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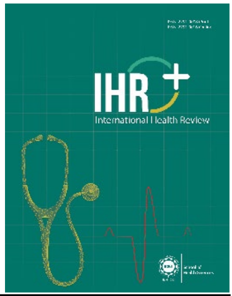

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Title: **Environmental Sustainability and Health in Pakistan: A Long-term Evaluation of Policy Effectiveness**

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Environmental Sustainability and Health in Pakistan: A Long-term Evaluation of Policy Effectiveness

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ABSTRACT

Environmental degradation continues to be a significant public health issue in Pakistan. However, evidence linking the overall environmental policy performance with measurable health outcomes over time is still limited. Using annual time-series data covering the years 1995-2022, this study highlighted the long-run relationship between environmental conditions, selected policy-related indicators, and health outcomes in Pakistan. Four health outcomes variables comprising life expectancy, maternal mortality ratio, out-of-pocket health expenditure, and current health expenditure as percent of Gross Domestic Product (GDP) were analyzed. Key explanatory variables included (Particulate Matter) PM2.5 exposure, water productivity, unsafe drinking water, EPI (Environmental Performance Index), GDP per capita, government expenditure on education, and urbanization. The empirical strategy itself included descriptive statistics, correlation analysis, unit root testing using Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests; multivariate estimation was based on Fully Modified Ordinary Least Squares (FMOLS), which was checked for robustness using Robust Least Squares (RLS). The stationarity results indicated that the variables were mostly integrated of order one. This justified employing long-run modelling approaches. However, formal cointegration evidence is mixed; therefore, the coefficients are interpreted as long-run associations rather than causal effects. Environmental stressors, especially air pollution and unsafe drinking water, were found to be still closely associated with negative maternal health effects as well as long-term financial burden on households. Whereas, better environmental performance was also correlated with improvements in the socioeconomic conditions affecting health expenditure trends. Some coefficients were found to be counterintuitive, notably for unsafe drinking water and life expectancy. This indicated issues related to measurement constraints, multicollinearity, and

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the limits of small-sample national time-series studies. The study determined that there is a need of more stringent enforcement, monitoring, as well as greater integration of environmental policy with public health financing, urban planning, and water governance in Pakistan. These findings introduced nuance to the policy debate, by providing a more conservative and policy-relevant perspective on environment–health linkages in Pakistan.

GRAPHICAL ABSTRACT

Keywords: environmental policy, fully modified ordinary least squares, health outcomes, Pakistan, PM2.5, time-series data, water quality

1. INTRODUCTION

Environmental conditions are being identified as an increasingly fundamental determinant of public health. In low- and middle-income countries, environmental degradation frequently co-exists with inadequate service delivery, rapid urbanization, and limited public expenditure, thereby intensifying health risks rather than remaining a separate ecological concern [1,2]. Nowhere is this intersection more evident than in Pakistan where epidemic levels of smog outbreaks, unsafe water, and solid waste mismanagement, coupled with inconsistent regulatory enforcement, continue to harm respiratory health, maternal health, and household welfare.

Pakistan has set in motion a number of policy instruments in response to environmental jeopardy: the National Environmental Policy 2005 being one and more recently a series of provincial initiatives, such as the Punjab Clean Air Policy [3,4]. The fact that policy frameworks exist does not, however, prove that environmental conditions have improved sufficiently to lead towards health benefits. This difference among policy adoption, policy implementation, and observed health outcomes provided the basis for motivation to conduct this study. World public health is threatened by environmental degradation in a more critical way in under-developed countries including Pakistan. Pakistan is faced with a range of environmental problems, such as smog, water pollution, and absence of proper waste management. These challenges along with a growing burden of respiratory, cardiovascular, and waterborne diseases are straining the country's healthcare system, hindering the economic growth [5]. Recent evidence also shows that Pakistan continues to face severe air quality challenges, with PM2.5 exposure remaining above World Health Organization guideline values in many settings [6]. Contaminated water sources are similarly associated with diarrheal disease, which remains an important contributor to child morbidity and mortality [7].

Understanding the seriousness of the status quo, Pakistan has implemented many environmental policies to reduce pollution and protect public health. The formulation of policies, such as the NEP (National Environmental policy) 2005, Clean Green Pakistan aimed to control air and water pollution. Furthermore, these policies intended to enhance sustainable development and awareness in public [8]. However, all of these changes did not shorten the environmental and health problems facing the country. For instance, the Air Quality Life Index of 2023 has calculated that the health effects of pollution tend to lower the average life expectancy by over four years in Pakistan.

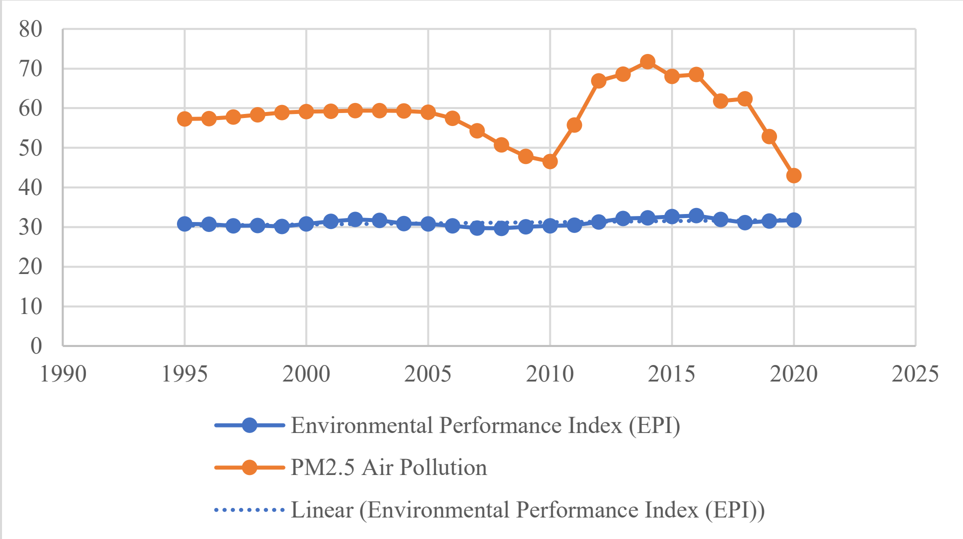

Figure 1. Environmental Performance Index (EPI) and PM2.5 Air Pollution Trend

Figure 1 presents the trends in EPI and PM2.5 air pollution. The EPI trend remains relatively flat across the study period, suggesting that overall environmental performance improved only modestly despite policy attention. In contrast, PM2.5 exposure shows periods of decline as well as renewed increases, indicating that air pollution trends may respond to specific regulatory, technological, economic, or energy-related factors. The divergence between the two indicators is important because EPI captures broader environmental dimensions, while PM2.5 reflects a specific air quality exposure. Therefore, a decline in PM2.5 does not necessarily imply a wider improvement in environmental governance. Further analysis is needed to identify whether reductions in PM2.5 were driven by policy enforcement, changes in fuel use, industrial activity, meteorological variation, or data-related factors, and why these changes were not matched by stronger overall gains in EPI.

Figure 2 shows trends in life expectancy, maternal mortality ratio, out-of-pocket expenditure, and current health expenditure. The limited change in health expenditure suggests that, although some health indicators have improved, financial access remains constrained, financial access remains stagnant, indicating continued adverse barriers to services. The flat trend of life expectancy presented in the results indicates that further investments into healthcare systems and policies may be necessary to make significant population health gains.

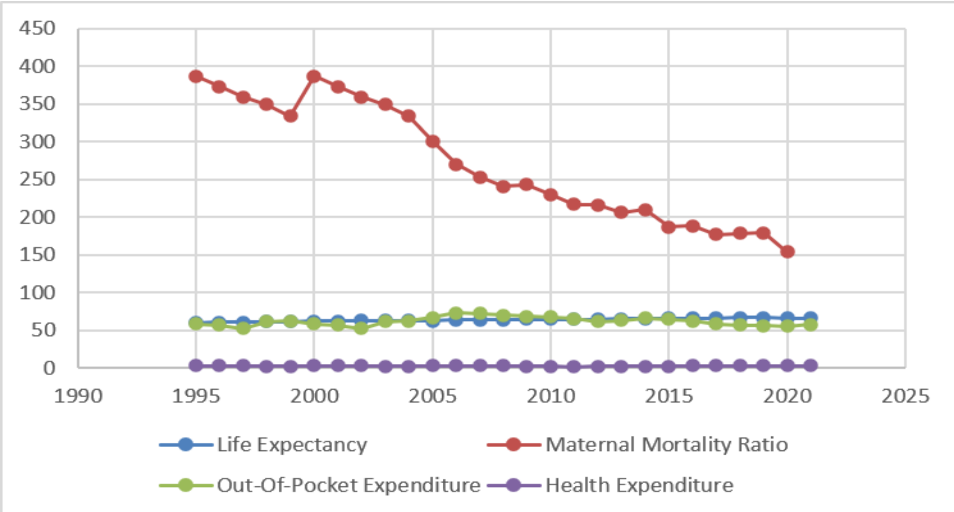

Figure 2. Trends in Life Expectancy, Maternal Mortality Ratio, Out-of-Pocket Expenditure, and Health Expenditure

This differentiation between policy design and observable health effects highlights the importance of empirically assessing the success of environmental policies in promoting public health. Global studies have shown that environmental regulations can, indeed, avert health hazards in various contexts. For instance, the US Clean Air Act is associated with a 35% reduction in premature mortality over two decades [9]. However, this study focused on the Pakistani environmental policies and their impact on health outcomes within the local context. The literature to date is replete with studies centered upon individual matters of health or environment rather than the interrelations between policy, environmental state, and health state genesis. Furthermore, sociodemographic elements of income, education, and healthcare availability also play a key role in determining the value of environmental policies. Learnedness and social class have been reported to be positively associated with the dietary diversity [10] and health behaviors in the general Pakistani population, while their interaction effects on having diverse diet are not known.

To address these limitations, the current study sought to conduct an overall assessment of the impact of environmental policies on health in Pakistan. Furthermore, the study evaluated the effectiveness of environmental policies on health outcomes by examining the interplay of environmental quality (respiratory and water) with disease burden and socioeconomic factors, providing a basis for policy development. Such assessment is particularly relevant in the present for Pakistan, which is faced with growing health and environmental issues due to rapid urbanization, industrialization, as well as climate change.

1.1. Study Objectives

The current study aimed to address the following research objectives:

- To analyze the environmental policies and their effects on health in Pakistan
- To investigate the correlation of air quality, water quality, and prevalence of diseases
- To explore the environmental policies in mitigating health spending.

1.2. Research Questions

The current study aimed to answer the following research questions:

- To what extent do environmental policies impact health in Pakistan?
- How does air and water quality affect the overall health and the spread of diseases?

The rationale for this study is grounded in Pakistan's growing exposure to pollution, climate-related environmental stress, and persistent gaps in public health financing. Although the country has adopted several environmental policies, there is limited Pakistan-specific evidence that jointly examines environmental indicators, policy performance, and multiple health outcomes within one longitudinal empirical framework. This study therefore addresses three interrelated questions: whether environmental performance indicators are systematically associated with health outcomes in Pakistan; how wider environmental quality relates to long-run health and financing indicators; and how socioeconomic controls, including income, education expenditure, and urbanization, shape these associations. The study contributes to the literature by combining environmental, economic, and health variables in a single national time-series design and by interpreting statistically significant but substantively unexpected coefficients with appropriate caution.

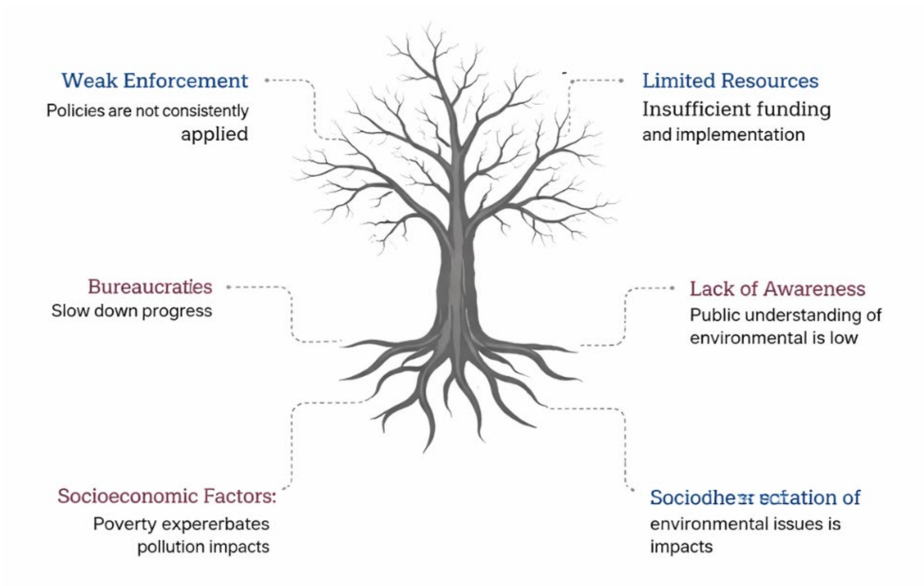

Figure 3. Ineffective Environmental Policies in Pakistan

2. LITERATURE REVIEW

The literature on environment and health consistently shows that air pollution and unsafe water are among the most important environmental determinants of morbidity and mortality in low- and middle-income countries. International evidence confirms that air pollution and unsafe water are among the most significant environmental threats to health [11]. International evidence confirms that exposure to PM2.5 is associated with cardiovascular disease, respiratory illness, stroke, adverse pregnancy outcomes, and premature mortality. And all-cause premature deaths have been linked to exposure to PM2.5 [12,13]. Global assessments in recent decades also demonstrate that air pollution continues to be one of the leading environmental risk factors for death globally. Global environmental measures have shown great promise in benefiting public health by reducing pollution and promoting sustainable resource use. For instance, carbon taxes introduced in nations, such as Sweden and Canada were effective in decreasing the concentration of greenhouse gases thus, resulting in more healthful air and a decreased frequency of respiratory diseases [14]. Additionally, the European Union (EU) water treatment law significantly decreased diseases transmitted by water in the EU, enforcing provision of clean and safe drinking water [15]. Control of air pollution, including the implementation of the Clean Air Act in the United States, has been associated with decreases in premature mortality and other health benefits. From 1990 through 2010, the Clean Air Act resulted in a 35% decrease in air pollutants' levels with associated public health benefits [16]. However, the efficacy of environmental policies is based on efficient implementation, enforcement, and socioeconomic variables. For instance, in low- and middle-income countries, inadequate infrastructure and financial resource may hinder the potential health impacts of these policies [17]. This helps to highlight the importance of adapting global policy frameworks to their local contexts for best impact.

Pakistan is at a critical juncture with environmental degradation and poor health status indicators. Industrial emissions, vehicular traffic, and agricultural burning are the major sources of air pollution that lead towards high prevalence of respiratory and CVDs [18]. Water-related diseases, such as diarrhea and cholera are common in rural areas with poor sanitation due to contaminated water sources [19]. Concerning public health, safe drinking water is similarly central due to its close links with diarrheal diseases, child health, and household welfare more widely. In low-income countries, including Pakistan (where environmental exposures vary sharply between urban and rural settings), the health burden is compounded by inequities in service provision, income, education, and access to the health system. Pakistan has enacted a number of environmental laws, such as the issuance of the National Environmental Policy in 2005 and the adoption of provincial measures for instance, Punjab Clean Air Action Plan. However, their enforcement is still minimal [19]. Studies conducted by [19] indicate that even if these policies recognize the interrelationship between quality of environment and human health, their implementation would be affected due to scarcity of financial resources, inefficiencies in institutions, and lack of public awareness. Pakistan-specific research has also focused more on individual environmental risks than on the combined effect of air quality, water quality, policy performance, and health financing. This study addresses that gap by examining how environmental policy performance and environmental quality are associated with multiple health outcomes over time.

2.1. Environmental Kuznets Curve (EKC) Hypothesis

The EKC hypothesis argues that the environmental decline increases with economic growth and decreases as societies move towards sustainable policies and technologies [20]. In Pakistan, this framework is useful for examining whether economic growth has been accompanied by improved environmental governance and better health outcomes. For instance, while industrialization generates and increases pollution, better public awareness and government action may possibly change this. However, the EKC may not be appropriate for Pakistan due to the weak implementation of regulations as well as ineffective institutions, which may slow down technology-adoption towards sustainable paths [21].

2.2. Social Factors of Health Framework

This framework emphasized the effect of socioeconomic status, income, education, and living environment on health [22]. In the context of environmental health, it helps explain why poorer communities are often more vulnerable to pollution and unsafe water. For instance, poor communities in Pakistan are more vulnerable to air and water pollution because they live near contaminated areas and do not have the resources to address health risks. This study applied the framework as to how social factors moderate the effectiveness of environmental policies on health outcomes.

In contrast, Pakistan-specific study is more typically aimed at explicit environmental risks and pollutants, particularly urban particulate pollution rather than the overall linkages between environmental policy performance outcomes in relation to multiple health outcomes. This presents a significant gap as virtually no studies in Pakistan have integrated air quality, water-related indicators, and environmental performance variables alongside health financing within a common longitudinal framework.

3. DATA AND METHODOLOGY

This study used a structured time-series methodology to examine the relationship between environmental policy performance and health outcomes in Pakistan. Annual data were gathered, standardized, and aligned over a common sample period. Descriptive statistics and bivariate correlations were first used to summarize the data and identify preliminary patterns. Stationarity was then assessed using Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit-root tests. Engle-Granger and Phillips-Ouliaris tests were applied to examine whether the variables showed evidence of long-run cointegration. Long-run parameters were estimated using Fully Modified Ordinary Least Squares (FMOLS), and Robust Least

Squares (RLS) was used as a robustness check to assess the sensitivity of the results to influential observations.

3.1. Data Description and Sources

The data for this study was collected for the time period (1995-2022) using secondary data from reliable sources, such as World Development Indicators (WDI) and World Population Review (WPR). As the data was collected from publicly available aggregated datasets, no ethical approval was required. The variables and their descriptions are outlined in Table 1.

Table 1. Variables' Information

Variables	Description	Source
	Dependent variables	
Life Expectancy	Life expectancy at birth, total (years)	WDI
Maternal Mortality Ratio	Maternal mortality ratio (modeled estimate, per 100,000 live births)	WDI
Out-Of-Pocket Expenditure	Out-of-pocket expenditure (% of current health expenditure)	WDI
Health Expenditure	Current health expenditure (% of GDP)	WDI
	Independent variables	
PM2.5 Air Pollution	PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)	WDI
Water productivity	Water productivity, total (constant 2015 US$ GDP per cubic meter of total freshwater withdrawal)	WDI
Unsafe drinking water	Environmental Performance Index: Unsafe drinking water	WPR
Environmental Performance Index	Environmental Performance Index (EPI)	WPR
GDP per capita	GDP per capita (current US$)	WDI
Government education expenditure	Government expenditure on education, total (% of government expenditure)	WDI
Urbanization	Urban population growth (annual %)	WDI

Data collection and processing followed these stages:

- Annual series for Pakistan were retrieved from the WDI database.
- The Environmental Performance Index (EPI) and the unsafe drinking water indicators were sourced from WPR.
- All series were retrieved as spreadsheets (Excel) and pooled together to create a single panel-free (country-level) time-series data.
- The variables were compared with metadata to ensure consistency.
- Missing values were handled using linear interpolation but longer gaps were discarded to maintain consistency.

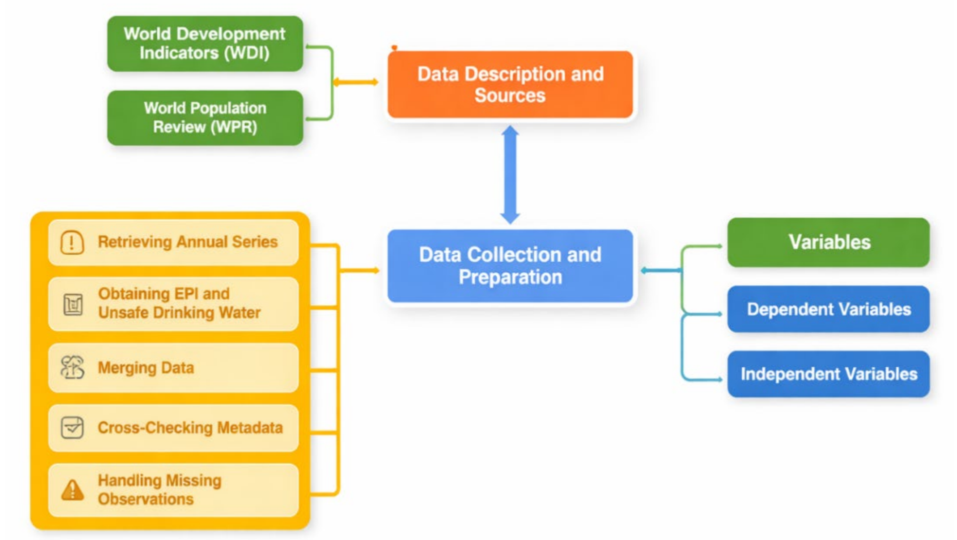

Figure 4. Data Description and Sources for Health and Environmental Performance Analysis

3.2. Covariance and Correlation Analysis

Pearson correlation coefficients were used to assess the direction and strength of bivariate associations among the variables. The correlation matrix is treated here as an exploratory diagnostic rather than the evidence of causation. This is because the study relied on annual macro time-series data. The matrix mainly helped identify broad patterns and potential multicollinearity prior to regression estimation [23].

Equation for Correlation Coefficient (r_{xy}):

$$\mathbf{r}_{xy} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \tag{1}$$

Where:

- x_i, y_i: Specific data facts for variables x and y
- $\bar{x}, \bar{y}$: Means of variables x and y

The matrix values are added by *p*-values to measure statistical significance (p<0.05).

3.3. Unit Root Testing

Since regression with non-stationary series can produce spurious results, the order of integration of each variable was tested using the ADF and PP unit-root tests. The ADF test controls for serial correlation by adding lagged differences, while the PP test provides a non-parametric correction for heteroskedasticity and autocorrelation. Robustness can be improved in a relatively short time-series using both tests [24,25].

Equation for ADF Test

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \epsilon_t \tag{2}$$

Where:

- Y_t: Variable at time t
- ΔY_t: First difference of Y_t
- α, β, γ, δ_i: Parameters
- ϵ_t: White noise error term

Phillips-Perron (PP) Test: This test adapts the ADF test by means of nonparametric modifications to the t-statistic.

3.4. Cointegration Testing

After establishing that the series are predominantly integrated of order one, cointegration testing was used to assess whether a stable long-run relationship exists between the health indicators and the environmental covariates. The Engle-Granger and Phillips-Ouliaris tests are appropriate because they examine whether regression residuals are stationary even when the underlying variables are non-stationary [26].

Equation for Cointegration (Engle-Granger)

Estimation the long-run association:

$Y_t = \beta_0 + \beta_1 X_t + u_t$

Test stationarity of residuals (u_t) using ADF:

$\Delta u_t = \alpha u_{t-1} + \epsilon_t$

3.5. Fully Modified Ordinary Least Squares (FMOLS)

FMOLS was selected as the primary long-run estimator because it corrects for endogeneity and serial correlation that commonly arise in cointegrated systems. This makes it well-suited for macro time-series applications where regressors and the error term may be correlated in the long-run [27].

FMOLS Equation

$Yt = \alpha + \beta Xt + ut$

Where:

- α, β: Parameters to be estimated
- X_t: Independent variable(s)
- Y_t: Dependent variable
- u_t: Error term, used to account for serial correlation.

3.6. Robust Least Squares (RLS) Estimation

RLS was estimated as a robustness check. Since the sample is relatively small and some years may exert disproportionate influence on coefficient estimates, RLS down-weights outlying observations and helps assess whether the main patterns are sensitive to influential points. RLS minimizes a weighted loss function in which observations with large residuals receive smaller weights [28].

RLS Objective Function

$$\min \sum w_i (Y_i - \beta_0 - \beta_1 X_i)^2$$

Where:

- w_i: Weight for observation i, inversely proportional to residual scale.

If FMOLS and RLS point in similar directions, confidence in the stability of the findings increases. Differences between the two estimators are used to identify coefficients that may be specification-sensitive.

3.7. Model Validation

Model adequacy was assessed using R-squared and adjusted R-squared statistics, overall model significance, and the consistency of results across FMOLS and RLS. Cointegration and residual-based diagnostics were used to evaluate whether the estimated long-run relationships were empirically defensible. Since the study is based on aggregate annual data, the findings are interpreted as macro-level associations rather than causal effects [29,30].

3.8. Empirical Model Specification and Analytical Assumptions

This study estimated four separate long-run equations by considering life expectancy at birth, maternal mortality ratio, out-of-pocket health expenditure, and current health expenditure as a share of the GDP as dependent variables in turn. This was preferable to a single composite health index as the four outcomes reflect different welfare dimensions and are not necessarily positively correlated. Life expectancy is a global measure of health improvement, maternal mortality an intermediate and more system-sensitive outcome (worse for women), out-of-pocket expenditure is a clear indicator of household financial burden, and current health expenditure reflects macro-level resource allocation. Estimating separate equations therefore provides with a way to discern if environmental pressures have the same impact on survival, maternal health, and financing channels or operate through different mechanisms.

The explanatory variables were chosen on theoretical as well as practical grounds. PM2.5 denotes ambient air pollution, which is considered to be associated with a worse health outcome when exposure is longer. Water Productivity (WP) is included as a resource-efficiency indicator that might proxy improvements in water management and broader environmental governance. Unsafe drinking water signals direct contact with a well-known health risk. EPI was used as a general summary measure of environmental policy performance. This should be interpreted cautiously since it combines several different environmental areas. Importantly, the EPI is not a pure implementation variable. Structural controls include GDP per capita, government education expenditure, and urbanization since health outcomes are determined by income growth, human capital investment, demographic concentration as well as the ability of households and institutions to respond to risk.

Expected coefficient signs were informed by prior literature but were not imposed mechanically. In general, higher PM2.5 exposure, and greater unsafe drinking water risk are expected to lower life expectancy, increase maternal mortality, and raise financial pressure on households as well as the health sector. In contrast, one would usually expect that better environmental performance, more income, and higher educational investment would promote health outcomes. Urbanization is less clear cut: it may improve access to services but may also increase exposure to congestion, pollution, and stress of urban infrastructure. Such vagueness is particularly pertinent given that urban growth in Pakistan has been rapid but often poorly planned. Due to this, the urbanization coefficient is considered as a structural contextual effect but not as an indicator of modernization.

Two further analytical choices should be observed. Isolated missing observations were dealt conservatively, such that the final series remained year-aligned and appropriate for time-series estimation. Secondly, the results would be regarded as long-run associations rather than causal effects. National annual data is good for detecting broad directional relationships but too aggregated to detect district-level patterns of exposure (identity/exposure) implementation heterogeneity or short-run shocks, such as floods, fuel crises or sudden top-down policy enforcement campaigns. The value of the current design is that it can test whether environmental deterioration and environmental improvement are consistently correlated with health outcomes over an extended period. This helps provide evidence to focus on more detailed provincial or micro-level work in future.

4. RESULTS

This section presents the descriptive profile of the data, the correlation patterns, the stationarity and cointegration tests, as well as the long-run estimates from FMOLS and RLS. The emphasis is on whether environmental indicators are systematically associated with health status and health financing outcomes in Pakistan.

The results presented in Table 2 demonstrate that during the study period improvements were seen in lifetime expectancies at birth for those born in Pakistan. On the other hand, maternal mortality remained high and household financial protection from health costs was low. Of current health expenditure, mean out-of-pocket payment accounted for over 61%, whereas only 2.55% of GDP was allocated to total health expenditure. Environmental pressures were also acute, with high average PM2.5 exposure, continued unsafe drinking water concerns, and a low mean EPI score. Collectively, these results highlighted simultaneous environmental stress, limited public financing, and heterogenous health progress across the study period. The descriptive statistics highlighted three structural problems from a policy perspective. Environmental risk, particularly related to air quality and water safety, continues to be large. Secondly, household spending was retained as the lion share of health financing, which can magnify welfare effects from exposure to environment. Thirdly, low public health expenditure despite significant environmental stress indicates that strong integration of both environmental and health policy goals has not taken place yet.

Table 2. Descriptive Statistics for Data Overview

Variables	Mean	Median	Max	Min	*SD*	Obs
Life Expectancy	63.715	63.944	66.756	59.878	2.007	26
Maternal Mortality Ratio	271.31	248.00	387.00	154.00	78.834	26
Out-Of-Pocket Expenditure	61.778	61.750	72.946	51.767	5.746	26
Health Expenditure	2.552	2.550	2.953	2.140	0.233	26
PM2.5 Air Pollution	58.516	58.935	71.712	42.998	6.885	26
Water Productivity	1.290	1.291	2.051	0.849	0.342	26
Unsafe Drinking Water	9.995	10.330	15.270	4.390	3.185	26
Environmental Performance Index	31.093	30.867	32.897	29.687	0.891	26
GDP per capita	967.20	998.47	1620.7	420.68	390.67	26
Government education expenditure	11.711	11.479	15.446	8.490	1.648	26
Urbanization	2.796	2.760	3.847	1.780	0.650	26

Several strong bivariate associations are indicated in Table 3. At the same time, as life expectancy increases, the maternal mortality decreases and there is a positive correlation with GDP per capita, water productivity, and EPI. Maternal mortality has the inverse trend. There are also some counterintuitive correlations among them, that is, as life expectancy increases, the correlation with lack of access to clean drinking water increases too.

Table 3. Correlation Matrix

Variables	1	2	3	4	5	6	7	8	9	10
1. Life Expectancy	-									
2. Maternal Mortality Ratio	-0.943 0.00	-								
3. Out-Of-Pocket Expenditure	0.773 0.097	-0.666 0.089	-							
4. Health Expenditure	0.607 0.011	-0.684 0.068	-0.579 0.082	-						
5. PM2.5 Air Pollution	0.598 0.032	-0.544 0.031	-0.576 0.011	-0.299 0.138	-					
6. Water Productivity	0.953 0.000	-0.942 0.000	0.566 0.050	0.329 0.100	-0.515 0.042	-				
7. Unsafe Drinking Water	0.986 0.000	-0.943 0.000	0.166 0.417	0.276 0.173	0.545 0.029	0.972 0.000	-			
8. Environmental Performance Index	0.577 0.014	-0.357 0.074	-0.560 0.071	0.013 0.949	0.607 0.001	0.519 0.033	0.662 0.018	-		
9. GDP per capita	0.965 0.000	-0.951 0.000	0.579 0.083	0.541 0.036	0.197 0.335	0.942 0.000	0.957 0.000	0.681 0.013	-	
10. Government education expenditure	0.649 0.021	-0.370 0.063	0.672 0.000	0.545 0.027	-0.094 0.649	0.530 0.059	0.995 0.044	-0.691 0.050	0.577 0.071	-
11. Urbanization	-0.918 0.000	0.897 0.000	-0.280 0.166	-0.587 0.074	-0.340 0.089	-0.848 0.000	-0.913 0.000	-0.580 0.002	-0.932 0.000	-0.389 0.050

It is suspected that this pattern is a product of aggregate time-series data limitations, overlapping trends or multicollinearity rather than an actual protective effect. Thus, the correlation matrix must be taken with caution and should only be used as exploratory diagnostics. Thus, the correlation structure suggests that environmental conditions are interconnected with economic change and social investment. It further suggests against the use of simple pairwise associations and for multivariate long-run estimation.

Table 4. Augmented Dickey-Fuller (ADF) Test and Phillips-Perron (PP) Test

Variables	ADF Test		PP Test		Decision
	t-Statistic/ Prob.*	*t*-Statistic/ Prob.*	Adj. *t*-Stat / Prob.*	Adj. t-Stat / Prob.*	
Dependent variables					
Life Expectancy	-1.995 (0.287)	-6.202 (0.000)	-2.829 (0.067)	-6.202 (0.000)	I(1)
Maternal Mortality Ratio	-0.477 (0.880)	-4.815 (0.000)	-0.477 (0.880)	-4.815 (0.000)	I(1)
Out-Of-Pocket Expenditure	-1.775 (0.383)	-4.986 (0.000)	-1.775 (0.383)	-4.986 (0.000)	I(1)
Health Expenditure	-2.291 (0.182)	-4.917 (0.000)	-2.133 (0.233)	-5.152 (0.000)	I(1)
Independent variables					
PM2.5 Air Pollution	-2.933 (0.056)	——	-1.654 (0.440)	-2.399 (0.152)	I(1)
Water Productivity	0.286 (0.972)	-4.609 (0.001)	0.723 (0.990)	-4.609 (0.001)	I(1)
Unsafe Drinking Water	-1.356 (0.587)	-2.874 (0.052)	-1.463(0.536)	-2.876 (0.051)	I(1)
Environmental Performance Index	-2.434 (0.142)	-2.937 (0.056)	-1.735 (0.402)	-3.071 (0.041)	I(1)
GDP per capita	-0.852 (0.786)	-5.348 (0.000)	-0.150 (0.933)	-6.515 (0.000)	I(1)
Government education expenditure	-2.058 (0.261)	-4.662 (0.001)	-2.058 (0.261)	-4.645 (0.001)	I(1)
Urbanization	-1.703 (0.415)	-1.886 (0.032)	-1.579 (0.479)	-2.988 (0.049)	I(1)

Table 4 reports unit-root results. It was found that the majority of variables are non-stationary at levels but stationary after first differencing thus integrated of order one, I(1). This pattern is widely expected in macro time-series variables, for instance health expenditure, income, environmental quality, and mortality indicators. Since the series are mostly I(1), cointegration-based estimation is appropriate for examining whether the variables share meaningful long-run associations despite trending over time. It means that the variables may have significant long-run relationships with each other even if they are trending (in levels) in the time. With this result in mind, it is safe to use FMOLS and RLS for long-run associations with a lower probability of spurious inference.

Table 5. FMOLS Model Estimation

Variables	Life Expectancy	Maternal Mortality Ratio	Out-of-Pocket Expenditure	Health Expenditure
PM2.5 Air Pollution	0.002 (0.041)	1.733 (0.025)	-0.139 (0.030)	-0.002 (0.070)
Water Productivity	-0.853 (0.069)	-81.177 (0.007)	-22.634 (0.009)	-0.165 (0.041)
Unsafe Drinking Water	0.497 (0.000)	21.115 (0.036)	0.589 (0.030)	0.092 (0.002)
Environmental Performance Index	-0.206 (0.092)	12.483 (0.095)	-5.126 (0.000)	0.305 (0.000)
GDP per capita	0.001 (0.054)	-0.100 (0.058)	0.003 (0.040)	0.000 (0.003)
Government Education Expenditure	-0.150 (0.006)	0.488 (0.001)	0.253 (0.021)	0.162 (0.000)
Urbanization	-0.525 (0.075)	84.258 (0.011)	-12.53 (0.004)	1.244 (0.000)
C	68.07 (0.000)	-341.08 (0.073)	281.929 (0.000)	-13.83 (0.000)
R^2	0.982	0.947	0.693	0.697
Adjusted R^2	0.975	0.926	0.566	0.573
Long-run variance	0.048	315.146	5.291	0.010
Cointegration Test				
Engle-Granger tau-statistic	-4.963 (0.249)	-3.159 (0.889)	-4.876 (0.274)	-5.367 (0.153)
Engle-Granger	-25.055	-15.468	-24.644	-26.622

Variables	Life Expectancy	Maternal Mortality Ratio	Out-of-Pocket Expenditure	Health Expenditure
z-statistic	(0.254)	(0.865)	(0.278)	(0.173)
Hansen Parameter Instability	0.753 (0.113)	1.032 (0.033)	1.023 (0.034)	0.815 (0.085)
Park Added Variables	7.231 (0.026)	325.775 (0.000)	8.135 (0.017)	16.061 (0.000)
Phillips-Ouliaris tau-statistic	-5.066 (0.221)	-3.282 (0.857)	-4.982 (0.244)	-5.519 (0.126)
Phillips-Ouliaris z-statistic	-25.075 (0.252)	-16.327 (0.825)	-23.668 (0.339)	-25.436 (0.232)

The FMOLS estimates are reported in Table 5. Environmental attributes in the overall four dependent variables seem to be important for certain aspects of health statuses and health financing, although some coefficient effects appear mixed across models. PM2.5.

A total of 5 exposures share a positive correlation with maternal mortality, and FMOLS model has a clear negative correlation with out-of-pocket expenditure, and its relationship with life expectancy is small. Maternal mortality result is substantively plausible and in line with the wider literature on air pollution in pregnancy and adverse maternal and respiratory outcomes. This weak and sometimes unexpected evidence for other outcomes may indicate that the health effects in specific pathways are masked by aggregate national data. Water-related indicators also matter. The negative association between water productivity with maternal mortality and out-of-pocket expenditure supports the argument that better management of water may reduce health burden. Nevertheless, the positive coefficient on unsafe drinking water for life expectancy is unlikely to be literally true (perhaps due to measurement error, common time shocks, or interactions with unobserved institutional factors).

The unsafe drinking water is intuitively associated with higher maternal mortality, higher per capita expenditure out-of-pocket and health expenditure. The findings of this study lend support to the assertion that water insecurity impacts health services outcomes as well as the financial cost borne by households and the public system. The effects are mixed according to the EPI. Healthcare expenditure is negatively associated with out-of-pocket expenditure and positively associated with health expenditure. This implies that improvement in environmental performance may decrease household financial burden but may rather call for higher public investment. This pattern aligns well with the concept that stronger environmental governance tends to occur in conjunction with increased public outlays, rather than as a replacement of them.

Life expectancy and health expenditure have a positive relationship with GDP per capita. This means that when incomes grow, both health statuses and extent of spending can be supported. This is consistent with wider literature connecting economic development to better health infrastructure and service utilization.

Education expenditure at government level and urbanization level is also important in many of the models, however, their sign is mixed. This probably correlates with the fact that whilst social investment and city expansion can improve service accessibility, they also strengthen congestion, inequality, and environmental exposure. These variables must be thus interpreted as context-related variables rather than just dynamics linear determinants.

Overall, the FMOLS results are consistent with a statistically significant long-run relationship between ambient environmental conditions and health outcomes. However, they also imply that coefficient interpretation must be circumspect where signs are unstable or even counterintuitive.

The residual-based cointegration statistics are of mixed strength across the specifications. This presents obstacles to any assertion of a unique, stable long-run equilibrium for each model and underlines the necessity of interpreting estimates as suggestive associations rather than definitive causal conclusions.

Table 6. Robust Least Squares (RLS) Model Estimation

Variables	Life Expectancy	Maternal Mortality Ratio	Out-of-Pocket Expenditure	Health Expenditure
PM2.5 Air Pollution	0.006 (0.038)	1.255 (0.025)	-0.108 (0.008)	-0.012 (0.047)
Water	-1.433	-138.639	-21.081	0.291

Variables	Life Expectancy	Maternal Mortality Ratio	Out-of-Pocket Expenditure	Health Expenditure
Productivity	(0.044)	(0.050)	(0.071)	(0.008)
Unsafe Drinking Water	0.670 (0.000)	10.8238 (0.061)	0.736 (0.043)	-0.024 (0.002)
Environmental Performance Index	-0.177 (0.016)	12.136 (0.080)	-3.471 (0.061)	0.423 (0.000)
GDP per capita	0.000 (0.000)	-0.070 (0.047)	0.003 (0.046)	0.00121 (0.000)
Government Education Expenditure	-0.100 (0.041)	0.784 (0.072)	0.783 (0.032)	0.216 (0.000)
Urbanization	-0.346 (0.055)	71.153 (0.056)	-8.577 (0.063)	1.100 (0.000)
C	65.627 (0.000)	-249.58 (0.594)	208.17 (0.007)	-16.79 (0.000)
R^2	0.843	0.831	0.607	0.644
Rw-squared	0.993	0.955	0.793	0.891
Prob (Rn-squared stat.)	0.0000	0.000	0.000	0.000

Table 6 reports the RLS estimates. The broad pattern is similar to FMOLS in several respects: PM2.5 remains positively associated with maternal mortality; water productivity and unsafe drinking water continue to matter across several specifications; and health expenditure rises with stronger environmental performance, income, education spending, and urbanization. For life expectancy, the RLS model again produces some unexpected signs for pollution and unsafe drinking water. Since RLS is designed to reduce the influence of extreme observations, the persistence of these signs suggests that the issue is not simply driven by outliers. Instead, it may reflect the use of aggregate proxies, the limited time span, and the fact that national averages do not capture distributional exposure differences. For maternal mortality, the positive coefficient on PM2.5 and the negative coefficient on water productivity are consistent with a public health interpretation in which polluted air and weak water management increase maternal risk. This is one of the most substantively coherent findings across the models. For out-of-pocket expenditure, the estimates suggest that environmental stress affects household financial burden, although the direction is not always stable across specifications. This may indicate that pollution and water risk influence private spending through multiple channels, including foregone care, public substitution, and delayed treatment. For current health expenditure, the positive coefficients on the EPI, GDP per capita, education spending, and urbanization indicate that better environmental governance and socioeconomic development tend to accompany greater formal spending on health. This pattern is plausible in settings where environmental management and health investment reinforce one another. The RLS results support the main conclusion that environmental variables are linked to both health outcomes and health financing in Pakistan, even though some coefficients should be treated as diagnostic signals rather than precise causal effects.

5. CONCLUSION

This study examined whether environmental conditions and environmental policy performance are associated with health outcomes in Pakistan over the time period (1995-2022). The evidence suggested that environmental stress is linked with worse maternal health outcomes and continued pressure on household and public health financing. While not all coefficients were stable across models, the overall pattern indicated that weak air and water conditions remain an important part of Pakistan's public health challenge. The study showed significant links between outcomes of health and environmental, economic, and social factors.

Environmental factors show the clearest relevance for maternal health and health financing. PM2.5 exposure is positively associated with maternal mortality, indicating that air pollution may contribute to higher health risks for women and households. Water productivity appears to have a protective association in some models, particularly for maternal mortality and out-of-pocket expenditure, suggesting that more efficient water management may reduce health burdens. Unsafe drinking water is associated with higher maternal mortality and higher health spending, reinforcing the view that water safety is not only an environmental issue but also a public health and financing concern. The unexpected positive association between unsafe drinking water and life expectancy should not be interpreted literally. It more likely reflects measurement limitations, multicollinearity, omitted variables, and the constraints of aggregate national time-series data.

Socioeconomic indicators also require careful interpretation. GDP per capita is generally associated with higher health expenditure and improved health capacity, suggesting that income growth can expand the fiscal and institutional space for healthcare. Education expenditure and urbanization show mixed signs across models. These results do not imply that education or urbanization are harmful in themselves. Rather, they suggest that the benefits of social investment and urban growth may be weakened when public services, environmental safeguards, and health systems do not expand at the same pace. The counterintuitive coefficients therefore point to the need for better data, more disaggregated analysis, and cautious interpretation of national-level estimates.

5.1. Policy Implications

Policy action should therefore focus on stronger enforcement of air quality and water safety regulations, improved monitoring of environmental indicators, better coordination between environmental and health institutions, as well as higher public investment in preventive and primary health services. Urban planning, clean transport, water system upgrading, and public health education should be treated as complementary rather than separate policy domains. In addition, future environmental policies should be assessed not only by legal adoption but by implementation quality, exposure reduction, and measurable health gains.

5.1.1. Reinforce Environmental Policies: A situation must be established where governments are compelled to issue stricter regulations on environments for PM2.5, to assist health-care providers and accelerate the adoption of cleaner technologies. Better water management is actually a health issue, and it could even affect maternal deaths.

5.1.2. Work Towards Sustainable Urbanization: It is necessary to invest in healthcare infrastructure capital for urban cities against increased population and unequal distribution of available resources. Public transit and green urban development could also be funded which would help reduce pollution and mean longer average life expectancies.

5.1.3. Scaling up Health Spending: Channel resources strategically to check out of pocket health spending and establish universal health coverage. Invest more in primary care and prevention of pollution-based diseases.

5.1.4. Reconsider Educational Investments: Review all education spending with an eye on its long-term impact on health. Cultivate health literacy and awareness in the formal courses of study to augment educations indirect effects on health.

5.1.5. Addressing Data Challenges: It is imperative to establish good measurement of indicators, such as poor drinking water and water productivity in order to avoid harmful misinterpretation. Data collection mechanisms should be strengthened to support improved policy and monitoring.

5.1.6. Promote Inclusive Economic Growth: Advocate for policies that grow the GDP/capita, which would result in greater "economic" healthcare outcomes and better funded healthcare. Foster public-private partnerships to expand and improve healthcare access.

Sound policies including sustainability of environment, economic growth, and social investments are essential for better health. A comprehensive policy approach including strengthening regulations, enhancing economic resilience, and addressing health disparities is needed to reach the sustainable development goals (SDGs)**.**

Author Contribution

Jawad Khan: conceptualization, methodology, formal analysis, data curation, writing – original draft preparation, visualization, project administration. **Nain Tara:** investigation, literature review, validation, writing – review & editing, resources.

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

The data used in this study are publicly available from the World Development Indicators (World Bank) and World Population Review. The compiled dataset used for the analysis is available from the corresponding author upon reasonable request.

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