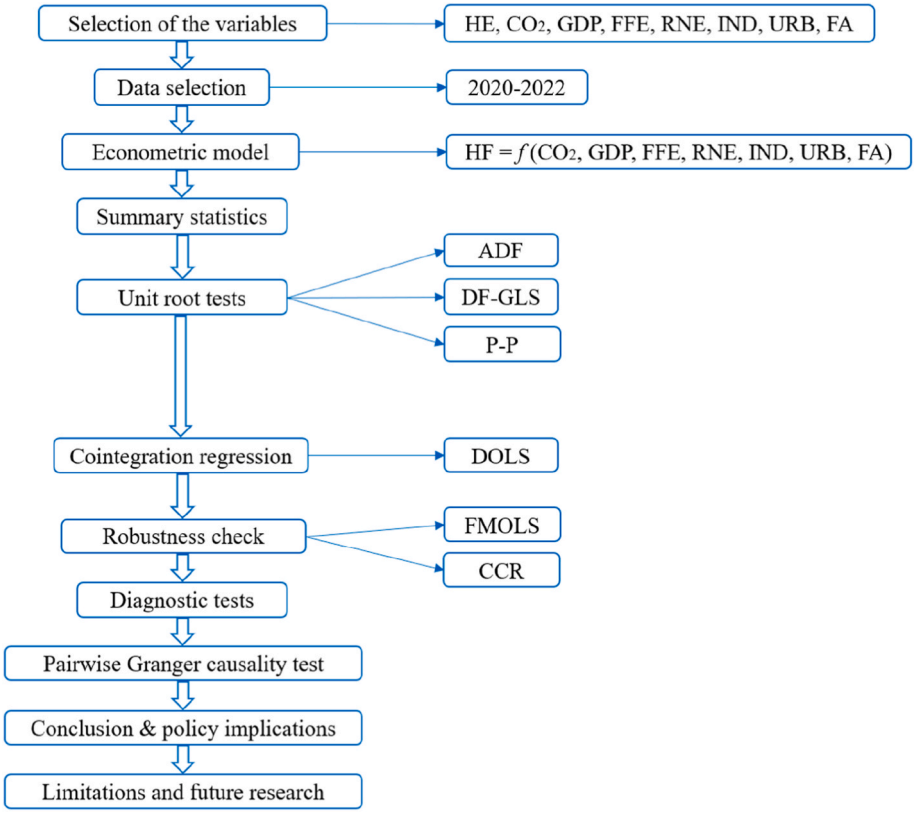

Fig. 1. Flowchart of the analysis.

conditions under which DOLS excels in producing reliable estimates. Additionally, DOLS is flexible in handling heteroscedasticity and autocorrelation in the residuals, enhancing its empirical robustness. The choice of DOLS over other cointegration techniques, such as the Engle–Granger or Johansen approaches, is further justified by its superior small-sample properties and its ability to incorporate deterministic trends and structural breaks when needed. The estimations derived from the DOLS framework provide the foundation for the empirical conclusions in this study and are corroborated through robustness checks via fully modified OLS (FMOLS) and canonical cointegrating regression (CCR) techniques. In this study, the following equation was used to determine the long-term coefficients of the factors influencing health expenditure in Bangladesh:

$$\begin{aligned}\Delta LHE_t = {} & \tau_0 + \tau_1 LHE_{t-1} + \tau_2 LCO2_{t-1} + \tau_3 LGDP_{t-1} + \tau_4 LFFE_{t-1} \\ & + \tau_5 LRNE_{t-1} + \tau_6 LURB_{t-1} + \tau_7 LIND_{t-1} + \tau_8 LFA_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta LHE_{t-i} \\ & + \sum_{i=1}^{q} \gamma_2 \Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta LGDP_{t-i} + \sum_{i=1}^{q} \gamma_4 \Delta LFFE_{t-i} \\ & + \sum_{i=1}^{q} \gamma_5 \Delta LRNE_{t-i} + \sum_{i=1}^{q} \gamma_6 \Delta LURB_{t-i} + \sum_{i=1}^{q} \gamma_7 \Delta LIND_{t-i} \\ & + \sum_{i=1}^{q} \gamma_8 \Delta LFA_{t-i} + \varepsilon_t \end{aligned} \tag{2}$$

where the first difference operator and optimum lag length are denoted by Δ and q, respectively.

The DOLS method is often chosen in econometric analysis, particularly when handling time series data that exhibit nonstationarity and are cointegrated. In the presence of cointegration, traditional OLS estimates can suffer from bias and inefficiency due to endogeneity and serial correlation. Endogeneity often arises because of omitted variable bias, measurement errors, or simultaneous causality between the dependent and independent variables. In simpler terms, endogeneity means that something outside the model or within its structure is causing a two-way relationship, making it difficult to determine the true implication of the exogenous factor on the endogenous factor. Conversely, when residuals (errors) in a regression model correlate with other residuals at different points, a violation occurs, which is known as serial correlation (or autocorrelation). Both endogeneity and serial correlation can severely affect the validity of regression results if not properly addressed. DOLS addresses these issues by adding leads and lags of the first differences of the independent variables to the cointegrating regression. This makes DOLS a trustworthy option for studying long-term correlations between integrated variables, as it consistently and unbiasedly predicts long-term variables, even with small samples.

Another important rationale for choosing DOLS is its flexibility and robustness compared with other cointegration methods, such as the Engle–Granger two-step method or fully modified OLS (FMOLS). In contrast to Engle-Granger, which may be fragile in the determination of the dependent variable and susceptible to small-sample biases, DOLS has better small-sample qualities and is not extremely dependent on equation standardization. Moreover, DOLS allows researchers to easily test and correct for structural breaks and trends within the data. This makes DOLS particularly suitable when working with macroeconomic time series, where structural shifts and dynamic interactions are often present. Ultimately, DOLS is selected for its ability to provide accurate long-run estimations in cointegrated systems while handling common econometric issues, ensuring the consistency and reliability of the findings.

4.5. Robustness check

The CCR and FMOLS estimations were used to test the results of DOLS. Hansen and Phillips (1990) invented the FMOLS regression to obtain the best estimates of the cointegrating regressions. This test is an extension of least squares, and it can handle the endogeneity of the independent variables and the problem of serial correlation caused by cointegration. Park (1992) developed the CCR approach; this methodology necessitates processing the data by utilizing the stationary component of a cointegration theory. Even after such processing, a cointegration relationship generated by the cointegration paradigm would persist. An example of a cointegrating transformation is the CCR applied to the above error term in terms of zero-frequency regression coefficients. The FMOLS and CCR approaches can achieve asymptotic consistency when the effects of serial correlation are examined. The FMOLS and CCR estimators require the application of equation (2) to evaluate the long-term elasticity.

4.6. Causality test

The present study employed the pairwise Granger causality test (Granger, 1969) to investigate the causal effects of one variable on the other. Granger causation is a statistical theory of causality based on a projection, and it is advantageous over other time series evaluation methods in several ways. An important advantage of this test is its ability to analyze many lags while ignoring higher-order lags. When a time series Y can be helpful in predicting the future alteration of a second time series X, then Y is said to "Granger-cause" X. By employing the F tests, one can establish Granger causality between variables Y and X and, at the same time, estimate coefficients via the ordinary least squares (OLS) test. The time series of these two factors is denoted by Y_t, X_t (where Y_t and X_t represent the values of the variables at time t). However, the variables Y_t and X_t could be shown through a bivariate autoregressive model.

$$Y_t = \beta_2 + \sum_{i=1}^{n} \Omega_i Y_t{-}_1 + \sum_{i=1}^{n} \infty_i X_t{-}_i + u_t \tag{3}$$

$$X_t = \beta_1 + \sum_{i=1}^{n} \alpha_i Y_t{-}_i + \sum_{i=1}^{n} \mu_i X_t{-}_1 + e_t \tag{4}$$

Where "n" is the number of lags and "e_t" and "u_t" are the residual factors.

5. Empirical results

Table 2 illustrates the outcomes of the variable-level summaries. The annual time series data collected for Bangladesh ranged from 2000 to 2022. The outcomes for the DF-GLS, P-P, and ADF unit root assessments in log levels (I(0)) and first difference (I(1)) are summarized in Table 3. According to the results, LHE, LGDP, LRNE, LFFE, LURB, LIND, and LFA were initially nonstationary but became stationary in I(1). The DF-GLS test shows that although LCO2 was nonstationary at I(0), it was stationary after adjusting for I(1). LCO2 was stationary at I(0) and remained stationary after I(1) was derived, as determined by the ADF and P-P analyses. Therefore, we can conclude that the variables exhibit mixed-order integration and show the superiority of DOLS over other cointegration approaches.

Table 4 shows the DOLS results and assumes that health expenditure is a dependent variable. According to the DOLS findings, the LCO2 coefficient is significant at the 1 % level and has a positive value. Therefore, a 1 % improvement in CO_2 emissions causes a 1.45 % increase in health spending. Additionally, the coefficient of LGDP is 0.38, and it is statistically significant at the 5 % level. Consequently, a 1 % increase in economic growth will cause a health expenditure increase of approximately 0.38 %. Moreover, the coefficient of LFFE is positive and, at the same time, extremely significant at the 1 % level. This means that every 1 % rise in fossil fuel consumption will cause a rise of 1.04 percentage points in healthcare expenditure. In addition, the coefficients for forest area and renewable energy use showed a highly significant negative

Table 2
Summary statistics of the variables.

Variables	LHE	LCO2	LGDP	LFFE	LRNE	LURB	LIND	LFA
Mean	0.90918	10.7699	29.4534	3.72589	3.72297	17.6102	3.25633	9.84945
Median	0.91167	10.8313	29.4345	3.71539	3.71539	17.6212	3.22069	9.84604
Maximum	1.01566	11.3617	30.0687	4.07791	4.07791	17.9566	3.49382	9.86284
Minimum	0.72453	9.98276	28.8921	3.35006	3.29691	17.2205	3.10366	9.84342
Std. dev.	0.08231	0.43731	0.37360	0.22772	0.23301	0.22813	0.13182	0.06069

Notes: LHE = Health expenditure, LCO2=CO_2 emissions, LGDP = Economic growth, LFFE = Fossil fuel energy use, LRNE = Renewable energy use, LURB=Urbanization, LIND = Industrialization, LFA = Forest area.

Table 3
Outcomes of unit root testing from the ADF, DF-GLS, and P-P tests.

Variables	ADF		DF-GLS		P-P	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
LHE	−2.17574	−3.30058**	−1.34725	−3.43848***	−2.18894	−3.30058**
LCO2	−2.48889*	−5.16377***	−1.08422	−3.50558***	−2.63683*	−5.12724***
LGDP	1.90596	−3.08111**	−1.20221	−2.81227**	1.81585	−2.82078**
LFFE	−0.01856	−4.93771***	−0.18514	−5.10755***	0.04076	−4.93589***
LRNE	1.25328	−4.12569***	0.54709	−3.99058***	1.84269	−4.12569***
LURB	−0.39675	−2.84093**	0.30084	−2.46189*	−0.11874	−3.70143***
LIND	0.38965	−4.37338***	0.40513	−4.46822***	0.58683	−4.37339***
LFA	−0.55212	−2.40158*	−0.50813	−2.52146*	−0.46592	−4.16799***

Notes: ADF=Augmented Dickey-Fuller, DF-GLS = Dickey-Fuller generalized least squares, P-P=Phillips-Perron, LHE = Health expenditure, LCO2=CO_2 emissions, LGDP = Economic growth, LFFE = Fossil fuel energy use, LRNE = Renewable energy use, LURB=Urbanization, LIND = Industrialization, LFA = Forest area, ***p < 0.01, **p < 0.05, and *p < 0.1.

Table 4
Results of the factors influencing health expenditure.

Variables	Coefficient	Standard error	t-statistic	p value
LCO2	1.448173***	0.243770	5.940735	0.0001
LGDP	0.383913**	0.268031	2.432345	0.0195
LFFE	1.038218***	0.294268	3.528137	0.0042
LRNE	−0.484987***	0.108616	−4.465152	0.0008
LURB	0.907301**	0.418855	2.166146	0.0411
LIND	1.389388***	0.807994	3.719552	0.0036
LFA	−1.913655***	0.391328	−4.890156	0.0004
C	192.0200***	40.19948	4.776679	0.0016
R^2	0.912901			
Adjusted R^2	0.903432			

Notes: LCO2=CO_2 emissions, LGDP = economic growth, LFFE = fossil fuel energy use, LRNE = renewable energy use, LURB = urbanization, LIND = industrialization, LFA = forest area, C = constant term, ***p < 0.01, and **p < 0.05.

relationship with health expenditures. According to the results, a 1 % point increase in forest area and renewable energy use will lead to a 1.91 % and 0.48 % point decrease in health expenditure, respectively. Finally, the results show that a 1 % point increase in urbanization and industrialization leads to increases in health expenditures of 0.91 % and 1.39 % points, respectively.

The results revealed that ecosystem damage in Bangladesh is caused by CO_2 emissions, economic growth, increasing use of fossil fuels, rapid urbanization, industrialization, and deforestation, leading to increased healthcare expenditures. In addition, this research has shown how the utilization of forests and clean energy resources in Bangladesh can reduce health expenditures by improving environmental quality. In addition, the expected coefficients are significantly consistent from both theoretical and application perspectives. The R^2 value is 0.9129, and the adjusted R^2 value is 0.9034; these values reflect how well the constructed regression model fits the data. This shows that approximately 90 % of the variance in the change caused by the explained factor can be explained by the explanatory parameters.

Moreover, the size of the coefficients indicates that the top reason for rising healthcare costs in Bangladesh is CO_2 emissions, followed by industrialization, fossil fuels, urbanization, and economic growth. This is not surprising, as air pollution and industrial waste are the major causes of worsening public health in Bangladesh. In addition, the rapid urbanization and economic growth backed by fossil fuels have caused increasing environmental degradation, which is also worsening public health in Bangladesh. On the other hand, the coefficient size of forest area is larger than that of renewable energy consumption. This indicates the greater potential of forest areas than renewable energy consumption to reduce health expenditures in Bangladesh. In addition to increasing air quality and lowering temperature, forests and green spaces also lower health risks by strengthening the immune system, improving blood pressure, diminishing stress, ameliorating mood, enhancing the ability to concentrate, hastening recovery after surgery or illness, elevating energy levels, and enhancing sleep. Moreover, substituting fossil fuels with sustainable power can reduce pollution and improve air quality, leading to a decrease in health risk and associated healthcare costs in Bangladesh.

The current paper evaluates the consistency of estimating DOLS by incorporating the FMOLS and CCR techniques. Tables 5 and 6 show the regression coefficients of FMOLS and CCR. The FMOLS and CCR outcomes demonstrate the robustness of the DOLS prediction. The coefficients for CO_2 emissions, GDP growth, fossil fuels, urbanization, and

Table 5
FMOLS results for the factors influencing health expenditure.

Variables	Coefficient	Standard error	t-statistic	p value
LCO2	1.498352***	0.427181	3.507534	0.0001
LGDP	0.401524**	0.293526	2.367933	0.0311
LFFE	1.111638***	0.206358	5.386939	0.0061
LRNE	−0.518257***	0.127834	−4.054140	0.0025
LURB	0.817634**	0.425284	2.922559	0.0132
LIND	1.319353**	0.550362	2.397245	0.0287
LFA	−1.880462***	0.326286	−5.763232	0.0001
C	201.3173***	52.04532	3.868115	0.0048
R^2	0.928732			
Adjusted R^2	0.915369			

Notes: LCO2=CO_2 emissions, LGDP = economic growth, LFFE = fossil fuel energy use, LRNE = renewable energy use, LURB = urbanization, LIND = industrialization, LFA = forest area, C = constant term, ***p < 0.01, and **p < 0.05.

Table 6
CCR results for the factors influencing health expenditure.

Variables	Coefficient	Standard error	t-statistic	p value
LCO2	1.501733***	0.417352	3.598240	0.0003
LGDP	0.391635***	0.310183	3.262593	0.0088
LFFE	1.128715***	0.291634	3.870313	0.0005
LRNE	−0.529361**	0.213761	−2.476415	0.0137
LURB	0.882729*	0.483651	1.825136	0.0708
LIND	1.382745**	0.619257	2.232909	0.0373
LFA	−1.940388***	0.440265	−4.407318	0.0013
C	213.5601***	56.23763	3.797459	0.0069
R^2	0.927419			
Adjusted R^2	0.918725			

Notes: LCO2=CO_2 emissions, LGDP = economic growth, LFFE = fossil fuel energy use, LRNE = renewable energy use, LURB = urbanization, LIND = industrialization, LFA = forest area, C = constant term, ***p < 0.01, **p < 0.05, and *p < 0.1.

industrialization are all positive and statistically significant. In addition, the use of renewable energy and forestland can minimize healthcare costs. The findings of the FMOLS and CCR validate the findings of the DOLS. The components explain approximately 91 % of the variations in the changes in the dependent variable, which is indicated by both FMOLS and CCR estimates of R^2 and modified R^2, which measures how well a model fits.

The relevance of the cointegration score was tested in this study via normality (J-B test), heteroskedasticity (B-P-G test), and serial correlation (LM) tests. Table 7 shows the results of the different diagnostic tests performed. The model results have no autocorrelation or heteroskedasticity, and this conforms to normality. Moreover, an endogenous issue may emerge once the error element of the formula is connected to one or more predictive factors. The OLS method is incapable of producing a consistent estimate if the model has endogeneity issues. Thus, the Hausman (1978) endogeneity test (or the Hausman specification test) was applied to determine whether this problem exists in the statistical model under investigation. If there are too many instruments in relation to the system's available observations, time series estimates may become vulnerable to overfitting the endogenous variables and might compromise the test's ability to observe undue constraints. As seen in Table 7, the Hausman specification test outcome showed that the chi-square test coefficient is not significant, supporting the acceptance of the null hypothesis regarding the suitability of the random effect regression model and demonstrating the absence of any endogenous issues with the study's regression.

Moreover, the CUSUM and CUSUM of squares tests were also employed to assess the strength of the model more readily in the present study. Fig. 2 presents the CUSUM and CUSUM of squares plots at the 5 % significance level. The blue lines depict residual values, and the red lines represent confidence intervals. The findings affirm the stability of the model because the values of the analyzed residuals fall within the confidence limits at the 5 % significance level.

The F statistic is employed to ascertain the existence of Granger causality, which is shown by the interrelation between the variables. Table 8 presents concise details of the pairwise Granger causality, indicating the specific direction of causality between the variables. Both

Table 7
Diagnostic test outcomes.

Diagnostic tests	Coefficient	p value	Decision
Jarque-Bera test	0.751958	0.6866	Normally distributed residuals
Lagrange Multiplier test	0.508616	0.6128	No serial correlation
Breusch−Pagan-Godfrey test	1.250075	0.1122	No heteroscedasticity
Hausman specification test	2.132054	0.6754	No endogenous problem

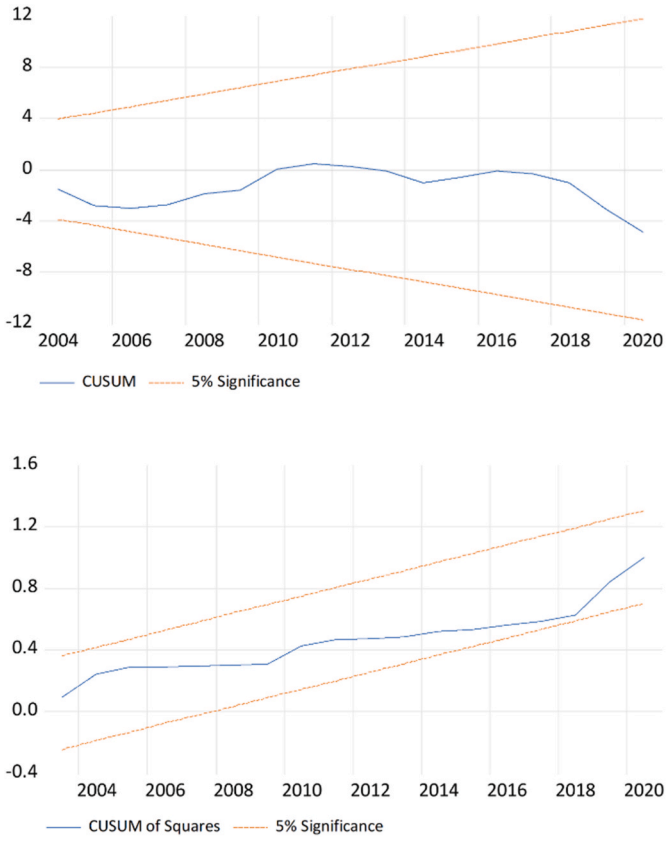

Fig. 2. Outcomes of the CUSUM and CUSUM of squares tests.

the occurrence of causality from left to right (→) and the occurrence of causality from right to left (←) are instances of unidirectional causality. Bidirectional causality (↔) refers to a situation where two variables mutually influence one another, whereas no causality (≠) suggests that there is no connection between the variables. The results of the pairwise Granger causality test indicate that there is a one-way causal relationship between LCO2 and LHE, LGDP and LHE, LFFE and LHE, LURB and LHE, LIND and LHE, LGDP and LCO2, LFFE and LCO2, LRNE and LCO2, LURB and LCO2, LIND and LCO2, and LIND and LGDP. These connections are statistically significant, leading to the rejection of the null hypothesis (H_0) of no causality. CO_2 emissions, economic expansion, fossil fuel energy use, urbanization, and industrialization show unidirectional causality with respect to health expenditures. Moreover, unidirectional causality exists from GDP expansion, fossil fuel energy adoption, urbanization, and industrialization to CO_2 release. Additionally, green power Granger-causes CO_2 emissions, and industrialization Granger-causes economic growth.

According to the pairwise Granger causality test, there are two-way causality relationships between LFFE and LGDP, LRNE and LGDP, LURB and LGDP, LURB and LFFE, LIND and LFFE, LURB and LRNE, LIND and LRNE, and LURB and LIND. This suggests that fossil fuels, renewable energy, and urbanization have a causal link with economic growth, and vice versa. In addition, urbanization and industrialization have a causal relationship with fossil fuel energy usage, and vice versa. Furthermore, urbanization and industrialization have a causal relationship with renewable energy use, and vice versa. Finally, industrialization has a causal link with urbanization, and vice versa. Nevertheless, the current study did not identify causal connections involving the extent of forested land and other characteristics. Fig. 3 illustrates the causal linkages between the factors.

Table 8
Outcomes of pairwise Granger causality analysis.

Null hypothesis (H_0)	F-statistic	Decision on H_0	Causality direction
LCO2 ≠ LHE	7.3656***	×	LCO2 → LHE
LHE ≠ LCO2	2.5515	✓	
LGDP ≠ LHE	5.4124***	×	LGDP → LHE
LHE ≠ LGDP	0.3059	✓	
LFFE ≠ LHE	9.1753***	×	LFFE → LHE
LHE ≠ LFFE	0.2945	✓	
LRNE ≠ LHE	0.4712	✓	LRNE ≠ LHE
LHE ≠ LRNE	1.5946	✓	
LURB ≠ LHE	5.2334***	×	LURB → LHE
LHE ≠ LURB	0.1406	✓	
LIND ≠ LHE	7.2816***	×	LIND → LHE
LHE ≠ LIND	0.6208	✓	
LFA ≠ LHE	0.3016	✓	LFA ≠ LHE
LHE ≠ LFA	1.0431	✓	
LGDP ≠ LCO2	6.0816***	×	LGDP → LCO2
LCO2 ≠ LGDP	0.6258	✓	
LFFE ≠ LCO2	7.1614***	×	LFFE → LCO2
LCO2 ≠ LFFE	0.2773	✓	
LRNE ≠ LCO2	0.10371	✓	LRNE ← LCO2
LCO2 ≠ LRNE	2.9558*	×	
LURB ≠ LCO2	5.9132***	×	LURB → LCO2
LCO2 ≠ LURB	0.2531	✓	
LIND ≠ LCO2	4.9376**	×	LIND → LCO2
LCO2 ≠ LIND	0.3719	✓	
LFA ≠ LCO2	0.1403	✓	LFA ≠ LCO2
LCO2 ≠ LFA	1.1096	✓	
LFFE ≠ LGDP	5.4803***	×	LFFE ↔ LGDP
LGDP ≠ LFFE	4.4169**	×	
LRNE ≠ LGDP	5.0083***	×	LRNE ↔ LGDP
LGDP ≠ LRNE	7.4127***	×	
LURB ≠ LGDP	4.0258**	×	LURB ↔ LGDP
LGDP ≠ LURB	5.8134***	×	
LIND ≠ LGDP	7.1729***	×	LIND → LGDP
LGDP ≠ LIND	1.9512	✓	
LFA ≠ LGDP	2.1365	✓	LFA ≠ LGDP
LGDP ≠ LFA	0.2943	✓	
LRNE ≠ LFFE	2.1735	✓	LRNE ≠ LFFE
LFFE ≠ LRNE	0.2486	✓	
LURB ≠ LFFE	4.7825***	×	LURB ↔ LFFE
LFFE ≠ LURB	6.2749***	×	
LIND ≠ LFFE	5.3649***	×	LIND ↔ LFFE
LFFE ≠ LIND	5.9551***	×	
LFA ≠ LFFE	0.1874	✓	LFA ≠ LFFE
LFFE ≠ LFA	0.1923	✓	
LURB ≠ LRNE	2.4429*	×	LURB ↔ LRNE
LRNE ≠ LURB	3.8353**	×	
LIND ≠ LRNE	7.1247***	×	LIND ↔ LRNE
LRNE ≠ LIND	5.1643***	×	
LFA ≠ LRNE	0.1235	✓	LFA ≠ LRNE
LRNE ≠ LFA	1.3158	✓	
LIND ≠ LURB	4.1647**	×	LIND ↔ LURB
LURB ≠ LIND	5.1443***	×	
LFA ≠ LURB	0.2476	✓	LFA ≠ LURB
LURB ≠ LFA	0.7163	✓	
LFA ≠ LIND	1.0781	✓	LFA ≠ LIND
LIND ≠ LFA	0.26707	✓	

Notes: LHE = Health expenditure, LCO2=CO_2 emissions, LGDP = Economic growth, LFFE = Fossil fuel energy use, LRNE = Renewable energy use, LURB=Urbanization, LIND = Industrialization, LFA = Forest area, ***p < 0.01, **p < 0.05, and *p < 0.1, ✓ = Accept, × = Reject.

6. Discussion

This study examined the link between changing environmental conditions and healthcare costs in Bangladesh. The present study examined the association between healthcare costs and carbon emissions. The findings show that rising CO_2 emissions are linked to a higher cost of healthcare. Elevated CO_2 levels contribute to climate change, which intensifies extreme weather events, worsens air quality, and increases the spread of diseases such as respiratory illnesses, heat-related conditions, and vector-borne diseases. Poor air quality from high CO_2 and related emissions (such as particulate matter and ground-level ozone) aggravates chronic conditions such as asthma, cardiovascular diseases, and other respiratory problems, leading to increased hospital visits and long-term treatments. Additionally, climate-related disruptions strain public health systems, requiring more resources for emergency responses and disease prevention. These health burdens translate into higher direct medical costs (treatment, hospitalization, and medications) and indirect costs (loss of productivity and long-term care), collectively increasing overall healthcare expenditures as societies respond to the growing health challenges fueled by CO_2-driven climate change.

The results of this study revealed a positive link between healthcare spending and CO_2 releases, which are similar to those reported by Mehmood et al. (2022), Yazdi and Khanalizadeh (2017), Hao et al. (2018), Liu et al. (2015), and Yassin and Aralas (2019). People's health is affected by CO_2 emissions, which is responsible for increased healthcare costs. Many chronic conditions, such as long-term chronic diseases, may require continuous medical care, and this result partially illustrates the importance of medical expenditure. Medical spending has a significant level of inertia. Our findings highlight the fact that rising health costs are a consequence of increasing CO_2 outputs and other environmental diseases caused by pollutants. The harmful effects of CO_2 release on human health include several potentially fatal diseases, including bronchitis, heart problems, and lung problems. In light of this, it is necessary to advance a sustainable environmental strategy that ensures a reduction in CO_2 emissions. Climate change and pollution are exacerbated by increased economic activity. Even when compositional and technological factors are considered, a better quality of life is linked to a larger carbon footprint. After adjusting for economies of scale, healthcare costs increase in line with income. As a consequence of structural and technological changes leading to lower emissions per capita, several countries have started to consider the intensity of energy consumption. Owing to structural and technological advancements, energy intensity has steadily decreased over time. Together, these efforts lead to further reductions in CO_2 emissions and healthcare costs.

The present research examined the correlation between GDP expansion and health expenditure in Bangladesh. The results show that increasing health spending in Bangladesh is linked to economic development. As economies expand and incomes rise, individuals and governments tend to allocate a larger share of resources to healthcare, both because they can afford to and because demand for higher-quality, specialized, and technologically advanced treatments increases. This is further supported by Baumol's cost disease theory, which explains that sectors such as healthcare, with limited productivity gains due to their labor-intensive nature, experience rising costs as wages increase in line with more productive sectors. Economic growth also leads to demographic shifts, such as increased life expectancy and aging populations, which further escalate healthcare demand and expenditures. In summary, higher economic growth drives up healthcare costs through increased income, greater demand for advanced care, rising wages, and demographic transitions, all of which contribute to sustained growth in healthcare spending.

Numerous researchers, including Slathia et al. (2024), Azad et al. (2018), Metu et al. (2018), and Patdu et al. (2022), have confirmed the positive correlation between economic expansion and health spending. Rising economic growth in emerging countries such as Bangladesh is related to increased ecological deterioration. Economic growth aids in meeting societal demands through consumption and development, but this comes at the expense of the environment and people's health by increasing the likelihood of illness and the cost of treatment. This suggests that financial operations do not pose long-term harm to ecosystem conditions or public health but rather are consistent with safeguarding both. However, Wang et al. (2019) and Mehmood et al. (2022) reported contradictory findings, indicating that GDP diminishes healthcare costs. For Bangladesh to achieve equitable growth, a low-carbon economy, and health security, the country must implement effective economic policies and initiatives to lessen its reliance on the fossil fuel supply, increase

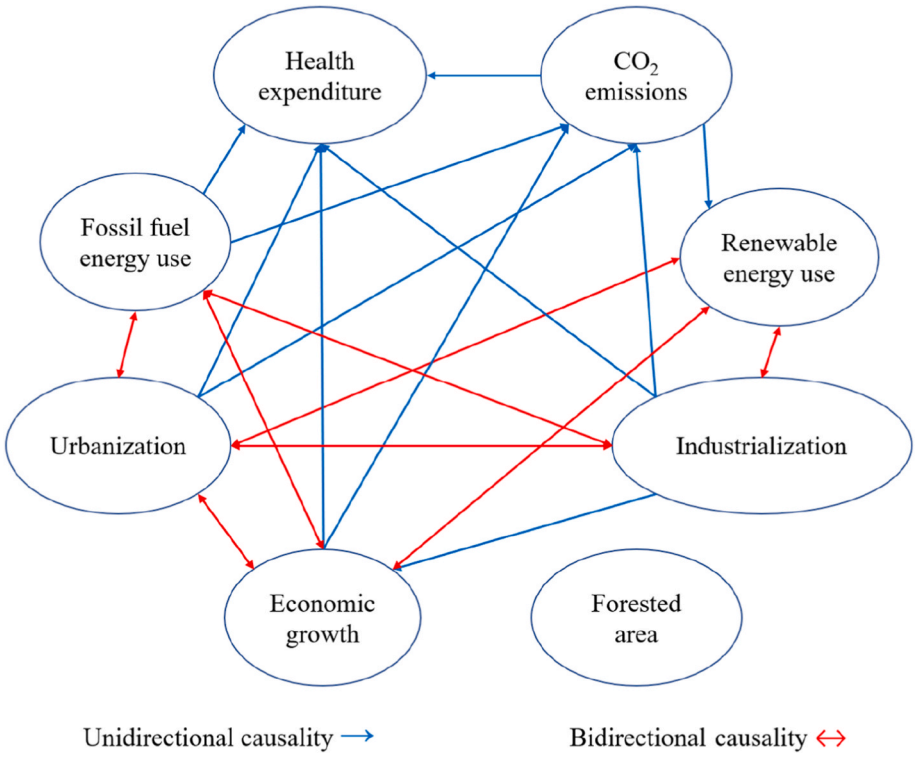

Fig. 3. Granger causality between the variables.

energy efficiency, and reduce emissions.

The objective of this study was to examine the link between Bangladesh's energy usage and healthcare expenses. The results show how much money can be saved by switching to renewable energy sources and how much money is lost from poor health caused by fossil fuel use. Research has shown that the combustion of fossil fuels for energy significantly impacts healthcare expenditures over time. This result suggests that increased usage of fossil fuels increases healthcare expenses in Bangladesh. The outcomes of the examined analysis are corroborated by those of previous studies from reputable sources such as Jermsittiparsert (2021). Bangladesh's dependency on fossil fuels for energy generation is beneficial to neither the environment nor the general population. Bangladesh, a developing country, continues to generate electricity from natural gas, oil, and coal, which poses major health risks due to pollution. Increased fossil fuel use leads to increased emissions of pollutants such as particulate matter (PM2.5), nitrogen oxides (NOx), and sulfur dioxide (SO_2), which degrade air quality and contribute to climate change. Poor air quality and rising global temperatures are associated with increased incidences of respiratory diseases, cardiovascular conditions, heat-related illnesses, and the spread of infectious diseases. As population health declines due to these environmental stressors, healthcare systems face greater demand for services, treatments, and hospitalizations, increasing operational costs and resource allocation. This highlights how unsustainable energy consumption indirectly strains healthcare systems through its harmful impacts on public health and environmental stability.

The present research also examined the impact of alterations to sustainable power resources on Bangladesh's healthcare expenditures. On the basis of these findings, increasing the proportion of renewable energy in Bangladesh's total energy mix might assist in reducing healthcare expenses in Bangladesh. The same outcomes were reported by Slathia et al. (2024), Mehmood et al. (2022), Badulescu et al. (2019), Shahzad et al. (2020), and Jermsittiparsert (2021). It is important to utilize green power sources for electricity production to safeguard public health, foster long-term economic growth, and limit the pace of temperature increase. With more demand for renewable energy, fossil energy will diminish, resulting in fewer emissions of air pollution, which is reported to cause respiratory and cardiovascular diseases, among others. By reducing harmful emissions, renewable energy helps improve air quality, thereby lowering the incidence of health problems and associated healthcare expenditures. Additionally, the shift to cleaner power resources supports equitable growth (Leung & Ko, 2025; Tanchangya et al., 2025), which has broader positive impacts on community well-being, further contributing to reduced healthcare costs through the prevention of environmentally induced health conditions.

The rapid urban population due to urbanization has caused a spike in the cost of healthcare in Bangladesh, as shown by the results of the urbanization process. The findings of the present study reveal a positive link between urbanization and health spending, similar to the findings of previous studies, such as those of Kutlu and Örün (2023), Islam et al. (2024), Shao et al. (2022), and Patdu et al. (2022). This discovery suggests that the growing population in the urban area of Bangladesh led to an increase in power demand, which was driven by assets derived from fossil fuels that increase the pollution of greenhouse gases and increase the risk of health problems by worsening the ecosystem of metropolitan areas. In addition, the increased urban population generates considerable waste and contaminants in the environment, leading to numerous diseases that increase health expenditures. As urban populations grow, there is often a greater demand for healthcare services due to an increased concentration of people, which leads to greater strain on existing healthcare infrastructure. Moreover, urbanization is typically accompanied by lifestyle changes, such as increased stress levels, sedentary behaviors, and poor dietary habits, which can contribute to chronic diseases such as obesity, diabetes, and hypertension. These conditions increase the demand for healthcare resources and treatments. Additionally, urban areas may have more diverse populations with varying healthcare needs, leading to more complex healthcare delivery systems and greater costs. The increased use of technology and specialized medical care in cities further drives up costs, as high-tech diagnostics and treatments become more prevalent in response to the growing and more diverse population. Overall, urbanization results in both direct and indirect pressures on healthcare

systems, contributing to rising healthcare expenditures.

Furthermore, the evaluations revealed a favorable correlation between industrialization and sustained expenditures on healthcare. Similarly, Anwar et al. (2021) and Xiu et al. (2022) reported a beneficial connection between industrialization and health spending. The expansion of industrialization would result in an increase in the pollution caused by manufacturing waste, hazardous materials, and heavy metals, contributing to the destruction of the effectiveness of the surroundings, along with the increased need for electricity. This poses public health risks through air and water contamination, leading to respiratory issues, cancers, and other health concerns. The need for more advanced healthcare infrastructure and increased medical interventions to address these health challenges often drives up healthcare costs. Moreover, as industries expand, workforce-related injuries and stress-related conditions also increase, placing further strain on healthcare systems and finances. Consequently, the economic burden of these health problems creates a feedback loop, intensifying the demand for healthcare services and increasing overall costs. The resulting industrial pollution in Bangladesh has a negative impact on the health of a significant number of people. In addition, the national pollution profile reveals that industrial subsectors are responsible for a significant proportion of the country's total pollution load, posing a serious threat to the health of its citizens.

The results of this study reveal a destructive connection between forest areas and health expenditures in Bangladesh. The study concluded that increasing forest area could be an effective strategy for providing better health services to the public while reducing CO_2 emissions and health costs in Bangladesh. This finding is similar to that of Anwar et al. (2021), who reported an unfavorable link between forest area and health expenditure. Forests, as natural ecosystems, provide numerous health benefits, such as improving the atmosphere through the release of oxygen and the ingestion of contaminants. This minimizes the incidence of respiratory diseases and cardiovascular conditions. Additionally, exposure to green spaces has been shown to alleviate stress, anxiety, and depression, which are prevalent mental health issues (Yang & Jiang, 2023). As forests expand, they increase biodiversity, promote physical activity through outdoor recreation, and mitigate the urban heat island effect, all of which contribute to lowering healthcare expenses by reducing the burden of chronic diseases, mental health issues, and environmental stressors. Therefore, the restoration and preservation of forests can lead to significant cost savings in healthcare systems by improving both physical and mental health outcomes.

In Bangladesh, global warming and climate change are attributed to CO_2 emissions due to deforestation and forest degradation. Changes in rainfall patterns and warmer temperatures increase the habitats of mosquitoes and other disease-carrying vectors. By reducing emissions through expanding forest areas, it is possible to slow the pace of climate change, helping to stabilize ecosystems and reduce the incidence of vector-borne diseases. When more forests are reforested, there are fewer health problems because there is more precipitation, which further lowers the average temperature. With heavy reforestation, a cycle of recycling occurs, which leads to an increase in the amount of precipitation that falls on the ground. For example, water vapor is absorbed from the ground by plants and then released into the atmosphere, where it eventually condenses into hail. Since plants are naturally capable of absorbing CO_2 through photosynthesis, the expansion of forest cover has been shown to have a significant impact on temperature regulation, which in turn mitigates global warming due to the resulting reduction in greenhouse gases. Reducing CO_2 emissions and the widespread adoption of silvicultural measures in Bangladesh's forestry industry have an enormous ability to reduce temperature increases, improve air quality, and reduce health costs.

The findings from investigating the influences of CO_2 emissions, a growing economy, energy use, urbanization, industrialization, and forest areas on health expenditure in Bangladesh offer crucial aspects that might be incorporated into other emerging countries with environmental and economic hurdles. Many developing nations, particularly South Asia, Africa, and parts of Latin America, are undergoing rapid urbanization and industrialization, often without strong environmental regulations. This process tends to increase pollution levels, such as CO_2 emissions, which can directly worsen public health and increase health expenditures due to rising cases of respiratory diseases, cardiovascular issues, and other emission-associated health problems. Therefore, these countries may observe comparable patterns where greater environmental degradation leads to increased health spending, reinforcing the requirement for equitable growth approaches. Additionally, the balance involving monetary expansion and environmental conditions highlighted in Bangladesh's case is relevant to many developing economies striving to grow rapidly. While economic growth typically increases national income and can improve healthcare infrastructure, if it relies heavily on energy-intensive industries and fossil fuels, it may also contribute to higher emissions and health costs. Countries with similar economic structures might learn from such findings that prioritizing cleaner energy sources and regulating industrial pollution are crucial to controlling future health expenditures. Moreover, the protective role of forest areas, as identified in the Bangladesh study, suggests that maintaining or expanding forest cover can help mitigate environmental damage and reduce health costs. For other developing countries, investing in green spaces and afforestation may not only mitigate global warming but also alleviate the financial burden on healthcare systems. Finally, the findings underscore the interconnectedness of green policies and public health budgets in developing contexts. Countries with limited healthcare resources must consider that unchecked urbanization and industrialization can indirectly strain public health services. Thus, these insights can encourage governments in similar regions to adopt integrated strategies that bring harmony between financial ambition and ecosystem preservation, and healthcare planning. This approach ensures long-term sustainability while safeguarding public health and managing health expenditures more effectively.

7. Conclusions and policy recommendations

7.1. Conclusions

This study carefully examined the numerous variables that impact health expenditures in Bangladesh, providing details of the evolving relationship between socioeconomic and ecological factors. The research utilized the DOLS methodology to analyze various factors, including urbanization, industrialization, forestation, carbon emissions, GDP growth, and the adoption of fossil fuels and clean energy. The study covered a time series from 2000 to 2022. The integration order of the data was determined through rigorous testing, which included DF-GLS, P-P, and ADF unit root assessments. The findings of this paper reveal substantial correlations between the examined variables and healthcare costs. For every 1 % increase in CO_2 release, GDP expansion, fossil fuel energy usage, urbanization, and industrialization, long-term healthcare expenses exhibited corresponding increases of 1.45 %, 0.38 %, 1.04 %, 0.91 %, and 1.39 %, respectively. Conversely, a 1 % increase in green power utilization and forest area demonstrated potential reductions in health costs of 0.49 % and 1.91 %, respectively. Both FMOLS and CCR estimations, which converge to offer cogent insights, confirm the validity of the study's projections. The results of this research highlight the intricate connections between healthcare expenses and their determinants. Additionally, the study provides policy insights into how to balance economic development with environmental sustainability to manage public health expenditures effectively. These insights have important implications for policymakers and stakeholders who are working to understand and improve the complex landscape of healthcare costs in Bangladesh, as well as accomplish climate goals and SDGs.

7.2. Policy recommendations

Since declining environmental standards are associated with rising healthcare costs, this study suggests that Bangladesh should adopt strategies and regulations to improve ecosystem conditions to reduce the number of health problems and, consequently, healthcare costs. The overall cost of healthcare has been steadily increasing without any noticeable improvement in the quality of the ecosystem provided. The poor and needy in Bangladesh are disproportionately affected by this disparity. The government of Bangladesh should focus on finding ways to make healthcare in the country more affordable and responsive to the needs of its citizens. The healthcare system in Bangladesh would benefit if the government developed methods to quantify the impact of legislation on care, affordability, and accessibility.

Policymakers in Bangladesh must use an extensive and multidimensional technique to address the interconnected issues of health expenditure, economic growth, environmental sustainability, and energy consumption. To support economic growth without exacerbating health expenditures, Bangladesh should consider diversifying its economy. By investing in industries that are less reliant on fossil fuels and focusing on sectors such as information technology, sustainable agriculture, and clean energy, the country can achieve economic growth while minimizing destructive ecological consequences. The government could motivate the development of a green economy by offering financial incentives and support for green startups and businesses. Furthermore, policymakers should prioritize the promotion of clean power sources, such as solar, wind, and hydropower. This can be achieved by delivering financial incentives, subsidies, and tax breaks for both businesses and households that invest in sustainable energy technologies. In addition, the use of renewable energy has increased; health spending can be dramatically reduced in terms of fewer cases of diseases caused by pollution, i.e., respiratory diseases.

Additionally, urbanization and industrialization in Bangladesh should be managed in a way that encourages sustainable development. Policymakers should implement stricter regulations on industrial emissions and set enforceable standards for clean production processes. Incentives should be provided to industries that adopt cleaner technologies and transition to more energy-efficient operations. Creating green zones and encouraging sustainable urban planning can also help minimize the health risks associated with overcrowded urban areas. Ensuring that cities are equipped with the necessary infrastructure to manage waste, control pollution, and offer public green spaces would contribute to a healthier urban environment and help reduce health costs in the long run. Simultaneously, expanding and protecting forested areas is crucial in reducing health expenditures. Forests play a vital role in absorbing CO_2 emissions, improving air quality, and providing a habitat for biodiversity. Policymakers should strengthen conservation policies and promote reforestation programs. This can include incentivizing communities to engage in afforestation efforts, integrating forest conservation into urban planning, and ensuring that land use policies are aligned with environmental sustainability goals. These efforts would contribute to both mitigating climate change and reducing the public health burden by improving the overall quality of the environment.

Finally, public health programs should be integrated with environmental policies. For example, raising awareness about the links between pollution and health and promoting lifestyle changes such as increased physical activity in green spaces can help reduce the burden of preventable diseases. Healthcare systems should also be strengthened to manage the health effects of urbanization, industrialization, and climate change. The government could allocate more resources toward healthcare infrastructure, particularly in areas that are most vulnerable to the effects of industrialization and environmental degradation. Indeed, there is a pressing need for a comprehensive approach to healthcare spending that is inclusive, adaptable, and affordable, incorporating both public and private initiatives to modify healthcare services. More investment in public services can be a viable strategy to reduce the social costs of environmental degradation. To ensure better health, it is essential to build many hospitals; provide a greater number of trained doctors, nurses, and medical professionals; and coordinate sophisticated health services and improved diagnostic tools. The government can simultaneously track and analyze the number of air pollutants and promptly inform citizens about specific air qualities, related health hazards, and practical ways to reduce exposure. The findings of the paper argue for the use of zero-carbon technologies, increased spending on healthcare for those whose health is threatened by environmental degradation, and future calls for more government funding. In addition to fossil fuels, sustainable technologies such as solar energy could be used to meet the energy needs of healthcare facilities.

By embracing the above strategies, Bangladesh would successfully cut its healthcare spending and achieve good health and well-being (SDG 3), clean water and sanitation to reduce the health risks to rural populations (SDG 6), affordable renewable energy (SDG 7), sustainable economic growth (SDG 8), green industrialization (SDG 9), sustainable urbanization (SDG 11), sustainable consumption and production (SDG 12), emission reduction (SDG 13), green spaces and forest landscapes (SDG 14), ecosystem management (SDG 15), peacemaking and strong institutions in the healthcare sector (SDG 16), and partnerships toward sustainability (SDG 17).

7.3. Limitations and future research

While this investigation provides crucial empirical data on Bangladesh, it acknowledges certain limitations that can be explored in future research. There is an apparent drawback in the lack of preanalysis data on health expenditures, which significantly undermines the effectiveness of the applied econometric methodologies. It is crucial to bridge this gap to achieve a thorough comprehension of how ecological sustainability and healthcare costs are related. An extended scope could include recycling, waste management, and technological innovation. Additionally, it might be helpful for future research to analyze additional indicators of air pollution that require further exploration, in addition to carbon emissions from consumer activities. Some of the gases that contribute to climate change, such as methane, PM2.5, NOx, and SO_2, have relatively short lifespans. Further exploration of pollution indicators, including soil and water contamination, and their impact on public health will enhance the understanding of the environmental issues confronting Bangladesh. This thorough analysis of these pollutants will help determine the environmental factors that impact public health and healthcare expenses in Bangladesh more broadly. Another aspect worth considering is the potential impact of technological advancements on mitigating healthcare costs related to environmental factors. Exploring the latest technological advancements, such as the integration of smart city solutions and sustainable infrastructure, can provide valuable insights into how they can positively impact public health. Examining the potential health effects of pollutants in these media enables researchers to establish links with healthcare costs, offering significant insights into the complicated connections between ecosystem conditions and public health in the context of Bangladesh. Furthermore, the methodologies used by the investigation (DOLS, FMOLS, and CCR) are robust methods for estimating long-term relationships in cointegrated systems, but they have limitations. These techniques rely on large sample sizes for reliable inference and assume stable, linear relationships, which may not hold across different regions or economic contexts with structural breaks, policy shifts, or unique institutional factors. Consequently, findings using these methods may lack generalizability when applied to economies with different dynamics, levels of development, or external shocks. Future studies may use advanced econometric methods with updated and latest datasets for similar investigations.

CRediT authorship contribution statement

Asif Raihan: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mohammad Ridwan:** Writing – review & editing, Visualization, Software, Methodology, Formal analysis, Data curation. **Syed Masiur Rahman:** Writing – review & editing, Validation, Supervision, Resources, Investigation. **Tapan Sarker:** Writing – review & editing, Validation, Supervision, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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