Effects of Environmental Degradation on Health Outcome: A Case of Pakistan

Hasan Ali[1], Sada Caravan[2], Saman Habib[3], Atif Ur Rahman[4], Muhammad Abbas [5]

Article History:

Received Date:
18th September 2025

Revised Date:
31st October 2025

Accepted Date:
30th November 2025

Published:
2nd December 2025

Funding
This research received no specific grant from any funding agency in thepublic, commercial, or not-for-profit sectors.

Abstract

This study investigates the dynamic relationship between environmental degradation, specifically carbon dioxide (CO_2) emissions, and public health outcomes in Pakistan over the period 1980–2023. Employing the Autoregressive Distributed Lag (ARDL) bounds testing approach and the Error Correction Model (ECM), the research explores both short-run and long-run effects of CO_2 emissions on life expectancy and infant mortality. Additional socio-economic variables, including public health expenditure, secondary school enrollment, food production index, and age dependency ratio, are incorporated to capture their moderating roles on health outcomes. The findings indicate that the high levels of CO_2 emissions have a serious negative long-term effect on the life expectancy, and it is possible to confirm the harmful role of environmental decline on the health of the population. The relationship between health expenditure in the short run is intricate, although there are also positive outcomes in the long run, there are also adverse outcomes that may be caused by reactive spending in health crises. Education is shown to have delayed yet positive relationship with health with the focus on long-run investment in human capital. The ECM confirms that there is a stable connection between the long-run, and about 69 percent of short-term disequilibrium in life expectancy is resolved each year. The results highlight the importance of active environmental control, effective investment in the health sector, and increased access to education in developing economies such as Pakistan as a solution to reduce the negative health impacts of environmental deterioration. This study uniquely contributes to the literature by providing country-specific, long-run empirical evidence on the environment-health nexus Pakistan.

Keywords: Environmental Degradation, Public Health, CO_2 Emissions, ARDL Model, Life Expectancy, Infant Mortality.

---

[1] Hasan Ali: MS Student/ Researcher at National University of Science and Technology, Islamabad. Email. Hassan.eco@uom.edu.pk
[2] Sada Caravan: Researcher at University of Malakand. Email. caravansada@gmail.com
[3] Saman Habib: Researcher at University of Malakand. Email. Samanhabib050@gmail.com
[4] Atif Ur Rehaman: Department of Chemical Engineering, Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Topi 23640, Pakistan; atifups7@gmail.com
[5] Muhammad Abbas: MS student at Department of Sustainable Environment and Energy Systems in Middle East Technical University, Northern Cyprus Campus, Turkey. Email. muhammad.abbas@metu.edu.tr

1. Introduction

1.1 Background of the Study

Environmental degradation has become a burning issue of international concern in recent decades with the increase in carbon dioxide (CO_2) emissions attracting the specific attention of the researchers, policymakers, and public health experts. The biggest percentage of anthropogenic greenhouse gaseous emissions that cause global warming and climate change is the CO_2 gas emissions that are mostly emitted through the burning of fossil fuels in industry, transportation, and energy generation. Emission of CO_2 has begun to rise exponentially since the beginning of industrialization, and as the Global Carbon Atlas states, in recent years, the amount of emission decreased to over 36 billion metric tons worldwide. The increasing trend has been added by developing countries such as Pakistan with the growing industrialization, growth of urban areas and overdependence on fossil fuels and sometimes with no regulations to control excessive consumption.

The negative consequences of the elevated CO_2 emissions are not only limited to the destruction of the environment but also manifest themselves in the form of serious health hazards. Air pollution caused by the elevated rates of CO_2 and other pollutants such as the particulate matter (PM25), nitrogen dioxide (NO3) and sulfur dioxide (SO2) has been identified to cause various health complications. Dockery and Pope (1994) state that exposure to air pollution caused by particles is highly related to death and respiratory diseases. More recently, Majeed and Ozturk (2020) used data covering 180 countries during the 19902016 period and discovered that the greater the CO_2 emissions, the lower the life expectancy and the higher the infant mortality rate, especially in developing countries. Their findings highlight the fact that environmental degradation is an increasing menace to the health of the world, particularly among the vulnerable groups with low adaptive capacity.

Climate change which is mainly caused by the emission of CO_2 also increases indirect health impacts as it changes the occurrence and distribution of climate sensitive illnesses. Patz et al. (2005) and McMichael (2013) have pointed out that global warming causes the proliferation of malaria and dengue fever, food and water insecurity, and other forms of vectors. Moreover, Gosling et al. (2009) reported a strong association between high atmospheric temperature and high mortality rates during heatwave. Poor infrastructure, high population density and low access to healthcare in rural areas in Pakistan make the health consequences of CO_2 emission particularly extreme.

The major causes of the escalating CO_2 emissions are the intensification of industrialization, deforestation, urbanization, and the increasing reliance on non-renewable sources of energy. These tendencies are driven by the socio-economic forces of poverty, high rate of population increase, and laxity in environmental regulations. According to the Environmental Kuznets Curve (EKC), the environment is postulated to be initially deteriorating with growth and could eventually improve with the rise in incomes and institutional capacity. Nonetheless, the environment-health relationship can still worsen in the future without proper intervention in such countries as Pakistan where economic and institutional development is still uneven (Grossman et al., 1995; Majeed et al., 2017).

International and national levels of combating the emission of CO_2 are in progress. An example is the Paris agreement which has enlisted international resolve towards the lowering of greenhouse gas emissions and sustainable growth. National climate action plans, renewable energy schemes and emissions trading schemes have also been adopted in many countries. However, local governance bodies, financial resources, and awareness of the populace are usually the determining factors of the effectiveness of such initiatives. According to Costello et al. (2009), environmental sustainability should be incorporated into the strategies of the population health to develop climate-resilient health systems, especially in low- and middle-income nations.

Although the number of studies conducted in the global field is gradually increasing, there is still a huge gap in the literature on the long-term and country-specific relationship between CO_2 emissions and health outcomes in Pakistan. Although a number of studies investigate the overall impact of environmental pollution on health, little has been done on time-series studies to understand both short- and long-term processes that are embedded on the local setting. Further on, such moderating factors as the public health expenditure, education and demographic pressures are not considered to be that important. The present piece of research will fill in these gaps by evaluating how CO_2 emissions affect two major health variables, namely life expectancy and infant mortality by using data on Pakistan during the period 1980 to 2023. It also brings in the functions of the public health expenditure, food security, education, and age dependency hence presenting a more detailed picture of health-environment relationship in Pakistan.

1.2 Problem Statement

The deterioration of the environment, especially due to the increasing carbon dioxide emissions, has been proven as a major factor that will lead to ill health across the world. Nevertheless, there exists little in-depth studies on the exact way in which these environmental issues impact on the health of the population in Pakistan in the long term. Past studies have mainly used cross-sectional or panel data and fail to pay much attention to country-specific dynamics and policy environment of developing nations. Besides, few studies that are currently available include the variables like public health spending or education that can mediate the health consequences of environmental stress. This requires a prompt and long-term study with a narrow, sharp focus to reflect the idiomatic socio-economic and institutional facts of Pakistan.

The proposed study is aimed at addressing this gap in research by using the time series analysis of Pakistan data between 1980 and 2023. Through the ARDL bounds testing model and the Error Correction Model (ECM), it examines the short-run variations as well as the relationship at the long-run equilibrium between CO_2 emissions and the public health outcomes where the life expectancy and infant mortality are the main indicators. The study also considers how public health expenditure, education, and other social variables influence or mitigate the impact of environmental degradation. By doing so, this research provides new insights that are relevant for policymakers, scholars, and public health professionals working in Pakistan and similar developing contexts.

1.3 Objectives of the Study

The primary objective of this study is to examine the relationship between environmental degradation—measured through CO_2 emissions—and health outcomes in Pakistan. Specifically, it aims to:

1. Evaluate the long-run and short-run effects of CO_2 emissions on life expectancy and infant mortality.

2. Investigate the moderate roles of public health expenditure, secondary education, food production, and age dependency on health outcomes.

1.4 Significance of the Study

This research holds significant value for various stakeholders. For policymakers, it offers empirical evidence to guide environmental and health-related policy decisions. Understanding how CO_2 emissions impact life expectancy and infant mortality can help design better-targeted interventions. For public health officials, the findings can inform resource allocation, especially in vulnerable regions. Academics and researchers will benefit from the study's methodological approach and its contribution to the literature on environmental economics and public health. International organizations and development agencies concerned with sustainable development and climate action may also find the study useful for designing collaborative initiatives in Pakistan and similar developing countries.

2. Literature Review

2.1 Introduction

Climate change, environmental pollution and human health are a complicated and dynamic area of study. The chapter presents the literature review by relying on cross-country studies, empirical frameworks, and theories to explain the complex effects of climate variability and environmental degradation on the health outcomes of the population.

2.2 Theoretical Framework

The theoretical framework that will be used to undertake this research on the relationship between climate change, environmental pollution, and human health relies on various theories that belong to a number of interdisciplinary theories to ensure that a holistic approach is achieved to the relationship between these interconnected dynamics. Environmental Kuznets Curve (EKC) theory is a theoretical point of view, which argues that with the progress of economies, environmental degradation is first rising but is then falling with the rise of incomes and the improvement of technologies. This framework is used to put cross-country comparisons in perspective and the differing health effects of climate change among different income groups.

Also, the Health Production Function (Grossman, 1972) is an economic perspective that suggests the impact of investments in medical care, education, and the environment on health outcomes. By incorporating this model, it is possible to study the role of public health spending and state capacity in reducing or enhancing climate-related health vulnerabilities. Another critical view of vulnerability to climate, used by the Intergovernmental Panel on Climate Change (IPCC) is the Vulnerability and Adaptation Framework, which considers the vulnerability of the population to climate effects and the ability of the population to adapt. The theory will aid in exploring the regional differences in health outcomes and the need to have climate-resilient health systems.

Moreover, Social Determinants of Health (SDH) framework would be a vital dimension to the research considering the impact of socioeconomic and environmental health determinants on the health outcomes. The SDH model can be used to explain that health inequities originate in the circumstances under which individuals are born, grow, live, work, and age, and that climate change in a disproportionately harmful way to vulnerable groups makes them important to tackle such disparities with the help of policy interventions.

The research can use the approach of incorporating the elements of the systems theory that studies intricate interactions within the environmental, economic, and health systems to capture the feedback loops and non-linear dynamics that define the nature of the interactions between climate and health. The given view plays a critical role in explaining how health effects of the environmental stressors caused by the climate are cascading and necessitate multi-sectoral response.

2.3 Empirical Evidence

The direct and indirect impacts of climate change on human health have been studied in many studies. Epstein (2005) and McMichael (2013) explained the impact of increasing global temperatures on enhancing health risks, such as spreading of vector-borne diseases and heat-related diseases. The same results are supported by Patz et al. (2005) who highlighted that a regional climate change is a factor that promotes the change in disease patterns and generates much public health impact. The goal of the study by Majeed and Ozturk (2020) is to examine the connection between population health and environmental degradation based on the data on 180 countries (1990 2016). They suggest that increased CO_2 emissions can be associated with a reduced life expectancy and a greater rate of babies dying, which proves the adverse health outcomes of climate change. Climate change has direct (extreme weather, health effects), indirect (air pollutants, disease transmission) and delayed effects (disruption to health care systems). Their econometric study verifies that economic growth, education and access to healthcare are important towards limiting such effects. The analysis highlights the importance of the policy interventions, including enhanced sanitation, the use of clean water, and higher spending directed at health, to mitigate the negative outcomes of environmental degradation (Majeed et al., 2020).

Both high and low ambient temperatures have been discussed as associated with high risk of mortality as emphasized by Gasparrini et al. (2015) and Martens (1998). On the same note, Barreca (2012) investigated the correlation between the humidity level and mortality in the United States and found that the extreme weather situations are closely linked to negative health conditions (Deschenes et al., 2009). Molina and Saldarriaga (2016) and Ngo and Horton (2016) examined how changes in temperature affect fetal health and birth outcomes and added to the knowledge of the effects of climate on health vulnerabilities.

Gosling et al. (2009) also gave a critical review of relationship between high atmospheric temperatures and human deaths, supporting the significance of climate adaptation measures. Haines et al. (2006) and Woodward et al. (2014) provided an account of the global views on the impact of climate change on human health and required a more broad-based assessment of health risks.

Air pollution remains a critical environmental determinant of health. Dockery and Pope (1994) provided foundational evidence of the acute respiratory effects of particulate air pollution, findings that have been extensively validated in subsequent research (Lippmann, 1989; Thurston & Ito, 1999). Bell et al. (2007) and Bernard et al. (2001) examined the health impacts of ambient ozone in the United States, noting that climate variability significantly influences air quality and associated respiratory morbidity.

Evaluating the first-order effects of temperature variability on urban air pollution, Aw and Kleeman (2003) and Seinfeld and Pandis (2016) emphasized that atmospheric chemistry plays a crucial role in mediating the health consequences of air pollution under changing climatic conditions. Constable et al. (1999) modeled changes in VOC emissions in response to climate change, shedding light on the dynamic interactions between air quality and environmental stressors. Sillman and Samson (1995) further explored oxidant photochemistry and its implications for urban and rural air quality management.

The potential for climate change to alter the distribution of vector-borne and waterborne diseases is well-documented. Reiter (1998) and Tanser et al. (2003) modeled the effects of rising temperatures on malaria transmission in Africa, predicting substantial increases in disease incidence. Similarly, Hales et al. (2002) projected shifts in the global distribution of dengue fever under different climate scenarios.

In Canada, Charron et al. (2004) reviewed the vulnerability of waterborne diseases to climate variability, while Casman et al. (2001) conducted a qualitative analysis linking cryptosporidiosis outbreaks to climatic fluctuations. Levinsohn (1994) provided empirical evidence linking climatic warming with increased malaria incidence in Rwanda, adding to the growing body of literature on climate-sensitive infectious diseases.

Literature also underscores the importance of socioeconomic determinants in shaping health outcomes amid environmental changes. Gupta et al. (2002) and Rogers and Wofford (1989) analyzed the effectiveness of government spending on healthcare and education in developing countries, revealing strong correlations between public health investment and life expectancy.

Effective climate adaptation requires interdisciplinary strategies that address both environmental and public health challenges. Costello et al. (2009) and Campbell-Lendrum and Corvalán (2007) emphasized the need for integrated health and environmental policies to mitigate the health impacts of climate change, particularly in developing-country cities.

Rosenzweig (2011) highlighted climate adaptation efforts in New York State, offering a model for proactive policymaking that balances economic growth with environmental sustainability. Ikeda et al. (2005) and Knowlton et al. (2004) similarly advocated for flood management and air quality interventions as essential components of climate resilience. Deschenes, Greenstone, and Guryan

(2009) explored the long-term socioeconomic consequences of extreme weather events, including impacts on migration patterns and economic stability.

This literature review reveals that the intersection of climate change, environmental pollution, and human health is an urgent area of scholarly inquiry. By synthesizing findings from diverse studies, this chapter provides a comprehensive understanding of the mechanisms through which climate variability impacts public health while also identifying critical policy and research gaps that warrant further attention. Notably, while some studies (e.g., Majeed & Ozturk, 2020) find that CO_2 emissions reduce life expectancy and raise infant mortality, others emphasize the mediating role of income growth and institutional capacity in reversing such effects (Grossman & Krueger, 1995). The present study addresses the gap created by the absence of single-country, time-series evidence for Pakistan that jointly considers environmental, health expenditure, and education channels. Further research incorporating more recent data for Pakistan and advanced econometric techniques could provide additional insights into this relationship and inform more effective policy interventions.

3. Data and Methodology

3.1 Introduction

In this section, the authors provide the data and the empirical framework that is applied to study the relationship between environmental degradation and health outcomes, focusing on the contribution of public health expenditure and education. In contrast to multi-equation models, the paper of the analysis is based on a single-equation framework, according to which the life expectancy and infant mortality are dependent on the CO_2 emission, the public health spending, the food production index, the age dependency ratio, and education. The time series data used to analyze the research dates back to 1980 to 2023 and is mainly obtained through World Bank, economic surveys, and Global Carbon Atlas to have an inclusive evaluation of the most significant factors influencing the health of the population.

3.2 Data Description and Empirical Framework

This study utilizes a time-series dataset for Pakistan from 1980 to 2023. Below is an overview of the variables used and their data sources.

3.2.1 Dependent Variables

Health Outcomes:

Two key indicators measure health outcomes: life expectancy at birth (years) and infant mortality rate (per 1,000 live births). Data for both variables are sourced from the World Bank (1980–2023).

3.2.2 Independent Variables

Environmental Degradation:

The primary independent variable is environmental degradation, assessed through CO_2 emissions data. This information is obtained from the Global Carbon Atlas (1980–2023). Higher CO_2 levels pose risks to human health, with anticipated negative effects on life expectancy and positive effects on infant mortality.

Food Production Index:

Adequate nutrition is essential for good health. The food production index measures the production of edible, nutrient-containing food crops (excluding non-nutritive items like coffee and tea).

Age Dependency Ratio:

A high dependency ratio, where a significant portion of the population is non-working, can negatively impact health by reducing individuals' ability to afford proper food, housing, and healthcare.

Public Health Expenditure:

Increased public health spending improves healthcare services and raises health awareness, leading to better health outcomes.

Education:

Education plays a vital role in improving health outcomes. Educated individuals are more aware of health risks and make informed choices. Female education, in particular, contributes to better child and family health. The study considers total school enrollment (secondary, % gross) for the life expectancy model.

Both education variables are expected to positively influence life expectancy and reduce infant mortality, with data sourced from the World Bank (1980–2023).

Table 3. 1: Summary of Variables and Data Sources

Variables	ABV	Definition	Data Source
Health outcomes	LEB	life expectancy at birth, total (years)	WDI
Environmental degradation	CO_2	CO_2 emissions	Global Carbon Atlas
Food production index	FPI	Food production index (2014-2016 = 100)	WDI
Education	SES	School enrollment, (% gross) ratio	WDI
Age dependency ratio	ARD	Age dependency ratio (% of working-age population)	WDI
Health Expenditure	CHE	Current health expenditure (% of GDP)	WDI, Economic survey

This study incorporates these variables to analyze the relationship between environmental, economic, and social factors and public health outcomes.

3.2.3 Empirical Model

To analyze the relationship between environmental degradation and health outcomes, we specify a linear regression model using key variables identified in Section 3.2. The general functional form of our model is:

Life Expectancy Model:

$$LEB_t = \alpha + \beta 1 CO2_t + \beta 2 CHE_t + \beta 3 FPI_t + \beta 4 SES_t + \beta 5 ARD_t + U_t \quad (1)$$

Infant Mortality Model:

$$MRI_t = \alpha + \gamma 1 CO2_t + \gamma 2 CHE_t + \gamma 3 FPI_t + \gamma 4 SES_t + \gamma 5 ARD_t + \eta_t \quad (2)$$

Where:

- LEB = Life expectancy at birth (years)
- IMR = Infant mortality rate (per 1,000 live births)
- CO_2 = CO_2 emissions (metric tons per capita)
- CHE= Current Health expenditure
- FPI=Food Production index
- ARD=Age dependency ratio
- SES = School enrollment, secondary (% gross)
- η_t = Error terms

3.3 Econometric Techniques for Time Series Analysis

3.3.1 Unit Root Testing

To determine the stationarity of variables, we conducted the Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test. The null hypothesis (H_0) assumes a unit root (non-stationarity), while rejection of H_0 indicates stationarity.

The ADF test equation is:

$$\Delta Y_t = \alpha + \delta Y_{t-1} + \sum \beta_i \Delta Y_{t-i} + U_t$$

3.3.2 Cointegration Analysis

If some variables are non-stationary but integrated of order I (1), we test for cointegration using the Johansen Cointegration Test or Bounds Testing (for ARDL). Cointegration implies a long-run equilibrium relationship.

3.3.3 ARDL Model Estimation and Error Correction Model (ECM)

The Autoregressive Distributed Lag (ARDL) Model is used to estimate both short-run and long-run relationships:

$$Y_t = \alpha + + \sum \beta_i Y_{t-i} + \sum \gamma_j X_{t-j} + \lambda ECM_{t-1} + U_t$$

Steps:

1. Choose optimal lag order using Akaike Information Criterion (AIC) or Schwarz Criterion (SC).
2. Conduct Bounds Test for cointegration.
3. Estimate long-run relationships.
4. Specify Error Correction Model (ECM):

$$\Delta Y_t = \phi + + \sum \theta_i \Delta X_{t-i} + \lambda ECM_{t-1} + U_t$$

where ECM measures how quickly deviations from equilibrium correct over time.

3.4 Recommended Methodology for Pakistan

For Pakistan, given limited data availability and potential endogeneity, the ARDL approach is preferred due to:

- Its suitability for small sample sizes.
- Flexibility in handling mixed stationarity.
- Capability of estimating long-run and short-run effects simultaneously.

Thus, this study employs ARDL with ECM to analyze the determinants of health outcomes in Pakistan.

Given the mixed stationarity of variables and the context of a single-country analysis, the Autoregressive Distributed Lag (ARDL) model, along with the Error Correction Model (ECM), is chosen as the most suitable econometric approach. This methodology enables robust estimation of both short-term dynamics and long-term relationships, making it particularly effective for the dataset and research objectives at hand. The chapter sets the stage for empirical analysis in the subsequent sections, providing a solid foundation for assessing how environmental and socio-economic factors shape public health outcomes in Pakistan.

Results and Discussion

4.1 Introduction

In this section, the main results of research has been discussed including descriptive statistics of all variables, results of unit root tests, including both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The ARDL bounds testing approach is applied to examine the existence of a long-run relationship among the variables. Long-run estimation results and the short-run dynamics using the Error Correction Model (ECM), results of the diagnostic and stability tests to ensure the validity of the model are also explained in details.

4.2 Descriptive statistics

Table 4. 1: Descriptive statistics

	LEB	MRI	SES	FPI	CO_2	CHE	ARD
Mean	62.36	88.99	26.89	67.18	0.70	2.30	82.63
Median	62.33	86.00	26.33	59.84	0.72	2.24	85.89
Maximum	67.65	127.10	42.36	122.43	0.99	3.01	92.12
Minimum	57.20	50.10	15.99	26.57	0.35	1.71	70.17
Std. Dev.	2.95	24.18	7.95	29.84	0.17	0.37	7.47
Skewness	0.11	0.07	0.45	0.39	-0.43	0.30	-0.28
Kurtosis	1.74	1.71	2.07	1.89	2.35	2.12	1.47
Jarque-Bera	2.97	3.08	3.07	3.38	2.16	2.12	4.85
Probability	0.23	0.21	0.22	0.18	0.34	0.35	0.09
Observations	44	44	44	44	44	44	44

Descriptive statistics include all the means, median, standard deviation, skewness, and other descriptive statistics that are contained in **Table 4.1**. The rows contain the mean, median, and other descriptive statistics, while the columns contain variable names and appropriate descriptive statistics of each variable, such as CO_2 emissions, education, public health expenditures, food production index, age dependency ratio, life expectancy at birth, and infant mortality rate. This study is based on 44 observations. The last line shows the observation of each variable, which is shown in the descriptive statistics.

4.3 Results of unit root test

Table 4. 2: Checking for stationarity of the variables

Variables	Test Statistics	Probability	Order of the Integration
ARD	-3.68	0.00	I (1)
CHE	-5.64	0.00	I (1)
CO_2	-5.28	0.00	I (1)
FPI	-6.61	0.00	I (1)
LEB	-6.42	0.00	I (1)
MRI	-2.72	0.00	I (0)
SES	-8.67	0.00	I (1)

The unit root test is an econometric technique that is used to evaluate the stationarity of variables. To estimate the data using the augmented Dickey-Fuller test for the unit root, we need to ensure the variable is stationary. The null hypothesis for all the unit root tests that we have applied is that the variable has a unit root (i.e., it is nonstationary), while the alternative hypothesis is that the variable is stationary. The results of the augmented Dickey–Fuller (ADF) unit root test are shown in table 4.2. The findings show that variables including ARD, CHE, CO_2, FPI, LEB, and SES are stationary at first difference L (1) based on the value of t-statistics and probability. According to t-statistics and probability, the value of MRI is stationary at L (0).

4.4 ARDL Bound Test

The Auto-Regressive Distributed Lag (ARDL) model was applied to explore the determinants of life expectancy at birth (LEB) in Pakistan using time series data from 1980 to 2023. Using the Akaike Information Criterion (AIC) for model selection, the optimal specification was ARDL (4, 3, 4, 3), where LEB is the dependent variable, and the independent variables are carbon dioxide emissions (CO_2), current health expenditure (CHE), and schooling enrollment secondary (SES). The model results reveal that the first lag of LEB is statistically significant and positive, indicating strong persistence in life expectancy over time. Dynamic effects of the regressors are also notable. For example, CO_2 at lag 2 is significantly positive, while at lag 3, it is significantly negative, suggesting a complex time-dependent impact of environmental degradation on health. Similarly, health expenditure has both positive and negative lagged effects; CHE at lags 2 and 4 positively affects LEB, while lag 3 shows a negative impact. SES at lag 3 is negatively significant, reflecting adverse delayed schooling enrollment's secondary effects on life expectancy. Overall, the model exhibits excellent fit, with an R-square of 0.997 and an adjusted R-square of 0.994. The Durbin-Watson statistics are 2.233, indicating no autocorrelation issues, and the F-statistics are highly significant, confirming the model's robustness.

Table 4. 3: Results of ARDL model

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LEB (-1)	0.688	0.158	4.361	0.000
LEB (-2)	-0.152	0.147	-1.034	0.313
LEB (-3)	0.119	0.185	0.644	0.526
LEB (-4)	-0.343	0.146	-2.356	0.028
CO_2	-1.779	1.391	-1.279	0.215
CO_2 (-1)	0.976	1.611	0.605	0.551
CO_2 (-2)	4.523	1.663	2.720	0.013
CO_2 (-3)	-8.230	1.614	-5.101	0.000
CHE	-0.424	0.381	-1.114	0.278
CHE (-1)	0.075	0.492	0.152	0.881
CHE (-2)	1.096	0.525	2.088	0.049
CHE (-3)	-1.737	0.533	-3.257	0.004
CHE (-4)	1.948	0.557	3.501	0.002
SES	-0.002	0.019	-0.121	0.905
SES (-1)	0.007	0.019	0.343	0.735
SES (-2)	0.019	0.017	1.091	0.288
SES (-3)	-0.059	0.018	-3.337	0.003
C	40.035	10.084	3.970	0.001
@TREND	0.213	0.058	3.678	0.001

4.5 Bound Test

The ARDL model used to examine the relationship among life expectancy (LEB), CO_2 emissions, current health expenditure (CHE), and secondary schooling enrollment (SES) reveals evidence of a long-run equilibrium relationship. Although the F-bounds test yields an inconclusive result—with the F-statistic of 3.766 falling between the I(0) lower bound (3.38) and I(1) upper bound (4.23) at the 5% level—this should be acknowledged explicitly. The inconclusive F-statistic means that cointegration cannot be definitively confirmed or rejected on the basis of the bounds test alone. Reliance on the significance of the ECM coefficient (CointEq(−1) = −0.69) as corroborating evidence is appropriate but should be presented as supplementary support rather than conclusive proof. The significance and negative sign of the error correction term (CointEq (-1) = -0.6893) confirm the presence of co-integration. This implies that about 69% of any short-run disequilibrium in life expectancy is corrected within a year, highlighting the system's tendency to return to equilibrium. In the long-run estimates, CO_2 has a significant negative effect on life expectancy (coefficient = -6.54), underscoring the adverse impact of environmental degradation. While CHE and SES are not statistically significant in the long run, a positive and highly significant trend variable points to a general improvement in life expectancy over time. Together, these results affirm that the ARDL model captures both the short- and long-run dynamics effectively in the context of Pakistan.

Table 4. 4: Results of Bound Tests

Conditional Error Correction Regression				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	40.03	10.08	3.97	0.0007
@TREND	0.21	0.05	3.67	0.0014
LEB (-1)*	-0.68	0.16	-4.05	0.0006
CO_2 (-1)	-4.51	1.74	-2.59	0.0171
CHE (-1)	0.95	0.69	1.37	0.1837
SES (-1)	-0.03	0.02	-1.31	0.2023
D (LEB (-1))	0.37	0.17	2.12	0.0453
D (LEB (-2))	0.22	0.17	1.25	0.2228
D (LEB (-3))	0.34	0.14	2.35	0.0282
D (CO_2)	-1.77	1.39	-1.27	0.2149
D (CO_2 (-1))	3.7	1.65	2.23	0.0363
D (CO_2 (-2))	8.22	1.61	5.1	0
D(CHE)	-0.42	0.38	-1.11	0.278
D (CHE (-1))	-1.3	0.63	-2.04	0.0533
D (CHE (-2))	-0.21	0.59	-0.35	0.7271
D (CHE (-3))	-1.94	0.55	-3.5	0.0021
D(SES)	0	0.01Tab	-0.12	0.9052
D (SES (-1))	0.03	0.01	2.14	0.0438
D (SES (-2))	0.05	0.01	3.33	0.0031

4.4.1 F-Bounds Test

Table-4.5. Bound Test

F-Bounds Test		**Null Hypothesis: No levels relationship**		
Test Statistic	Value	Significance	I (0)	I (1)
			Asymptotic: n=1000	
F-statistic	3.766008	10%	2.97	3.74
k	3	5%	3.38	4.23
		2.5%	3.8	4.68
		1%	4.3	5.23
Actual Sample Size	40		Finite Sample: n=40	
		10%	3.264	4.094
		5%	3.85	4.782
		1%	5.258	6.526

Table 4.6. Long Run Estimates

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
CO_2	-6.5437	1.95011	-3.3555	0.003
CHE	1.39081	1.01353	1.37225	0.1845
SES	-0.0518	0.03796	-1.3639	0.187
@TREND	0.30854	0.03208	9.61738	0
EC = LEB - (-6.5437*CO_2 + 1.3908*CHE -0.0518*SES + 0.3085				

4.6 Error Correction Model

The Error Correction Model (ECM) derived from the ARDL (4, 3, 4, 3) estimation captures the short-run dynamics and adjustment process toward the long-run equilibrium of life expectancy at birth (LEB) in Pakistan. The model includes the first differences of the variables CO_2 emissions, current health expenditures (CHE), and schooling enrollment secondary (SES), along with their respective lags. The key component of the ECM is the error correction term (CointEq(-1)), which is negative and statistically significant with a coefficient of -0.6893. This implies that approximately 69% of any deviation from the long-run equilibrium is corrected within one year, confirming the existence of a stable long-term relationship among the variables.

In the short run, the model reveals several important dynamics. The lagged differences of LEB at the first and third periods are statistically significant, indicating that life expectancy adjustments occur with some persistence.CO_2 emissions have a mixed but largely significant impact in the short term. The current level of CO_2 is negatively associated with life expectancy, consistent with its acute health burden. The positive coefficients at lags one and two may reflect a delayed adaptive response—as environmental stress intensifies, households and governments increase health-protective spending, temporarily buffering the impact. By lag three, the cumulative damage of sustained emissions reasserts a strongly negative effect, consistent with the literature on lagged pollution-health dynamics (Majeed & Ozturk, 2020). Health expenditure (CHE) displays a consistently negative impact in the short run, especially at the first and third lags, suggesting that increased spending may initially reflect health crises before yielding positive outcomes. SES is insignificant in its immediate effect but becomes significantly positive at the first and second lags, suggesting that improvements in secondary schooling enrollment take time to influence life expectancy.

The error correction model exhibits strong explanatory power, with an R-squared of 0.850 and an adjusted R-squared of 0.766, indicating that the model effectively captures the short-run variation in life expectancy. The Durbin-Watson statistics of 2.233 confirm the absence of autocorrelation, and the overall F-statistics are highly significant. These results reinforce the robustness of the model and its ability to reflect both short-term fluctuations and long-term trends in life expectancy in Pakistan**.**

Table 4.7. Results of Error Corrections model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	40.247	8.454	4.760	0.0001
D (LEB (-1))	0.376	0.151	2.496	0.0209
D (LEB (-2))	0.224	0.145	1.548	0.1366
D (LEB (-3))	0.343	0.129	2.642	0.0152
D (CO_2)	-1.778	0.981	-1.812	0.0843
D (CO_2 (-1))	3.707	1.262	2.937	0.0079
D (CO_2 (-2))	8.229	1.287	6.394	0
D(CHE)	-0.423	0.323	-1.312	0.2035
D (CHE (-1))	-1.307	0.377	-3.460	0.0023
D (CHE (-2))	-0.211	0.389	-0.543	0.5927
D (CHE (-3))	-1.948	0.331	-5.872	0
D(SES)	-0.002	0.015	-0.147	0.8839
D (SES (-1))	0.039	0.013	2.917	0.0082
D (SES (-2))	0.058	0.015	3.865	0.0009
CointEq(-1)*	-0.689	0.145	-4.734	0.0001

4.5.1 F-Bounds Test

Table-4.8. Bound Test

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Significance	I (0)	I (1)
F-statistic	3.766008	10%	2.97	3.74
k	3	5%	3.38	4.23
		2.5%	3.8	4.68
		1%	4.3	5.23

4.7 Cointegration Graph

The graph can be interpreted as representing the residuals or spread between two or more time series that are individually non-stationary but have a long-term equilibrium relationship.

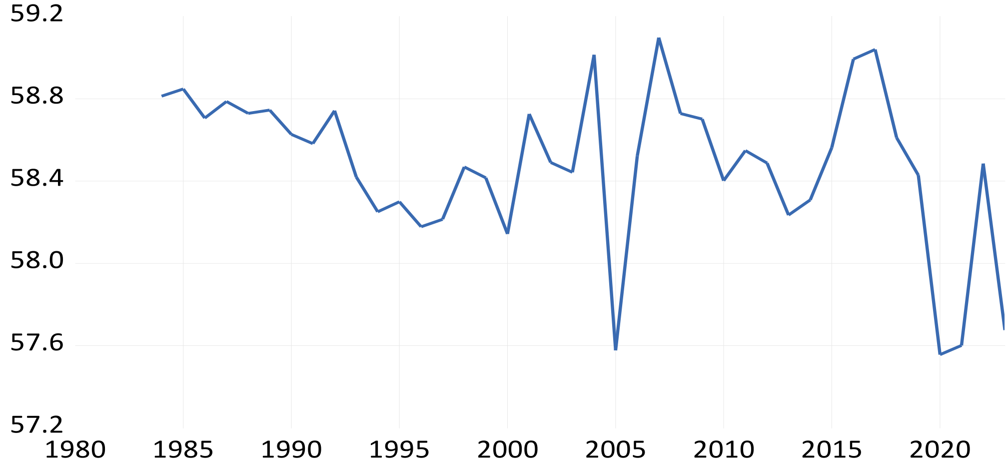

Figure 4. 1: Co integration Graph

This graph might be showing the difference (spread) between two assets or variables that are cointegrated. Even though each of these variables might move around a lot on their own (which means they are not stable or stationary), their relationship over time stays balanced. The sharp spikes and drops you see suggest that while the spread can move away from its average level in the short term, it tends to come back toward a central or "equilibrium" level. This behavior is typical when two series are cointegrated because any large gap between them usually corrects itself over time. So, even if the spread looks volatile, it often shows a pattern of coming back to the middle, which is how the error correction process works in such cases.

4.8 Histogram Normality Test

A time series model residual histogram along with statistical tests for normality. Verifying the normality of residuals is a crucial diagnostic step to support model assumptions in the context of cointegration or time series analysis.

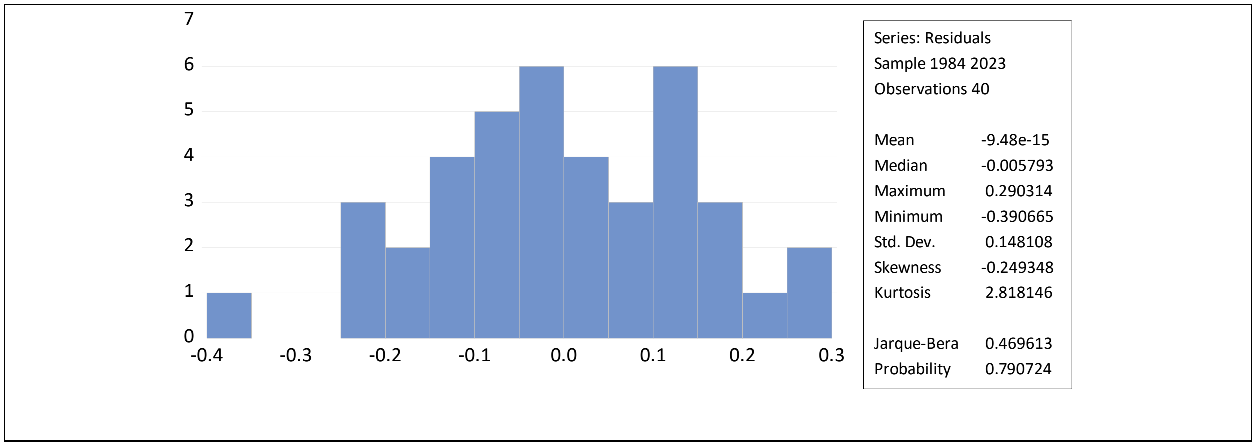

Figure 4. 2: Normality test

Conclusion and Policy Recommendations

5.1 Conclusion

In the case of Pakistan between 1980 and 2023, this chapter illustrates the intricate relationship between environmental degradation, health spending, and public health outcomes. In this study, we examined both short-term fluctuations and long-term equilibrium relationships using the ARDL bound testing approach and the Error Correction Model (ECM). We focused on the effects of CO_2 emissions, public health spending, and secondary school enrollment on important health metrics like life expectancy and infant mortality.

5.1.1 Environmental Degradation and Health Outcome

According to this analysis, increased CO_2 emissions (pollution) have a negative long-term impact on people's health by reducing life expectancy. This means that as pollution increases people tend to live shorter lives. In the short term the effect of CO_2 emission has mixed effects sometimes they might seem so bad right away, but the cumulative effect of pollution reduces life expectancy over time.

5.1.2. Health Expenditure and Health Outcomes

Public health expenditure shows a complex interaction with health outcomes Although it plays a positive role in the long term, in the short run, increased health spending is associated with declining health outcomes possibly reflecting reactive spending patterns during health crises, this underlines the importance of proactive rather than reactive health spending strategies.

5.1.3. Education and Health Outcome

Education measured by secondary school enrollment has delayed positive impacts on health outcomes, as indicated by the significance of its lagged effects in the short run .This demonstrates the time-depending nature of education's influence on improving life expectancy and reducing mortality rates.

5.1.4 Adjustment Dynamics

The ECM confirms a stable long-term relationship among the variables with about 69% of the short run disequilibrium in life expectancy corrected within a year. This indicates a strong tendency for the system to revert to its long-term path after short run shocks. These results enhance the central role of environmental sustainability consistent and adequate public health spending and educational investment enhancing public health outcomes in Pakistan.

5.2 Policy Recommendations

The conclusion of this study is based on the following policy recommendation proposed to mitigate the adverse effects CO_2 emission, public health expenditures, education, food production index and age dependency ratio.

Environmental policies: To protect the environment and people's health, it is important to have stronger rules that limit pollution, especially the release of CO_2 and other harmful gases. Enforce stricter environmental regulations to control CO_2 emissions, including penalties for high-emitting industries. Promote renewable energy and clean technology adoption to reduce environmental degradation and its adverse health effects. Strengthen monitoring and reporting mechanisms for environmental pollutants to guide policy actions effectively.

Health sector reforms: Improve the efficiency of public health expenditure by focusing on preventive healthcare, early detection programs, and community-based health service. Implement health system reforms to reduce bureaucratic inefficiencies and ensure that health spending translates into tangible improvements in service delivery and outcomes. Increase investment in health infrastructure in rural and underdeveloped areas to reduce regional disparities in health outcomes.

Educational reforms: Given its long-term advantages for family and child health, increase access to high-quality secondary and higher education, with an emphasis on female education. To increase awareness of the health risks connected to environmental degradation, incorporate environmental education into school curricula.

Other policies: Foster collaboration between the ministries of health, education, and environment to implement integrated policies addressing the nexus of environmental health and education. Implement family planning and social support programs to address high age dependency ratios, which strain public health systems and reduce individual well-being. Promote nutritional interventions and food security programs to ensure that the population, especially vulnerable groups, have access to adequate nutrition. Ensure sound fiscal and monetary policies to maintain macroeconomic stability, which is essential for sustaining public investments in health and education sectors.

5.3 Future Research Directions

While this study has provided important findings on the relationship between environmental degradation and health outcomes in Pakistan, future research can expand on these results in several ways to gain deeper and broader insights:

5.3.1 Sectoral and Regional Analysis

Future studies should focus on analyzing how environmental degradation affects different sectors (such as agriculture, industry, and services) and regions (such as urban vs. rural areas) within Pakistan. This approach can help identify which sectors or regions are most vulnerable and allow policymakers to develop more targeted and effective policies.

5.3.2 Dynamic and Non-linear Modeling

Future research can apply more advanced and flexible econometric methods to explore the relationship between environmental degradation and health outcomes. Using models that capture non-linear or changing relationships over time can provide a clearer understanding of both immediate and delayed effects, as well as possible thresholds where impacts become more severe.

5.3.3 Comparative Cross-country Studies

It would also be valuable to compare Pakistan's situation with other developing or emerging countries facing similar environmental and health challenges. Such studies can help identify successful strategies and best practices that Pakistan can adapt to strengthen its environmental and health policies.

Conflict of interest

Authors have no conflict of interest

Funding Sources

The authors received no funding to conduct this study

Data Availability

All the data is available in the manuscript. And the datasets used and or analyzed during the current study are available from the corresponding author on reasonable request.

Authors contributions

All authors have contributed to various sections of this manuscript.

References

Aw, J., & Kleeman, M. J. (2003). Evaluating the first-order effects of meteorological conditions on the concentrations of urban air pollutants. *Journal of Geophysical Research: Atmospheres*, *108*(D12), 4365. https://doi.org/10.1029/2002JD002688

Barreca, A. (2012). Climate change, humidity, and mortality in the United States. *Journal of Environmental Economics and Management*, *63*(1), 19–34. https://doi.org/10.1016/j.jeem.2011.07.004

Bell, M. L., Goldberg, R., Hogrefe, C., Kinney, P. L., Knowlton, K., Lynn, B., ... & Patz, J. A. (2007). Climate change, ambient ozone, and health in 50 US cities.*Climatic Change, 82(1–2), 61–76.*

Bernard, S. M., Samet, J. M., Grambsch, A., Ebi, K. L., & Romieu, I. (2001). The potential impacts of climate variability and change on air pollution-related health effects in the United States. *Environmental Health Perspectives*, *109*(Suppl 2), 199–209.

Campbell-Lendrum, D., & Corvalán, C. (2007). Climate change and developing-country cities: Implications for environmental health and equity. *Journal of Urban Health*, *84*(1), 109–117.

Casman, E. A., Fischhoff, B., & Palmgren, C. (2001). Climate change and cryptosporidiosis: A qualitative analysis. *Climatic Change*, *50*, 219–249.

Charron, D. F., Thomas, M. K., Waltner-Toews, D., Aramini, J. J., Edge, T., Kent, R. A., ... & Maarouf, A. R. (2004). Vulnerability of waterborne diseases to climate change in Canada: A review. *Journal of Toxicology and Environmental Health, Part A*, *67*(20–22), 1667–1677.

Constable, J. V. H., Guenther, A. B., Scholes, R. J., & Scholes, M. C. (1999). Modeling changes in VOC emission in response to climate change in the southern African region. *Geophysical Research Letters*, *26*(19), 2929–2932.

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., ... & Patterson, C. (2009). Managing the health effects of climate change. *The Lancet*, *373*(9676), 1693–1733.

Deschenes, O., & Moretti, E. (2009). Extreme weather events, mortality, and migration. *The Review of Economics and Statistics*, *91*(4), 659–681.

Deschenes, O., Greenstone, M., & Guryan, J. (2009). Climate change and birth weight. *American Economic Review: Papers & Proceedings*, *99*(2), 211–217.

Dockery, D. W., & Pope, C. A. (1994). Acute respiratory effects of particulate air pollution. *Annual Review of Public Health*, *15*, 107–132.

Epstein, P. R. (2005). Climate change and human health. *New England Journal of Medicine*, *353*(14), 1433–1436.

Fayissa, B., & Gutema, P. (2005). Estimating a health production function for Sub-Saharan Africa (SSA). *Applied Economics*, *37*(2), 155–164.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., ... & Armstrong, B. (2015). Mortality risk attributable to high and low ambient temperature: A multicountry observational study. *The Lancet*, *386*(9991), 369–375.

Gosling, S. N., McGregor, G. R., & Lowe, J. A. (2009). Climate change and heat-related mortality in six cities Part 1: Model construction and validation. *International Journal of Biometeorology*, *53*, 76–86.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics*, *110*(2), 353–377.

Gupta, S., Verhoeven, M., & Tiongson, E. R. (2002). The effectiveness of government spending on education and health care in developing and transition economies. *European Journal of Political Economy*, *18*(4), 717–737.

Haines, A., Kovats, R. S., Campbell-Lendrum, D., & Corvalán, C. (2006). Climate change and human health: Impacts, vulnerability, and public health. *Public Health*, *120*(7), 585–596.

Hales, S., de Wet, N., Maindonald, J., & Woodward, A. (2002). Potential effect of population and climate changes on global distribution of dengue fever: An empirical model. *The Lancet*, *360*(9336), 830–834.

Ikeda, K., Yagi, K., & Okada, N. (2005). Adaptive flood risk management: Integrating flood management and climate change adaptation. *Natural Hazards*, *36*(1–2), 25–43.

Khan, A. M., & Majeed, M. T. (2018). Public health expenditure and population health: Evidence from Pakistan. *Pakistan Development Review*, *57*(4), 289–310.

Knowlton, K., Rosenthal, J. E., Hogrefe, C., Lynn, B., Gaffin, S., Goldberg, R., ... & Kinney, P. L. (2004). Assessing ozone-related health impacts under a changing climate. *Environmental Health Perspectives*, *112*(15), 1557–1563.

Levinsohn, J. (1994). Testing the effects of climate change on malaria incidence in Rwanda. *Journal of Health Economics*, *13*(3), 369–388.

Lippmann, M. (1989). Health effects of ozone: A critical review. *Journal of the Air Pollution Control Association*, *39*(5), 672–695.

Majeed, M. T., & Gillani, S. Y. (2017). Environmental degradation and health outcomes: An empirical analysis for developing countries. *Environmental Economics and Policy Studies*, *19*(2), 253–274.

Majeed, M. T., & Ozturk, I. (2020). Environmental degradation and population health: Evidence from developing countries. *Social Indicators Research*, *147*, 621–639.

Martens, W. J. M. (1998). Climate change, thermal stress and mortality changes. *Social Science & Medicine*, *46*(3), 331–344.

McMichael, A. J. (2013). Globalization, climate change, and human health. *New England Journal of Medicine*, *368*(14), 1335–1343.

Molina, M. J., & Saldarriaga, W. (2016). Climate change impacts on birth outcomes in Latin America. *Environmental Health Perspectives*, *124*(2), 225–230.

Ngo, N. D., & Horton, R. (2016). Climate change and fetal health: Evidence from Africa. *World Bank Economic Review*, *30*(2), 329–355.

Patz, J. A., Campbell-Lendrum, D., Holloway, T., & Foley, J. A. (2005). Impact of regional climate change on human health. *Nature*, *438*(7066), 310–317.

Reiter, P. (1998). Global warming and vector-borne disease in temperate regions and at high altitude. *The Lancet*, *351*(9105), 839–840.

Rogers, R. G., & Wofford, S. (1989). Life expectancy and public health spending. *Public Health Reports*, *104*(5), 506–511.

Rosenzweig, C. (2011). Climate change adaptation in New York City: Building a risk management response. *Annals of the New York Academy of Sciences*, *1244*(1), 13–18.

Seinfeld, J. H., & Pandis, S. N. (2016). *Atmospheric chemistry and physics: From air pollution to climate change* (3rd ed.). Wiley.

Sillman, S., & Samson, P. J. (1995). Impact of temperature on oxidant photochemistry in urban, polluted rural and remote environments. *Journal of Geophysical Research: Atmospheres*, *100*(D6), 11497–11508.

Tanser, F. C., Sharp, B., & le Sueur, D. (2003). Potential effect of climate change on malaria transmission in Africa. *The Lancet*, *362*(9398), 1792–1798.

Thurston, G. D., & Ito, K. (1999). Epidemiological studies of acute ozone exposures and mortality. *Journal of Exposure Analysis and Environmental Epidemiology*, *9*(3), 273–284.