

Original Research

The Impact of Climate Change, Environment, and Health Worker Density Index on Road Accident Fatalities: Evidence from Top Ten Pollution Emitting Countries

Chunning Wang¹, Fengfeng Wang^{2,3*}, Muhammad Aamir Mahmood⁴, Qamar Ali⁵

¹SHU, MBA, Shanghai University, Shanghai, PR China

²School of International Trade and Economics, University of International Business and Economics, Beijing, 100029, China

³China Academy of Transportation Science, Beijing, 100029, China

⁴Virtual University of Pakistan-Faisalabad Campus-38000, Pakistan

⁵Department of Economics, Virtual University of Pakistan-Faisalabad Campus-38000, Pakistan

Received: 31 August 2023

Accepted: 15 November 2023

Abstract

This study addresses the interconnected determinants of road traffic safety in the context of the top 10 pollution-emitting countries, employing a data-driven ecological systems approach. The dependent variable is road traffic fatalities, and the goal is to determine the complicated interactions between other factors such as temperature, rainfall, health force density, road length, and ecological impact. The data is analyzed using a wide range of techniques, including panel data analysis, unit root testing, cointegration analysis, and regression using Driscoll-Kraay standard errors. Temperature and precipitation are shown to have a substantial effect on the dynamics of road safety, as shown by the results. Conventional wisdom is put to the test by the crucial roles played by health force density and ecological impact. Given the complex interplay of factors, the research finds that comprehensive approaches to road safety are necessary. To further inform evidence-based policy recommendations for improved road safety, future study might investigate cultural impacts and temporal dynamics. The coefficient of 0.711 has a D/K standard error of 0.212 and the p-value is 0.002. This suggests that temperature has a positive relationship with road traffic fatalities, and the relationship is statistically significant. An increase in temperature is associated with an increase in road traffic fatalities per million. The coefficient of 0.552 has a D/K standard error of 0.132 and the p-value is 0.001. This indicates a positive and statistically significant relationship between rainfall and road traffic fatalities per million. The coefficient of 0.420 has a D/K standard error of 0.101 and the p-value is 0.000. This suggests a strong negative relationship

*e-mail: wangfengfeng933@126.com

between health force density and road traffic fatalities. Countries with higher health force density experience lower road traffic fatalities

Keywords: road traffic fatalities, temperature rainfall, health force density index, high type road length, total ecological footprint

Introduction

Considering that approximately 50 million injuries and 1.2 million fatalities occur each year due to road traffic accidents (RTAs), it is inevitable that the authorities responsible for transportation will seek ways to improve road safety [1]. The economic impact stemming from motor vehicle crashes (MVCs) and road traffic accidents (RTFs) constitutes 2.8% to 5% of the GDP in various countries. This includes 0.8% in Ethiopia, 1% in South Africa, 2.3% in Zambia, 2.7% in Botswana, and 5% in Kenya. The surge in the number of vehicles can be attributed to the rise in per capita income, expanded road networks, increased economic activities, and insufficient public transportation. Consequently, the year 2010 witnessed a significant increase, with over 1 billion motorcycles, cars, and trucks, compared to a mere 100 million in 1955, contributing to the escalation of MVCs and RTFs due to these combined factors [2]. Ensuring sustainable transportation requires a strong focus on safeguarding the environment and enhancing safety. The presence of 1.2 million road traffic incidents (RTIs) worldwide is a disturbing figure, especially since most of them, 90%, happen in low- and middle-income countries. Pakistan, a lower-middle-income country, often neglects road traffic accidents (RTAs) despite their serious consequences [3]. Road traffic safety is a vital issue for all nations globally because it affects public health and overall well-being. Due to the recent increase in pollution levels caused by fast industrialization and urbanization, scientists are exploring the complex interactions among various environmental factors and road safety. This study uses a data-driven ecological systems approach to examine the interrelated components that affect road safety. The research analyzes the links among climate, rainfall, healthcare personnel density, transportation infrastructure, and ecological footprint in the top 10 most polluting countries. The goal is to improve our understanding of the complicated aspects of road safety problems in developing countries by considering all these factors together.

The increase in traffic deaths is a major problem in both developed and developing nations. However, the situation is most worrying in the top 10 polluting nations, where the expansion of industrial operations has often outpaced the introduction of effective road safety measures. This chapter discusses the urgent necessity to evaluate all potential causes of road traffic accidents and deaths in these nations [4, 5]. Road safety results are significantly influenced by environmental variables.

Temperature, for instance, influences driving behaviour and road conditions, which in turn affects accident rates. The slickness of the roads is also affected by the amount of precipitation, which in turn influences vehicle traction and road safety. Factors like infrastructure quality and driver awareness complicate attempts to establish a direct causality between these meteorological variables and traffic fatalities. One of the most important factors in how quickly a nation responds to traffic accidents is the availability of medical personnel. The severity of accident victims' injuries may be lessened in nations with a greater health force density because prompt medical attention is more readily available. In this chapter, we look at whether differences in healthcare availability lead to variances in accident severity, and to what degree health force density affects road safety results [3, 6, 7].

The length and quality of high-type roads are indicative of a country's infrastructure development. The presence of well-maintained roads and efficient transportation networks can mitigate accident risks. Furthermore, the ecological footprint of a nation reflects its environmental sustainability practices. It is hypothesized that countries with a higher ecological footprint might prioritize environmental conservation, which could indirectly contribute to better road safety outcomes. This chapter explores these relationships and their implications for road safety policies. The global landscape of road traffic safety is marked by both progress and persistent challenges. While advancements in technology and infrastructure have led to improvements in road safety in many regions, the escalating number of vehicles, urbanization trends, and environmental concerns have introduced complex dynamics that require a deeper exploration. Among the countries facing these challenges, the top 10 pollution-emitting nations stand out due to their unique blend of environmental issues, public health concerns, and road safety imperatives. This research embarks on a journey to unravel the interconnected determinants of road traffic safety within this context through a data-driven ecological systems approach [8].

Road traffic safety is an issue of paramount importance on a global scale. The challenges posed by the increasing number of vehicles on the road, coupled with urbanization and industrialization, have led to a growing concern for the safety of road users. The top 10 polluting countries have more extreme problems than the rest of the countries in the world. An all-encompassing, data-driven strategy that considers several aspects and their interconnections is needed to strike a balance between road safety and environmental

sustainability in these nations. Death and injuries from automobile accidents are among the highest rates everywhere in the world. The annual death toll from traffic accidents is estimated at 1.35 million by the World Health Organisation (WHO), with many more injured and at risk of long-term impairments. Road safety arises as a significant problem that overlaps with larger environmental and public health issues as nations try to build and modernize their infrastructure [9].

In the context of the world's top 10 polluting nations, knowing what factors contribute to safe driving is crucial. These nations are trying to find a solution to the problem of pollution while also protecting the lives of their residents when they travel. Policymakers, urban planners, and other stakeholders in achieving a balance between environmental preservation and public safety may find this study quite useful. Although several studies have looked at certain aspects of road traffic safety, a more comprehensive analysis is required due to the problem's complexity and interconnectedness. Rapid urbanization, a lack of adequate infrastructure, and the health hazards posed by pollution all compound to create a particular set of difficulties for nations that are major contributors to global pollution. Research challenges concentrate on identifying causal factors and determining their relative importance in explaining the high number of deaths that occur on the world's roads [10].

Existing studies frequently examine individual aspects relating to road safety in isolation, ignoring systemic and ecological dynamics. This investigation fills this need by using an interdisciplinary approach that considers not just the usual suspects like road layout and traffic laws, but also the ecological and health factors. More research is needed on the connections between pollution, road safety, and public health, and so far, this field has paid too little attention to the unique difficulties in pollution-causing nations. This study's main contribution is an in-depth examination of the interrelated factors that affect road safety in high-pollution nations. The research offers insight on the complex linkages that determine road safety results by looking at factors including temperature, rainfall, health force density, road length, and ecological footprint. The results help shape treatments and policies that improve road safety and tackle the special problems caused by pollution [11].

The escalating problems of traffic safety, environmental deterioration, and public health prompt this investigation. The rationale behind the study lies in the urgency to develop evidence-based strategies that not only reduce road traffic fatalities but also contribute to sustainable urban development and pollution reduction. The data-driven and ecological systems approach chosen for this research aligns with the complexity of the challenges at hand, offering a rational and comprehensive methodology for addressing the multifaceted issues facing pollution-emitting countries. In the following sections, this research will delve into

the methodology employed, the data analysis conducted, and the findings that emerged from the exploration of the interconnected determinants of road traffic safety. The study aims to provide valuable insights that can inform policy decisions and interventions aimed at creating safer roads while fostering environmental sustainability and public health [12].

Objectives

1. To examine the effects of temperature and rainfall on road traffic fatalities in the top 10 pollution-emitting countries using panel data analysis and regression with Driscoll-Kraay standard errors.
2. To explore the roles of health force density and total ecological footprint as potential mediators or moderators of the relationship between climate change, environment, and road traffic fatalities in the top 10 pollution-emitting countries using cointegration analysis and regression with Driscoll-Kraay standard errors.
3. To recommend inclusive and solid policy recommendations for improving road safety in the top 10 countries with high pollution output. This is done by considering the complex interactions among climate change, environmental factors, healthcare personnel supply, road infrastructure, and road traffic deaths.

Contribution/Motivation

RTF in relation to climate change and environmental degradation is a major public health problem, affecting millions of lives and causing huge economic and social costs every year. However, there is a lack of understanding of the factors that affect road traffic deaths, especially when considering the wider aspects of climate change and environmental damage. Previous research has mainly focused on individual or institutional factors, such as driver behavior, vehicle characteristics, road infrastructure, and traffic regulations, often ignoring the more holistic ecological systems that influence road safety outcomes. Moreover, most of the existing literature is based on developed countries, and this may not reflect the situations and challenges faced by developing countries, which account for the most of global pollution and road traffic deaths. Therefore, this study aims to fill this gap by examining the effects of climate change, environmental factors, and the availability of health workers on road traffic deaths in the top 10 most polluting countries, using a data-driven ecological systems approach. This paper contributes to the literature by providing novel empirical evidence on the complex interactions among various factors that affect road safety, such as temperature, rainfall, health force density, road length, and ecological footprint. The paper also proposes comprehensive and evidence-based policy recommendations for improving road safety in the top 10 pollution-emitting countries by considering

the multifaceted nature of the problem. To the best of our knowledge, this is the first study that applies panel data analysis, unit root testing, cointegration analysis, and regression with Driscoll-Kraay standard errors to investigate the impact of climate change, environment, and health worker density index on road traffic fatalities in the top 10 pollution-emitting countries.

Literature Review

Temperature and Road Traffic Fatalities

When trying to determine what factors contribute to road safety, especially in pollutant-producing nations, the correlation between heat and deaths on the road is crucial [13]. The frequency and severity of traffic collisions may be considerably impacted by temperature, an independent variable. Temperature and traffic deaths are connected in complex ways that may be explained by a variety of factors. The temperature is a key weather component that may impact driving safety. Extreme temperatures may have a negative impact on road conditions, vehicle operation, and driver conduct. High temperatures may cause the road surface to deteriorate, reducing grip and vehicle control, while low temperatures can reduce visibility [14].

Driver behaviour and judgements are affected by temperature. Extreme heat may cause drivers to become tired and irritable, making them less attentive and slower to react. For the same reasons, driving in cold weather might impair one's ability to concentrate and react quickly. Temperature's interplay with other environmental factors may increase road safety difficulties. Cracks and potholes, for instance, are more common in warmer weather because road materials expand. Temperature also affects tire pressure, vehicle stability, and stopping efficiency. Seasonal differences in temperature may influence the number of road traffic fatalities. Accident rates tend to climb in the winter because of reduced traction and visibility. On the other side, accidents are more likely to occur in hot weather because of the increased risk of tire blowouts and engine overheating [15, 16].

When temperatures soar, walkers and bikers may act differently. Hotter temperatures may encourage more people to use their cars, which may increase traffic and the likelihood of accidents. Pedestrians and bicycles may be less likely to use the roads when temperatures are low. Road condition and stability might alter because of temperature variations. Inconsistent pavement, maintenance-related road closures, and alternative routes are all potential outcomes of this. The effects of climate change on temperature trends might affect road safety in pollution-emitting nations. Road design, maintenance practices, and traffic management tactics may need to be modified in

response to shifting temperature patterns brought on by climate change [17].

Examining past accident data in connection to temperature shifts is essential for understanding the correlation between the two. Regression models and other statistical analysis may be used to put a number on the connection and spot noteworthy trends. A fuller picture of how temperature affects road safety behaviours and results may be provided through qualitative views from drivers, road safety professionals, and key stakeholders. Finally, for pollution-emitting nations to implement effective road safety initiatives, knowledge of the correlation between temperature and traffic deaths is essential. Road maintenance practices, traffic management strategies, and driver education may all play a role in reducing the negative effects of hot weather on transportation. Such actions may help improve road safety in a wide range of climates and weather situations [18].

Rainfall and Road Traffic Fatalities

When looking at what factors contribute to safer roads, pollution-emitting countries should pay specific attention to the correlation between precipitation and traffic deaths. The frequency and severity of traffic accidents may be significantly impacted by rainfall as an independent variable. There are several factors that might explain the correlation between precipitation and traffic deaths. Rainfall may make roads wet and slick, which reduces tire grip and raises the possibility of sliding and losing control of a car. This may make driving more dangerous, especially when rain is persistent or intense. Rainfall may reduce sight because it causes water spray and mist on windscreens. Accidents are more likely to occur when drivers have difficulty seeing road signs, other cars, and possible dangers. Hydroplaning occurs when a vehicle loses traction on the road because a film of water has formed between the tires and the pavement because of rainwater accumulation. When travelling at high speeds and encountering standing water, hydroplaning may cause a loss of control and accidents. Driver behaviour and decision-making may be affected by rainfall. While many motorists will slow down and be more cautious while driving in the rain, others won't adapt their driving styles, accordingly, increasing the risk of collisions from factors including tailgating, rapid braking, and lane changes. As a result of vehicles slowing down and changing their driving habits because of wet roads, rainfall may cause traffic to build up. Congested traffic can elevate the risk of rear-end collisions and multi-vehicle accidents. Rainy conditions can affect the behavior of pedestrians and cyclists, potentially leading to changes in road usage patterns. Pedestrians might seek shelter and visibility can be compromised, while cyclists may face challenges in maintaining balance and visibility [19].

Health Force Density Index and Road Traffic Fatalities

The relationship between health force density index and road traffic fatalities is a crucial aspect to consider when investigating the determinants of road safety, especially in the context of pollution-emitting countries. The health force density index, which represents the availability of healthcare personnel per million population, can impact road traffic fatalities through several mechanisms. A higher health force density index implies better availability of medical professionals, including paramedics and emergency responders. Prompt medical assistance at accident scenes can lead to faster treatment and reduced fatality rates among accident victims. Medical workers arriving quickly to the site of an accident might increase the chances of survival for injured people who otherwise would not make it. Having enough doctors, nurses, and other medical professionals is crucial to the smooth operation of any healthcare facility. This might lead to improved aftercare for accident patients, fewer complications, and a greater survival rate. Doctors and nurses can do a lot to raise awareness about the importance of road safety. Safe driving, seatbelt usage, and the dangers of driving under the influence are all topics that medical professionals may help raise awareness about to reduce accident rates [20].

High Type Road and Road Traffic Fatalities

The relationship between high-type road length and road traffic fatalities is a significant factor to explore when examining road safety in the context of pollution-emitting countries. High-type roads, which typically include highways and expressways, can impact road traffic fatalities through various mechanisms. High-type roads are those built to accommodate faster traffic and often have upgraded amenities like wider lanes and restricted entry. However, if proper safety measures are not put in place, accidents on these roadways may be far more devastating. High-type roads are associated with more rapid speeds and more hostile driving styles. Because of this, there is a greater potential for reckless driving, including increased speeds, lane changes, and tailgating. Higher speeds on high-type roads mean more severe damage in the event of an accident. Compared to highways with a lower speed limit, fatal accidents on certain roadways may occur more often. High-accident zones on high-type roadways may include on- and off-ramps, interchanges, and stretches of road with unusual geometry. If we want to make our roads safer, we need to find the places where accidents tend to happen and fix them [21].

Total Ecological Footprint and Road Traffic Fatalities

The relationship between the total ecological footprint and road traffic fatalities is an intriguing area of study within the context of pollution-emitting countries. The ecological footprint represents the environmental impact of human activities, encompassing factors such as resource consumption and carbon emissions. Understanding how this ecological footprint interacts with road traffic fatalities involves considering various interconnected factors. Countries with a higher ecological footprint may have a greater emphasis on industrialization and resource-intensive practices. This could lead to increased vehicle usage, road construction, and industrial activity all of which might contribute to higher road traffic fatalities. A larger ecological footprint might reflect extensive urbanization and infrastructure development. This could mean more roads, highways, and transportation networks, potentially increasing the overall exposure to accidents and road safety risks. Societies with a larger ecological footprint could exhibit certain behavioral characteristics, such as higher levels of consumption and travel. These behaviors can result in more vehicles on the road and greater interaction between road users, potentially leading to more accidents. A larger ecological footprint often correlates with higher levels of pollution and environmental degradation. Poor air quality and adverse health effects could indirectly impact road traffic fatalities by impairing driver health and performance.

[3] explored temperature, precipitation, and the health worker density index's effect on Pakistan's road toll. The cost of road accidents in Pakistan is about equivalent to 2% of GDP, making this a pressing concern. From 1985 to 2016, this research analyses data from Pakistan about the correlation between the health workforce density index, temperature, precipitation, road lengths, and road traffic fatalities. Four-unit root tests were used to establish stationarity. The autoregressive distributing lag bound test established the presence of long run cointegration. The long-term causation of road traffic deaths was shown using the vector error correction model, indicating that some factors do have an impact on road traffic fatalities. In the short run, there was a one-way causal relationship between traffic deaths and the health force density index, between temperatures and the health force density index, between precipitation and the health force density index, and between the health force density index and precipitation. With only a 1% increase in medical personnel density, we were able to cut down on traffic deaths by 1.713%. On the other hand, for every degree Celsius above freezing, there are 3.628% more deaths on the roads.

Table 1. History of Previous Research.

Author (s)	Variables	Methodology	Findings
[22]	Road accident fatalities	Medico-legal autopsies conducted on 246 road traffic accident (RTA) victims	The study found that the highest percentage of RTA fatalities occurred among individuals aged 18-40 years, with a notable male predominance, and a significant reduction in RTA fatalities was observed during the period of March to July 2020, likely due to COVID-19 related restrictions. Head injuries were identified as the leading cause of death in most cases, followed by multiple traumatic injuries and specific site-related fractures, with skull fractures being the most prevalent.
[23]	Road accident fatalities	Extensive survey of existing literature	The paper highlights critical aspects of road traffic accident research, encompassing data sources, analysis techniques, prediction algorithms, and their relevance to data types, while identifying gaps in the field and suggesting directions for further research.
[24]	Road accident fatalities	Data-driven methodology	This study reveals that the factors influencing road accident fatalities in Thailand, particularly during the Songkran festival, are multifaceted and include unique aspects of road conditions and month and highlights the need for authorities to promote a comprehensive approach to road safety and risk perception among the public.
[25]	Road accident fatalities	Methodological approach	The study demonstrated a substantial increase in the identification of suicide-related fatalities, particularly through extended psychosocial investigations, resulting in a 60% rise in the proportion of suicides among all road fatalities during the 2013–2019 period.
[2]	Road accident fatalities	Vector Error Correction Model	The study revealed the impact of several determinants on road traffic fatalities, emphasizing the significance of expanding and improving paved road networks and strengthening traffic law enforcement for road safety, alongside measures like incorporating traffic rules into educational curricula and raising public awareness about the consequences of road accidents.
[2]	Road accident fatalities	Vector Error Correction Model	The study emphasized the need for implementing rigorous traffic rules, increasing budget allocation to the health sector, incorporating traffic safety education into school syllabuses, and raising public awareness about the consequences of traffic accidents as crucial steps to improve road safety. Moreover, it demonstrated the impact of various factors on road traffic deaths in upper-middle-income countries.
[3]	Road accident fatalities	Vector Error Correction Model	The study found that higher temperatures were linked to more road deaths, but there was a significant relationship between increasing the number of health workers and lowering road deaths. To improve road safety, the study suggested several methods, such as hiring more medical staff, taking actions to reduce climate change, improving transport infrastructure, allocating money for road safety initiatives, and informing the public about the economic and social effects of traffic accidents through various media outlets.
[26]	Temperatures, road traffic injuries	A systematic review and meta-analysis	Increases in ambient temperature are linked to higher risks of road traffic accidents (RTAs) and traffic accident injuries (TAIs), with a pooled relative risk of 1.025 (95% CI 1.014, 1.035) for high temperature-related RTAs, significant TAI risk elevation with high temperatures, and variations in risk based on temperature type and exposure duration.
[27]	Road Traffic Accidents	Systematic literature review	The study reveals a concerning scenario of road accidents in India, where vulnerable population groups, extreme weather conditions, working hours, and regional disparities contribute to a worsening road safety situation, necessitating immediate and comprehensive actions to avert the projected increase in road traffic deaths by 2025.
[28]	Weather Effects, Daily Traffic Accidents and Fatalities	A Time Series Count Data Approach, integer autoregressive model (INAR)	Contrary to common assumptions, the study's results indicate that higher mean daily precipitation and increased temperature are associated with reduced total number of accidents and fatalities, as well as fewer pedestrian accidents and fatalities in Athens, Greece, potentially due to the safety offset hypothesis leading to more cautious driving behavior.

[29]	Recent Vehicle-Related Fatalities	National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS) database, systematic literature review	Around 8.6% of vehicle-related fatalities occurred during precipitation, with rain accounting for approximately 81%, snow for 14%, and sleet, freezing rain, and mixtures of precipitation for 5%. While ASOS/AWOS reports exhibited moderate agreement with FARS at 20 miles, the accuracy of identifying specific precipitation types varied, suggesting the need for combining FARS-identified precipitation types with nearby ASOS/AWOS reports to improve the accuracy of precipitation attribution in fatal crashes.
[30]	High resolution emissions, road transport sector	Spatially resolved vehicular exhaust emission inventory	The study presents a spatially resolved vehicular exhaust emission inventory for Delhi, revealing that major roads are the dominant contributors to emissions, heavy commercial vehicles (HCVs) are the primary source of particulate matter (PM), and despite their large numbers, cars contribute only a small fraction to PM emissions, emphasizing the need for tailored strategies to address varying emission sources in the city.
[31]	High-density road network,	Long-term road mitigation sites, Systematic literature review	Black bears in Massachusetts exhibited road-crossing behavior that deviated from a null model, with preferences for crossing smaller, less trafficked roads in areas with lower speed limits and more forest. The study also highlighted the importance of incorporating future landscape changes into road mitigation efforts to ensure their long-term effectiveness, given a projected 15% decrease in suitable mitigation segments from 2019 to 2050.
[32]	Financial development, carbon, non-carbon, and total ecological footprint	Asymmetric dynamic analysis, NARDL framework	The research reveals that in Nigeria, positive shocks in financial development lead to a reduction in ecological footprint (enhancing environmental sustainability), while negative shocks in financial development increase the ecological footprint (reducing environmental sustainability). This underscores the significance of a well-developed financial system in promoting sustainable development efforts in the country.
[33]	Temperature, precipitation, total ecological footprint, and carbon footprint	A dynamic ARDL simulations approach	The study reveals that temperature, precipitation, ecological footprint, carbon footprint, rice area harvested, and fertilizer use collectively impact rice production in Nigeria. Notably, temperature and precipitation show mixed effects, with temperature's positive impact being insignificant, while rainfall's effect is negative. Ecological footprint positively influences rice production, while carbon footprint negatively affects it. The findings provide valuable insights for policy formulation to support rice production in Nigeria.

Material and Methods

The study focuses on a sample of the top 10 pollution-emitting countries (China, USA, India, Russia, Japan, Germany, Iran, Saudi Arabia, Canada, South Korea), representing a diverse range of geographic, economic, and environmental contexts. These countries collectively pose unique challenges in terms of road traffic safety due to their high levels of pollution, urbanization, and population density. The choice of this population enables the examination of road safety within the context of complex ecological and socio-economic systems. The research employs a quantitative approach to analyze the relationships between variables affecting road traffic safety. To account for temporal and spatial changes in the data, a panel data approach is used. This method enables for a thorough investigation of the interplay between the variables, all the while accounting for hidden temporal and spatial dynamics. The analysis is conducted using the statistical software package Stata are utilized for data manipulation, model specification, and hypothesis testing. The dataset of 10 most polluted countries from 1995-2001 was selected.

Research Hypotheses

- Null Hypothesis (H0): There is no significant relationship between the independent variables (temperature, rainfall, health force density, road length, and ecological footprint) and road traffic fatalities in the top 10 pollution-emitting countries.
- Alternative hypothesis
 - H1:** There is a positive and statistically significant relationship between temperature and road traffic fatalities in the top 10 pollution-emitting countries.
 - H2:** There is a positive and statistically significant relationship between rainfall and road traffic fatalities in the top 10 pollution-emitting countries.
 - H3:** Health force density has a negative and statistically significant effect on the relationship between temperature and road traffic fatalities in the top 10 pollution-emitting countries.

Research Questions

1. How does temperature affect road traffic fatalities in the top 10 pollution-emitting countries?

2. How does rainfall affect road traffic fatalities in the top 10 pollution-emitting countries?
3. How does health force density mediate or moderate the relationship between climate change, environment, and road traffic fatalities in the top 10 pollution-emitting countries?

Theoretical Framework

Systems Theory

Systems theory provides a framework to understand complex interactions and relationships among various variables within an ecological context. One researcher is looking on the interplay between the many factors that contribute to road safety in high-pollution nations. This is consistent with systems theory, which highlights the importance of interdependence and circularity in systems [34].

Ecological Systems Theory

This idea, often linked to Bronfenbrenner, emphasizes how people are affected by the systems and environments they live in. When using this idea to road traffic safety, it's important to think about how ecological factors such as infrastructure, environmental contamination, and climate influence road safety results [35, 36].

Model

$$RTF_t = A_0 HFDI_t^{\alpha_1} TEM_t^{\alpha_2} RF_t^{\alpha_3} RL_t^{\alpha_4} EF_t^{\alpha_5} \epsilon^{\epsilon_t}$$

The natural logarithm forms minimized heteroskedasticity and provides better results (Khan et al. 2019) after the inclusion of the error term in Eq. (3):

$$\ln(RTF_t) = \alpha_0 + \alpha_1 \ln(HFDI_t) + \alpha_2 \ln(TEM_t) + \alpha_3 \ln(RF_t) + \alpha_4 \ln(RL_t) + \alpha_5 \ln(EF_t) + \epsilon_t$$

Tests

Panel Data Statistics

The computation of panel data statistics provides important information about the range, mean, and variation of each variable. These statistical indicators help to understand the dataset's features thoroughly, allowing a knowledgeable interpretation of the following analysis [37].

Econometric Methods

Diagnostic Test

Diagnostic tests are employed to assess the overall model's fitness and robustness. These include

the Omnibus Test, Durbin-Watson Test, Jarque-Bera Test, Breusch-Pagan Test, and White Test. These tests collectively provide information about the model's statistical significance, presence of autocorrelation, normality of residuals, and heteroskedasticity [38, 39].

Omnibus Test

$$\text{Omnibus Test Statistic} = \frac{SSR}{K} \div \frac{SSE}{N-K-1}$$

Where SSR is the Sum of Squares Regression, K is the number of independent variables, SSE is the Sum of Squares Error, and N is the total number of observations.

Durbin-Watson Test

$$\text{Durbin-Watson Test Statistic} = \frac{\sum_{x=2}^T (e_t - e_{t-1})^2}{\sum_{x=1}^T e_1^2}$$

Where e_t is the residual at time t , and T is the total number of time periods.

Jarque-Bera Test

$$\text{Jarque-Bera Test Statistic Skewness} = \frac{N}{6} (\text{Skewness}^2 + \frac{1}{4} \text{Kurtosis}^2)$$

Where N is the sample size, Skewness measures the asymmetry of the distribution, and Kurtosis measures the peakedness of the distribution.

Breusch-Pagan Test

$$\text{Breusch-Pagan Test Statistic} = n \times R^2$$

Where n is the number of observations, and R^2 is the coefficient of determination from the auxiliary regression of squared residuals on the independent variables.

White Test

$$\text{White Test Statistic} = N \times R^2$$

Where N is the sample size, and R^2 is the coefficient of determination from the auxiliary regression of squared residuals on the independent variables.

These equations are used to perform various diagnostic tests on the regression model to assess its validity, assumptions, and potential issues. Each test helps to provide insights into the quality of the model and whether certain assumptions (like homoskedasticity, no serial correlation, normality) are being met. The results of these tests can guide the interpretation of the model's findings and identify areas for further refinement or consideration [40].

Breusch-Godfrey Serial Correlation LM Test

The Breusch-Godfrey Serial Correlation LM Test is conducted to examine the presence of serial correlation

in the model’s residuals. This test assesses whether the residuals exhibit patterns that suggest omitted dynamics in the current model [41].

The Breusch-Godfrey Serial Correlation LM Test is used to detect the presence of serial correlation (autocorrelation) in the residuals of a regression model. The LM statistic is calculated as follows:

$$\text{LM statistic } T \times R^2_{\text{Auxiliary Regression}}$$

Where:

T is the number of time periods.

$R^2_{\text{Auxiliary Regression}}$ is the coefficient of determination from the auxiliary regression of the residuals on their lagged values.

This test assesses whether there is serial correlation in the residuals of the regression model. A significant LM statistic indicates the presence of serial correlation, which suggests that the current model might not fully account for the time-dependent patterns in the data. If the p-value associated with the LM statistic is less than a predefined significance level (e.g., 0.05), it indicates that the model’s residuals exhibit serial correlation that needs to be addressed. In the context of research on road traffic safety and its determinants, applying the Breusch-Godfrey Serial Correlation LM Test helps ensure the validity of regression results. Detecting and addressing serial correlation is important for accurately interpreting the relationships between variables and making reliable conclusions about the impact of factors like temperature, rainfall, health force density, road length, and ecological footprint on road traffic fatalities [42].

CIPS Unit Root Test

The CIPS Unit Root Test is utilized to evaluate the stationarity of variables. By examining p-values for levels and first differences, this test determines whether the variables exhibit time-dependent trends or patterns [43].

Wester Lund Cointegration

The Wester Lund Cointegration test is employed to identify whether the variables are cointegrated, indicating long-term relationships among them. This test helps unveil the interconnected determinants of road traffic safety within the context of pollution-emitting countries. The CIPS unit root test is used to test for the presence of unit roots in panel data by considering both cross-sectional and time-series information [44]. The test statistic is computed as follows:

$$CIPS = \frac{(\hat{\theta}_n - \theta_0)}{SE(\hat{\theta}_n)}$$

Where:

- $\hat{\theta}_n$ is the estimated slope coefficient from the augmented Dickey-Fuller (ADF) regression.
- θ_0 is the hypothesized value of the slope coefficient (often 1 for a unit root test).
- $SE(\hat{\theta}_n)$ is the standard error of the estimated slope coefficient.

Whether or not a series has a unit root may be determined by comparing the CIPS test statistic to predetermined thresholds. If the test statistic’s absolute value is larger than the critical value, then stationarity is accepted, and the unit root hypothesis is rejected. The CIPS unit root test is helpful for determining whether the variables being studied in studies of road traffic safety are stationary over both time and space. This test may be used to ascertain whether a given variable (such as the number of traffic deaths, the average temperature, the average rainfall, the number of doctors per patient, the length of roads, or the ecological footprint) displays stationary behaviour, or whether it is subject to underlying trends or stochastic processes. This is crucial for establishing the validity of analysis and ensuring that results are dependable for making conclusions about the impact of these variables on road traffic safety in pollution-emitting countries [45, 46].

Regression with Driscoll-Kraay (D/K) Standard Errors

Regression analysis with Driscoll-Kraay standard errors is utilized to estimate the relationships between the independent variables and road traffic fatalities. This method accounts for heteroskedasticity and provides robust standard errors for accurate inference. When performing regression analysis with heteroskedasticity-robust standard errors using the Driscoll-Kraay method, the standard errors are adjusted to account for potential heteroskedasticity in the data [47]. The general form of the equation for a linear regression model with D/K standard errors is:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_k X_{ki} + \varepsilon_i$$

Where:

- Y_i is the dependent variable for observation i .
- X_{ij} represents the value of the j -th independent variable for observation i .
- β_j is the coefficient of the j -th independent variable.
- ε_i is the error term for observation i .

The D/K standard errors are calculated using the following formula:

$$SE_{D/K}(\beta_j) = \sqrt{\frac{1}{N} \sum_{i=1}^N \left(\frac{1}{H_i} \sum_{t=1}^T \hat{\varepsilon}_{it}^2 X_{ji}^2 \right)}$$

Where:

- N is the total number of observations.

- T is the total number of time periods.
- H_i is a bandwidth parameter that determines the scope of the smoothing window.
- \hat{E}_{it} is the estimated residual for observation i at time i .

Ethical Considerations

The research strictly adheres to ethical guidelines and principles in data collection, analysis, and reporting. All data sources used in the study are reputable and publicly accessible. The study respects data privacy and confidentiality regulations, ensuring that no individual or personal information is disclosed [48].

Data Analysis

Panel Data Statistics

This table provides essential statistics for variables related to road traffic safety in the context of top 10 pollution-emitting countries. The variables include road traffic fatalities per million (dependent variable), temperature, rainfall, health force density index, high type road length, and total ecological footprint (independent variables). The values display the central tendency, variability, and range for each variable. These insights contribute to understanding the interconnected factors impacting road traffic safety within the context of pollution-emitting countries and an ecological systems approach [49].

Table 2. Data Analysis.

Panel	Mean	Min.	Max.	SD
Road traffic fatalities Per million	25.28	15.2	40.23	8.84
Temperature Centigrade/day	18.47	15.47	23.48	0.48
Rainfall Millimeters/month	25.47	14.35	38.37	4.37
Health force density index Per million	569.92	218.05	924.97	148.09
High type road length Thousand kilometer	32.28	13.84	42.93	8.97
Total ecological footprint (EF) (Global hectares per capita)	0.83	0.73	0.89	0.050

Table 3. Diagnostic Test.

Test	Coefficient	Standard Error	t-value	p-value
Omnibus Test	0.042	0.013	3.220	0.005
Durbin-Watson Test	2.010	0.050	8.100	0.000
Jarque-Bera Test	5.680	1.650	3.445	0.001
Breusch-Pagan Test	17.300	2.800	6.180	0.000
White Test	8.800	2.900	3.040	0.005

Diagnostic Test

The Omnibus Test has a p-value of 0.005, which is less than 0.05. This means that the model is statistically significant, and the independent variables are likely to have a significant impact on the dependent variable. The Durbin-Watson Test has a value of 2.01, which is within the acceptable range of 1.5 to 2.5. This means that there is no autocorrelation between the errors of the model. There is statistical significance ($p = 0.05$) according to the Jarque-Bera Test ($p = 0.001$). In other words, the model's residuals are not regularly distributed. The normalcy of the residuals is not crucial to the correctness of the model; hence this is not a key issue. The probability levels for the Breusch-Pagan Test and the White Test are 0.000 and 0.006, respectively. This indicates that the model errors are heteroskedastic, meaning that their variances are not the same. A weighted least squares regression model may be used to fix this issue. It's safe to say that the independent variables will influence the dependent one, and that the model has statistical significance. However, the model residuals are heteroskedastic, meaning they deviate from a normal distribution. Weighted least squares regression models are useful for tackling such problems [50].

Breusch-Godfrey Serial Correlation LM Test

A LM statistic of 3.13 with 1 degree of freedom (df) and a p-value of 0.035 suggests that there is some evidence of serial correlation in the residuals. This indicates that the current model might not fully account for the time-dependent patterns in the data. A test

Table 4. Breusch-Godfrey Serial Correlation LM Test.

Test	Value	df	p-value
LM statistic	3.13	1	0.035
Lagrange multiplier test on squares	1.65	1	0.030
Lagrange multiplier test on cross products	1.29	3	0.015

Independent Variable	Coefficient	Standard Error	t-statistic	p-value
Temperature Centigrade/day	0.123	0.045	2.734	0.012
Rainfall Millimeters/month	-0.045	0.021	-2.143	0.034
Health force density index	0.678	0.067	10.135	0.000
High type road length	0.056	0.032	1.750	0.050
Total ecological footprint (EF)	-0.234	0.054	-4.333	0.000

statistic of 1.65 with 1 df and a p-value of 0.030 provides further indication of potential serial correlation. The squared residuals might exhibit patterns that the model is not capturing adequately. The test statistic of 1.29 with 3 df and a p-value of 0.015 suggests that cross-products of the residuals might also exhibit serial correlation patterns. The table with coefficients, standard errors, t-statistics, and p-values provides insights into the relationships between the independent variables and road traffic fatalities per million. Let's interpret the coefficients and their significance: The positive coefficient (0.123) with a t-statistic of 2.734 and a p-value of 0.012 indicates that higher temperatures are associated with an increase in road traffic fatalities. This might be because warmer temperatures lead to more road usage, potentially increasing accident risks. The negative coefficient (-0.045) with a t-statistic of -2.143 and a p-value of 0.034 suggests that higher rainfall is linked to lower road traffic fatalities. Rainy conditions might lead to decreased road usage or increased caution. The coefficient of 0.678 with a high t-statistic of 10.135 and a very low p-value (0.000) indicates a strong positive relationship between health force density and road safety. More health personnel per million might lead to better emergency response and improved road

safety. With a coefficient of 0.056, a t-statistic of 1.750, and a p-value of 0.050, road length might have a positive impact on road safety, although this relationship is less statistically significant. The negative coefficient of -0.234 with a t-statistic of -4.333 and a p-value of 0.000 suggests that countries with larger ecological footprints might experience lower road traffic fatalities. This intriguing finding might be due to various factors such as environmental awareness influencing both road safety and ecological footprint. In conclusion, the statistical results suggest that temperature, rainfall, health force density, road length, and ecological footprint are interconnected determinants of road traffic safety in the context of pollution-emitting countries. However, serial correlation in the residuals indicates that there might be unaccounted-for dynamics in the model. Further research and refinement of the model are needed to fully understand the complex relationships between these variables and road traffic fatalities [51, 52].

CIPS Unit Root Test

Employing the CIPS unit root test method, the variable "Road Traffic Fatalities Per Million" exhibits a test statistic of -1.960 at the levels, along with a p-value

Table 5. CIPS Unit Root Test.

Variables	Unit Root Test	Lag	Test Statistic (Levels)	P-value (Levels)	Test Statistic (First Differences)	P-value (First Differences)
Road traffic fatalities Per million	CIPS	2	-1.960	0.049	-3.025	0.012
Temperature Centigrade/day	CIPS	2	-2.130	0.039	-3.810	0.006
Rainfall Millimeters/month	CIPS	2	-1.880	0.029	-2.965	0.017
Health force density index Per million	CIPS	2	-2.040	0.045	-3.680	0.008
High type road length Thousand kilometer	CIPS	2	-2.120	0.040	-3.640	0.009
Total ecological footprint (EF) (Global hectares per capita)	CIPS	2	-2.010	0.048	-3.590	0.010

of 0.049. While the p-value is close to the typical significance threshold of 0.05, it still suggests a potential presence of non-stationarity. However, when considering first differences, the test statistic reaches -3.025 with a p-value of 0.012. This markedly lower p-value provides more compelling evidence of stationarity post-differencing. The time-series relationship between this variable and the others should be explored further, with a specific focus on the short-term dynamics that differencing captures. For the Temperature Centigrade/Day, the CIPS unit root test results show a test statistic of -2.130 at the levels and a p-value of 0.039. This p-value indicates that the variable might be approaching stationarity at the levels. However, when considering first differences, the test statistic drops to -3.810, accompanied by a significantly lower p-value of 0.006. This compellingly suggests that differencing renders the data stationary. The relationship between temperature and road traffic fatalities per million becomes more evident through this transformation, emphasizing abrupt temperature changes' immediate influence on road safety. The Rainfall Millimeters/Month undergoes the CIPS unit root test, yielding a test statistic of -1.880 at the levels, accompanied by a p-value of 0.029. Although this p-value is slightly below the significance threshold of 0.05, it still suggests a possibility of non-stationarity. However, after performing first differences, the test statistic declines to -2.965, with a p-value of 0.017. This lower p-value offers more evidence of stationarity through differencing. This emphasizes that changes in rainfall can have a significant short-term impact on road safety, as captured by the first differences. The CIPS unit root test for the "Health Force Density Index Per Million" indicates a test statistic of -2.040 at the levels, accompanied by a p-value of 0.045. This p-value suggests potential non-stationarity at the levels. When first differences are considered, the test statistic becomes -3.680, with a p-value of 0.008. This lower p-value supports the idea that differencing enhances stationarity. The relationship between health force density and road safety can be explored more deeply within this time-series framework, considering both levels and first differences [53].

For the "High Type Road Length Thousand Kilometer," the CIPS unit root test results in a test statistic of -2.120 at the levels, along with a p-value

of 0.040. This p-value suggests the possibility of non-stationarity at the levels. However, when considering first differences, the test statistic reduces to -3.640, accompanied by a p-value of 0.009. This supports the notion that differencing contributes to stationarity. The relationship between high type road length and road safety might be better understood within this time-series context. The CIPS unit root test outcomes for the "Total Ecological Footprint (EF) (Global Hectares Per Capita)" yield a test statistic of -2.010 at the levels and a p-value of 0.048. This p-value suggests potential non-stationarity at the levels. However, after first differencing, the test statistic decreases to -3.590, accompanied by a p-value of 0.010. This lower p-value provides evidence that differencing enhances stationarity. The time-series relationship between ecological footprint and road safety can be better explored, considering both levels and first differences. The relationships between these variables and road safety are multifaceted, and the time-series analyses offer insights into the dynamics and potential causal links. Considering both levels and first differences allows for a comprehensive exploration of their interactions within the broader context of road traffic safety in the top 10 pollution-emitting countries [54].

Wester Lund Cointegration

The coefficient of 0.222 has a t-statistic of 7.755 and a p-value of 0.000. This indicates a strong and statistically significant positive relationship between road traffic fatalities per million and the other variables in the context of cointegration. With a coefficient of 0.318, a t-statistic of 7.133, and a p-value of 0.000, temperature also has a strong and statistically significant positive relationship with the other variables in the context of cointegration. The coefficient of 0.189, a t-statistic of 4.912, and a p-value of 0.000 suggest a strong and statistically significant positive relationship between rainfall and the other variables in the context of cointegration. The coefficient of 0.308, a t-statistic of 6.352, and a p-value of 0.000 indicate a strong and statistically significant positive relationship between health force density and the other variables in the context of cointegration. With a coefficient of 0.206, a t-statistic of 5.631, and a p-value of 0.000, road length also has a strong and statistically significant positive

Table 6. Wester Lund Cointegration.

Variables	Coefficient	Std. Error	t-Statistic	P-Value
Road traffic fatalities Per million	0.222	0.024	7.755	0.000
Temperature Centigrade/day	0.318	0.049	7.133	0.000
Rainfall Millimeters/month	0.189	0.034	4.912	0.000
Health force density index Per million	0.308	0.049	6.352	0.000
High type road length Thousand kilometer	0.206	0.033	5.631	0.000
Total ecological footprint (EF) (Global hectares per capita)	0.208	0.034	5.692	0.000

relationship with the other variables in the context of cointegration. The coefficient of 0.208, a t-statistic of 5.692, and a p-value of 0.000 suggest a strong and statistically significant positive relationship between ecological footprint and the other variables in the context of cointegration. The strong and significant relationships indicated by the cointegration analysis suggest that there are long-term interconnected determinants of road traffic safety in the context of the top 10 pollution-emitting countries. Temperature, precipitation, the number of medical professionals, the length of roads, and the impact on the environment are all factors. Positive coefficients show that these independent variables contribute to the dynamics of road safety in these nations, since more of them relate to more deaths per million vehicles on the road. The findings stress the need of taking a comprehensive view of road safety while conducting research. Given the interdependence of these factors, an ecological systems perspective informed by empirical data is required for unravelling the web of causes and effects that shapes road traffic safety performance [55].

Regression with Driscoll-Kraay (D/K) Standard Errors

The coefficient of 0.711 has a D/K standard error of 0.212 and the p-value is 0.002. This suggests that temperature has a positive relationship with road traffic fatalities, and the relationship is statistically significant. An increase in temperature is associated with an increase in road traffic fatalities per million. The coefficient of 0.552 has a D/K standard error of 0.132 and the p-value is 0.001. This indicates a positive and statistically significant relationship between rainfall and road traffic fatalities per million. Higher rainfall is associated with higher road traffic fatalities. The coefficient of 0.420 has a D/K standard error of 0.101 and the p-value is 0.000. This suggests a strong negative relationship between health force density and road traffic fatalities. Countries with higher health force density experience lower road traffic fatalities. The coefficient of 0.761 has a D/K standard error of 0.182 and the p-value is 0.001. This indicates a positive and statistically significant relationship between high type road length and road traffic fatalities. Longer high type road lengths are associated with higher road traffic

fatalities. The coefficient of 0.382 has a D/K standard error of 0.092 and the p-value is 0.002. This suggests a positive and statistically significant relationship between ecological footprint and road traffic fatalities. Countries with larger ecological footprints experience higher road traffic fatalities. The results of the regression analysis with D/K standard errors reveal that temperature, rainfall, health force density, high type road length, and ecological footprint are significant determinants of road traffic fatalities in the context of the top 10 pollution-emitting countries. These variables demonstrate statistically significant relationships with road traffic fatalities, suggesting that they contribute to road safety dynamics in these countries. The interconnected nature of these variables underscores the importance of considering an ecological systems approach to understand the complex interactions and influences on road traffic safety. Policies and interventions targeting these factors could potentially improve road safety outcomes in pollution-emitting countries [49].

Discussions

The discussion chapter engages with the outcomes of the research, offering a comprehensive exploration of the interconnected determinants of road traffic safety within the framework of the top 10 pollution-emitting countries. The study adopted a data-driven ecological systems approach to unravel the complex relationships among various variables and road traffic fatalities. The positive correlation between temperature and road traffic fatalities signifies a potential influence of weather on road safety dynamics. Higher temperatures might encourage increased road usage, possibly contributing to elevated accident rates. This finding highlights the significance of considering weather-related patterns in road safety interventions. The inverse relationship between rainfall and road traffic fatalities hints at the role of adverse weather conditions in promoting cautious driving behaviors. Rainfall could potentially reduce road usage or encourage safer driving practices. This underscores the importance of accounting for weather-induced variations when designing road safety strategies. The strong positive correlation between health force density and road safety suggests

Table 7. Regression with Driscoll-Kraay (D/K) Standard Errors.

Variables	Coefficient	D/K Std. Error	P-value
Temperature Centigrade/day	0.711	0.212	0.002
Rainfall Millimeters/month	0.552	0.132	0.001
Health force density index Per million	-0.420	0.101	0.000
High type road length Thousand kilometer	0.761	0.182	0.001
Total ecological footprint (EF) (Global hectares per capita)	0.382	0.092	0.002

that regions with a higher concentration of health personnel per million experience improved road safety outcomes. This finding accentuates the importance of efficient emergency response systems in mitigating the consequences of accidents. The intriguing negative correlation between ecological footprint and road traffic fatalities challenges conventional assumptions. Countries with a larger ecological footprint seem to exhibit lower road traffic fatalities. This finding prompts a deeper investigation into potential factors connecting environmental awareness, road infrastructure, and road safety practices. These findings hold implications for policymakers aiming to enhance road safety. Tailored interventions could include weather-responsive road maintenance, health force distribution strategies, and sustainable road infrastructure development. However, limitations, such as serial correlation in residuals, call for careful consideration and model refinement in future studies. The study contributes to the understanding of road traffic safety determinants by adopting an integrated approach. The findings underscore the need for holistic strategies that account for diverse variables and their interactions. Future research could explore cultural influences, localized patterns, and longitudinal dynamics to enrich the comprehension of road safety complexities. In essence, the research provides insights into the intricate web of variables shaping road traffic safety in pollution-emitting countries. By considering weather, health resources, infrastructure, and ecological impact, the study informs evidence-based interventions that address the multifaceted nature of road safety challenges [56, 57].

Conclusion

In conclusion, this study delved into the intricate determinants of road traffic safety within the context of the top 10 pollution-emitting countries. Employing a data-driven ecological systems approach, the research highlighted the interconnected nature of variables influencing road traffic fatalities. The positive correlation between temperature and accidents emphasized weather's role, while the inverse link between rainfall and accidents indicated the impact of adverse conditions on driving behavior. The strong association between health force density and road safety underscored the importance of emergency response systems. Surprisingly, the negative correlation between ecological footprint and accidents challenged assumptions, necessitating further exploration. These findings contribute to the discourse on road safety, advocating for holistic strategies that encompass diverse variables and their interplay. While limitations exist, the study lays the foundation for future investigations into the intricate dynamics of road traffic safety, ultimately promoting safer road environments and improved well-being.

Recommendations

Implement weather-responsive road maintenance to mitigate the impact of adverse conditions on road safety. Strengthen health emergency response systems in regions with low health force density to enhance accident outcomes.

Limitations

It's essential to acknowledge and consider several limitations in this research, which should be addressed in future studies. Firstly, this study's focus is solely on the top 10 pollution-generating nations, potentially limiting the generalizability of the findings to a broader spectrum of countries. Secondly, reliance on secondary data sources introduces the possibility of missing data, measurement inaccuracies, or variations in results between different nations and time periods. Thirdly, the utilization of static panel data analysis overlooks the examination of causal relationships and the temporal dynamics among the variables. Fourthly, various factors, such as cultural disparities, driving behaviors, automotive safety regulations, and traffic law enforcement, which might impact traffic fatalities, have not been accounted for in this study. Lastly, each nation's unique circumstances and specific challenges can influence the implications and recommendations for policies, an aspect that warrants more comprehensive investigation beyond the scope of this article.

Implications

Those engaged in policymaking, practitioners, and scholars concerned with enhancing road safety in the top 10 most polluting countries should pay attention to the substantial implications presented in this research. The study underscores that road traffic fatalities are significantly influenced by environmental factors and climate change, with their effects being influenced or moderated by ecological footprint and health force density. Hence, the paper proposes that policy measures should not only target improvements in road infrastructure and traffic regulations but also address the fundamental contributors to climate change and environmental deterioration. This can be achieved through endeavors like reducing greenhouse gas emissions, promoting renewable energy sources, and advancing environmental conservation. Additionally, the research highlights the role of health force density in potentially reducing fatal traffic accidents by ensuring timely medical care and preventive services for drivers. As a result, the study recommends that policymakers allocate increased funding for the development of the healthcare workforce, enhancing its accessibility and quality. Furthermore, the study underscores the importance of further exploration into the temporal and cultural aspects of road traffic safety, as well as the

potential existence of feedback mechanisms or nonlinear relationships among the variables.

Future Research

Investigate cultural influences on road safety behaviors and their interactions with identified determinants. Longitudinal studies can explore temporal variations in the relationships among variables and their impact on road safety outcomes.

Conflict of Interest

The authors declare no conflict of interest.

References

1. ALI Q., YASEEN M.R., KHAN M.T.I. Road traffic fatalities and its determinants in high-income countries: a continent-wise comparison. *Environ Sci Pollut Res Int.* **26** (19), 19915, **2019**.
2. ALI Q., YASEEN M.R., KHAN M.T.I. The causality of road traffic fatalities with its determinants in upper middle income countries: a continent-wide comparison. *Transportation research part A: policy and practice.* **119** (1), 301, **2019**.
3. ALI Q., YASEEN M.R., KHAN M.T.I. The impact of temperature, rainfall, and health worker density index on road traffic fatalities in Pakistan. *Environmental Science and Pollution Research.* **27** (16), 19510, **2020**.
4. MWALE M., MWANGILWA K., KAKOMA E., IAYCH K. Estimation of the completeness of road traffic mortality data in Zambia using a three source capture recapture method. *Accident Analysis & Prevention.* **186** (2), 107048, **2023**.
5. TORIUMI A., ABU-LEBDEH G., ALHAJYASEEN W., CHRISTIE N., GEHLERT T., MEHRAN B., MUSSONE L., SHAWKY M., TANG K., NAKAMURA H. A multi-country survey for collecting and analyzing facts related to road traffic safety: Legislation, enforcement, and education for safer drivers. *IATSS research.* **46** (1), 14, **2022**.
6. GÁLVEZ-PÉREZ D., GUIRAO B., ORTUÑO A., PICADO-SANTOS L. The influence of built environment factors on elderly pedestrian road safety in cities: the experience of Madrid. *International journal of environmental research and public health.* **19** (4), 2280, **2022**.
7. ALZAFFIN K., KAYE S.-A., WATSON A., HAQUE M. M. Modelling the continuum of serious traffic injuries in police-hospital linked data by applying the random parameters hazard-based duration model. *Analytic Methods in Accident Research.* **40** (4), 100291, **2023**.
8. STRUYF B., VAN BOCKHAVEN W., MATTHYSSENS P. 4. Value-creation for Industry 4.0 and SMEs' data-driven growth: strategies and resource alignment. *Big Data in Small Business: Data-Driven Growth in Small and Medium-Sized Enterprises.* **1** (1), 64, **2021**.
9. NGUYEN T.N., NIELSEN P. The dynamics of information system development in developing countries: From mutual exclusion to hybrid vigor. *The Electronic Journal of Information Systems in Developing Countries.* **89** (4), e12266, **2023**.
10. RAMASAMY K., BALASBANEH A.T. The Safety and Health Management at Highway Construction Site in Malaysia. *Recent Trends in Civil Engineering and Built Environment.* **4** (1), 203, **2023**.
11. BEISER-MCGRATH L.F. Policy conflict between political elites shapes mass environmental beliefs. *Electoral Studies.* **85** (5), 102645, **2023**.
12. ADABANYA U., AWOSIKA A., MOON J.H., REDDY Y.U., UGWUJA F., UGWUJA F.C. Changing a Community: A Holistic View of the Fundamental Human Needs and Their Public Health Impacts. *Cureus.* **15** (8), **2023**.
13. SAMET J., HOLGUIN F., BURAN M. The Health Effects of Indoor Air Pollution. Springer, **2022**.
14. ZURLINDEN H., GAFFNEY J., HOVENDEN E. Can I stop? Considering opportunities to influence multidisciplinary factors that result in crashes. *Journal of road safety.* **34** (3), **2023**.
15. MARIN RODRIGUEZ I. R. Factors that influence an LHD operation: A Review. **2023**.
16. BAHARI N.A.Z., MOHD NUSA F.N., TARUDIN N.F., MOHAMAD N.D., MD MUROZI A.-F. Factors contributing to road accidents: case study of Jalan Seremban-Tampin/Nur Amalia Zulaikha...[et al.]. *Malaysian Journal of Computing (MJoC).* **8** (1), 1436, **2023**.
17. MAU N.J. The Forces Maintaining Fossil Fuel Dependence in the Age of Electric. University of Oregon, **2020**.
18. ZOU Y., ZHANG Y., CHENG K. Exploring the impact of climate and extreme weather on fatal traffic accidents. *Sustainability.* **13** (1), 390, **2021**.
19. HENSHER D.A., BECK M.J., NELSON J.D. What have we learned about long-term structural change brought about by COVID-19 and working from home? *Transportation Letters.* **13** (4), 1, **2023**.
20. MARTÍNEZ P., JOSEPH J., NAZIF-MUNOZ J. I. The absence of data on driving under the influence of alcohol in road traffic studies: a scoping review of non-randomized studies with vote counting based on the direction of effects of alcohol policies. *Substance abuse treatment, prevention, and policy.* **18** (1), 1, **2023**.
21. CABRERA-ARNAU C., PRIETO CURIEL R., BISHOP S. R. Uncovering the behaviour of road accidents in urban areas. *Royal Society open science.* **7** (4), 191739, **2020**.
22. KHURSHID A., SOHAIL A., KHURSHID M., SHAH M.U., JAFFRY A.A. Analysis of road traffic accident fatalities in Karachi, Pakistan: an autopsy-based study. *Cureus.* **13** (4), **2021**.
23. CHAND A., JAYESH S., BHASI A. Road traffic accidents: An overview of data sources, analysis techniques and contributing factors. *Materials Today: Proceedings.* **47** (15), 5135, **2021**.
24. SIMMACHAN T., WONGSAI N., WONGSAI S., LERDSUWANSRI R. Modeling road accident fatalities with underdispersion and zero-inflated counts. *PLoS one.* **17** (11), e0269022, **2022**.
25. ANDERSSON A.-L., SOKOLOWSKI M. Accident or suicide? Improvement in the classification of suicides among road traffic fatalities in Sweden by extended psychosocial investigations, during the years 2010-2019. *Journal of safety research.* **80** (1), 39, **2022**.
26. LIANG M., MIN M., GUO X., SONG Q., WANG H., LI N., SU W., LIANG Q., DING X., YE P. The relationship

- between ambient temperatures and road traffic injuries: a systematic review and meta-analysis. *Environmental Science and Pollution Research*. **29** (33), 50647, **2022**.
27. SINGH S.K. Road traffic accidents in India: issues and challenges. *Transportation research procedia*. **25** (1), 4708, **2017**.
 28. YANNIS G., KARLAFTIS M.G. Weather effects on daily traffic accidents and fatalities: a time series count data approach. **2010**.
 29. TOBIN D.M., KUMJIAN M.R., BLACK A.W. Characteristics of recent vehicle-related fatalities during active precipitation in the United States. *Weather, Climate, and Society*. **11** (4), 935, **2019**.
 30. SINGH V., SAHU S.K., KESARKAR A.P., BISWAL A. Estimation of high resolution emissions from road transport sector in a megacity Delhi. *Urban Climate*. **26** (1), 109, **2018**.
 31. ZELLER K., WATTLES D., CONLEE L., DESTEFANO S. Response of female black bears to a high-density road network and identification of long-term road mitigation sites. *Animal Conservation*. **24** (2), 167, **2021**.
 32. OMOKE P.C., NWANI C., EFFIONG E.L., EVBUOMWAN O.O., EMENEKWE C.C. The impact of financial development on carbon, non-carbon, and total ecological footprint in Nigeria: new evidence from asymmetric dynamic analysis. *Environmental science and pollution research*. **27** (17), 21628, **2020**.
 33. EMENEKWE C.C., ONYENEKE R.U., NWAJIUBA C.U. Assessing the combined effects of temperature, precipitation, total ecological footprint, and carbon footprint on rice production in Nigeria: A dynamic ARDL simulations approach. *Environmental Science and Pollution Research*. **29** (56), 85005, **2022**.
 34. SALA BENITES H. Regenerative Circularity for the Built Environment – A Positive Impact Framework for Urban Transitions. *UNSW Sydney*, **2023**.
 35. EDERER D.J., PANIK R.T., BOTCHWEY N., WATKINS K. The safe systems pyramid: a new framework for traffic safety. *Transportation Research Interdisciplinary Perspectives*. **21** (1), 100905, **2023**.
 36. LOIS D., WANG Y., BOGGIO-MARZET A., MONZON A. Multivariate analysis of fuel consumption related to eco-driving: Interaction of driving patterns and external factors. *Transportation Research Part D: Transport and Environment*. **72** (1), 232, **2019**.
 37. ABBAS F., ZHANG F., IQBAL J., ABBAS F., ALREFAEI A.F., ALBESHAR M. Assessing the Dimensionality Reduction of the Geospatial Dataset Using Principal Component Analysis (PCA) and Its Impact on the Accuracy and Performance of Ensembled and Non-ensembled Algorithms. **2023**.
 38. HORTA N., DIAS R., CHAMBINO M. Efficiency and Long-Term Correlation in Central and Eastern European Stock Indexes: An Approach in the Context of Extreme Events in 2020 and 2022. *Balkin*, **2022**.
 39. FAITEH A., AASRI M.R. Economic value added: The best indicator for measuring value creation or just an illusion. *Investment Management and Financial Innovations*. **20** (1), 138, **2023**.
 40. ALSHAMMRY M.A.D., MUNEER S. The influence of economic development, capital formation, and internet use on environmental degradation in Saudi Arabia. *Future Business Journal*. **9** (1), 1, **2023**.
 41. RAJABI-KIASARI S., DELPECHE-ELLMANN N., ELLMANN A. Forecasting of absolute dynamic topography using deep learning algorithm with application to the Baltic Sea. *Computers & Geosciences*. **178** (1), 105406, **2023**.
 42. WANG J. Carbon dioxide life cycle assessment on urban air mobility in context of emergency medical service. *finland*, **2023**.
 43. ZHANG W., LUCKERT M., QIU F. Asymmetric price transmission and impulse responses from US crude oil to jet fuel and diesel markets. *Energy*. **283** (1), 128425, **2023**.
 44. DAS P., DAS P. Panel Unit Root Test. **2019**.
 45. CHEN M., CHEN R., ZHENG S., LI B. Green Investment, Technological Progress, and Green Industrial Development: Implications for Sustainable Development. *Sustainability*. **15** (4), 3808, **2023**.
 46. ABBAS S., SHAH M.I., SINHA A., OLAYINKA O.A. A gender differentiated analysis of healthy life expectancy in South Asia: the role of greenhouse gas emission. *Evaluation Review*. **47** (6), 0193841X221134850, **2022**.
 47. AMNACHE-CHIKH S., MEKHZOUIMI L. Entrepreneurship And Economic Growth Nexus: Econometric Evidence From Brics Countries. **7** (2), **2022**.
 48. NAIR M.M., TYAGI A.K. Privacy: History, statistics, policy, laws, preservation and threat analysis. *Journal of information assurance & security*. **16** (1), **2021**.
 49. O'REGAN A.C., NYHAN M.M. Towards sustainable and net-zero cities: A review of environmental modelling and monitoring tools for optimizing emissions reduction strategies for improved air quality in urban areas. *Environmental Research*. **231** (1), 116242, **2023**.
 50. FRANSISKA W., NUGROHO S., RACHMAWATI R. A Comparison of Weighted Least Square and Quantile Regression for Solving Heteroscedasticity in Simple Linear Regression. *Journal of Statistics and Data Science*. **1** (1), 19, **2022**.
 51. MAGAZZINO C., MELE M., SCHNEIDER N. The relationship between air pollution and COVID-19-related deaths: an application to three French cities. *Applied Energy*. **279** (1), 115835, **2020**.
 52. AHMAD F., SHAH Z., AL-FAGIH L. Applications of evolutionary game theory in urban road transport network: a state of the art review. *Sustainable Cities and Society*. **98** (1), 104791, **2023**.
 53. BHATTACHARYA M., BEHERA S.R., DASH D.P., APERGIS N. FDI Inflows and Urbanization: A Cross-country Comparison from Asia, Africa and Latin America. *Global Business Review*. **24** (5), 09721509231185829, **2023**.
 54. LUCA O., ANDREI L., IACOBOAEA C., GAMAN F. Unveiling the Hidden Effects of Automated Vehicles on "Do No Significant Harm" Components. *Sustainability*. **15** (14), 11265, **2023**.
 55. LEE H. Unraveling the effect of pre-entry knowledge of founders on experimentation in nascent industries: A configurational approach. *Journal of Business Research*. **167** (1), 114155, **2023**.
 56. RAMALHO A., PETRICA J. The Quiet Epidemic: An Overview of Emerging Qualitative Research Trends on Sedentary Behavior in Aging Populations. *Healthcare*. **11** (15), 2215, **2023**.
 57. MASON H.M., RANDALL J., LEGGAT P.A., VOAKLANDER D., FRANKLIN R.C. Comparing rural traffic safety in Canada and Australia: a scoping review of the literature. *Rural and remote health*. **22** (4), 1, **2022**.