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The Nexus between Climate Change & Longevity in Pakistan: Contrasting Effects of Temperature

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Abstract

The present study deal with the time series data for Pakistan for the period of 1990 - 2023 to capture the short-term consequences of climate change, particularly rainfall and temperature, on life expectancy. These short-term impacts were estimated using the *Autoregressive Distributed Lag (ARDL)* bounds test, while the stationarity of the data was examined using the *Augmented Dickey-Fuller (ADF)* test. To ensure robustness, additionally, we have considered life expectancy at birth for both males and females as dependent variables. Our results show that there is a positive and statistically insignificant correlation between rainfall and life expectancy, a 1°C increase in temperature is associated with an approximate 0.59-year increase in life expectancy. Furthermore, the bounds test's F-statistic confirms that the results are restricted to the short run, indicating that there is no long-run relationship. The study concludes that investment in climate mitigation, resilient infrastructure, and improved healthcare access can help protect life expectancy from the impacts of climate change in Pakistan.

Key Words: Rainfall, Temperature, Climate Change, ARDL, Life Expectancy, Gender

JEL classification: F63, F64, I18, J13

1. Introduction

Climate change is referred to as long-term shifts in weather patterns. Global temperatures have risen since the middle of the 20th century due to human-induced factors, particularly the use of fossil fuels (NASA, 2024). Due to unsustainable energy usage, changes in land use, and consumption patterns, global warming increased by 1.1°C between 2011 and 2020 (IPCC, 2023). Its impact are uneven, with poorer countries suffering more due to their limited resources and adaptive capacity.

Ecosystems and human societies are being altered by climate change through a variety of interrelated effects. Rapid Arctic warming, wildfires, and heat-related diseases are all being caused by rising temperatures. While changing rainfall patterns cause droughts, water scarcity, and desert expansion, warmer oceans and increased evaporation intensify storms, floods, and cyclones. The oceans are warming and acidifying as a result of absorbing too much heat and carbon dioxide, which is raising sea levels and endangering marine life. The extinction of species is escalating, posing hitherto unheard-of hazards to biodiversity. By lowering crop yields,

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harming fisheries, and interfering with cattle grazing, these pressures compromise food security. Malnutrition, emotional stress, disease transmission, and air pollution all pose threats to human health. As poverty and relocation increases, vulnerable communities are most severely impacted. All of these consequences point to climate change as a worldwide emergency that threatens ecosystems, livelihoods, and human welfare. (United Nations, 2022).

Rising temperatures, unpredictable monsoons, glacier melt, and frequent catastrophic events make Pakistan extremely vulnerable (Malik, Awan, & Khan, 2012). Despite producing less than 0.9% of global emissions, it is ranked as the fifth most climate-vulnerable nation (Germanwatch, 2021; Global Carbon Project, 2023). Maximum daily temperatures have risen more quickly than averages, with warming reaching 0.57°C over the 20th century and 0.47°C between 1961 and 2007 (World Bank Group & Asian Development Bank, 2021). This pattern is supported by city-level research in the Lower Indus Basin, Karachi, and Lahore (Sajjad et al., 2009; Sadiq & Qureshi, 2010; Mahar & Zaigham, 2010).

The patterns of rainfall have also changed. Precipitation increased by almost 25% during the past century, with more frequent wet episodes, following early reductions. Future forecasts indicate more constant annual averages, reduced winter rainfall, and increased summer rainfall (Khan, Khan, Ali, Ahmad, & Ahmad, 2016).

Although the negative effects of climate change are well known, especially in nations like Pakistan, they are not entirely detrimental. Rising temperatures, floods, droughts, and erratic rainfall disrupt food and water supplies, increase the spread of infectious and respiratory diseases, and contribute to malnutrition and psychological distress (Iqbal, 2020). However, recent research points to some possible advantages: changing temperatures and precipitation can expand crop growing zones, improving agricultural suitability in some areas (Guo, Zhang, & Yue, 2024), and global warming may reduce cold-related mortality, which currently surpasses heat-related deaths (Gasparrini et al., 2015; García-León et al., 2024). Therefore, even while there are serious concerns overall, climate change can have both short-term benefits for agriculture and health along with long-term dangers.

Life expectancy is an essential factor of a population's health status, representing the average number of years a newborn is expected to live under constant death rates (OECD). Life expectancy is determined by a combination of socio-economic, environmental and demographic factors (Azam, Uddin, & Saqib, 2023). Climate change directly affects health by intensifying air pollution, raising ozone and particulate matter levels that contribute to respiratory illnesses, hospitalizations, and premature deaths. Rising temperatures and altered precipitation also extend pollen seasons and increase allergenicity, worsening allergic conditions such as hay fever. Moreover, warmer conditions and flooding heighten the survival of pathogens in food and water, increasing diarrheal diseases, while disasters such as floods, heatwaves, and wildfires trigger mental health disorders, including anxiety, depression, and post-traumatic stress, with heat exposure further exacerbating risks for those with illness like dementia, or schizophrenia. Indirectly, climate change undermines food security by reducing crop yields, livestock, and fish production through extreme weather, pests, and reduced rainfall, driving up prices and deepening malnutrition. Wildfires add to the burden by releasing smoke and pollutants that cause respiratory and cardiovascular complications (Roy, 2024; CDC, 2024). These climatic shifts in temperature and rainfall underscore Pakistan's acute vulnerability and provide the foundation for examining their impact on life expectancy.

Therefore, this study aims to investigate the impact of climate change on life expectancy in Pakistan.

2. Literature Review

Numerous studies have looked at the correlation between human health outcomes, especially life expectancy, and climate variables. Amuka et al. (2018) investigated the relationship between climate change and life expectancy in Nigeria, focusing specifically on carbon dioxide (CO_2) emissions as a proxy for greenhouse gas concentration. Using World Bank data from 1995-2013 and applying an error correction model with OLS estimation, the purpose of their research was to examine whether rising CO_2 emissions negatively affect longevity. It's interesting to note that the results for CO2 emissions showed a positive but statistically insignificant coefficient, indicating that although emissions have increased significantly over time, but the average life expectancy in Nigeria has not decreased. The authors concluded that life expectancy is more consistently improved by other socioeconomic determinants than by CO2 emissions alone, including calorie intake, immunization, sanitation, and health spending.

Bhutto et al. (2023) used annual data from 1990 to 2016 to investigate the long-term effects of forest area, economic development, and global warming on life expectancy in Pakistan. Their study evaluated the impact of GDP growth, forest cover, and greenhouse gas emissions (CO_2, CH_4, and N_2O) using ADF unit root testing, Johansen co-integration, and a Generalized Linear Model (GLM). The findings showed that life expectancy was negatively correlated with total greenhouse gas emissions, carbon dioxide emissions, and forest area, but positively correlated with methane and nitrous oxide emissions. Likewise, Ali and Audi (2016) used time series data from 1980 to 2015 to examine the effects of globalization, environmental degradation, and income inequality on life expectancy in Pakistan. Their study, which using ARDL cointegration techniques, found that whereas income inequality and environmental degradation have a negative and significant influence on life expectancy, globalization has a positive and significant impact.

The negative impact of climate change on population health are highlighted by recent cross-country data. Roy (2024) used fixed-effects modeling to evaluate the impacts of rainfall and temperature on longevity using panel data from 191 countries between 1940 and 2020. According to the findings, life expectancy at birth decreases by roughly 0.44 years for every 1°C increase in average annual temperature and by 0.50 years for every 10-point increase in a composite climate change index that combines rainfall and temperature. The data also reveals that women are disproportionately impacted by climate change, with women's life expectancy being lower than men's. Longevity in Europe is expected to drastically decline if climate change is not addressed. In 31 European nations, Hauer and Santos-Lozada (2021) translated excess death estimates from extreme weather events particularly heat waves, floods, droughts, and wildfires into decreases in life expectancy at birth. According to their estimates, the average life expectancy may drop by 0.24 years by the year 2100, with losses in some countries-most notably Spain exceeding one year. Although these estimates are cautious because they only take into consideration mortality that is directly related to climatic extremes, they nevertheless show that climate change is a serious new public health concern that has the potential to reverse the advances in longevity.

The study by Mazhar et al. explored the relationship between air pollutants, climate change, and economic growth on life expectancy across Pakistan, India, Bangladesh, and China. While the general expectation in empirical theory is that environmental degradation should reduce longevity, their results for Pakistan revealed the opposite: certain pollutants were found to have a positive association with life expectancy. This unexpected outcome highlights a contradiction with conventional theory and suggests that in Pakistan, socioeconomic improvements such as rising income levels or better healthcare access during the study period may have overshadowed the harmful effects of pollution, producing results that diverge from the established evidence.

Ali, Amjad, and Ahmad (2014) studied how CO_2 emissions, inflation, per capita income, food production, population growth, and school enrollment impact life expectancy in the Sultanate of Oman. Their approach used time series data spanning 1970 to 2012. Furthermore, the Autoregressive Distributed Lag (ARDL) model was used to examine variable cointegration. Except for CO_2 emissions, most research variables in the Sultanate of Oman showed consistent short-term and long-term trends. In the long term, CO_2 emissions have a positive and insignificant association with life expectancy. However, in the short run, their impact is negative and significant.

Bayati, Akbarian, and Kavosi (2013) identified factors of life expectancy using a health production function. The authors gathered data from 21 Eastern Mediterranean nations between 1995 and 2007, using fixed-effects econometric approaches to control for country-specific characteristics. The study found that numerous socioeconomic characteristics were positively associated with life expectancy. However, the environmental factor: CO_2 emissions was positive but not statistically significant for the overall population and males. For females, the coefficient was significant with a small magnitude.

The national study carried out in China (Liu et al., 2021), indicated that ambient temperature had a significant effect on premature mortality measured through years of life lost (YLL). The analysis of 364 locations revealed a clear U-shaped relationship between daily mean temperature and YLL rates, showing that both cold and hot extremes increase premature mortality, with cold-especially moderate cold, accounting for the biggest share. On average, 1.02 YLL per death was attributable to temperature exposure nationwide, with 0.98 years linked to cold and only 0.04 years to heat. The burden was greater among males (1.15 YLL per death), individuals aged 65–74 (1.31), and those suffering from cardiovascular or cerebrovascular diseases (1.14 and 1.37 respectively), while respiratory-related deaths showed a smaller effect (0.47). Regionally, central China experienced the highest YLL burden (1.34), followed by southern (1.19) and northern China (0.64). Similar results were found for the Hubei province in China (Zhang, Yu, Peng, & Zhang, 2018), where the research showed a U-shaped association between ambient temperature and years of life lost (YLL). It has been demonstrated that both hot and cold temperatures increase premature death, with the effects of cold being longer lasting and making a greater contribution to YLL than those of heat.

The retrospective multi-country study by Odhiambo Sewe et al. (2018) assessed the correlation between ambient temperature and years of life lost (YLL) across seven sites in low-, middle-, and high-income regions, using distributed lag nonlinear models to capture both immediate and delayed effects. The results revealed that five of the study sites-Kisumu, Nairobi, Phoenix, Philadelphia, and Stockholm-exhibited a clear U-shaped relationship between temperature and YLL, indicating that both cold and hot extremes increase premature mortality, with cold effects generally more prolonged. In contrast, Nouna in Burkina Faso showed a continuous increase in YLL with rising temperatures, reflecting a heat-only burden, while Vadu in India also demonstrated higher YLL associated primarily with heat exposure. These findings highlight that temperature extremes shorten life expectancy across diverse climatic and socioeconomic contexts, but the relative importance of cold and heat varies by region, with cold dominating in temperate and subtropical settings and heat driving the burden in hotter climates.

Lloyd et al. (2024) examined the interplay between rising longevity and temperature-related mortality among older adults in Spain between 1980 and 2018. The study aimed to assess how extreme hot and cold temperatures influence life expectancy at age 65 and to what extent reductions in temperature-related deaths have contributed to increases in longevity and changes in lifespan inequality. Using demographic data and a counterfactual decomposition approach, the authors found that the absolute risk of dying from extreme temperatures has decreased over time, contributing to about 20% of the observed increase in life expectancy. Reductions in deaths from moderate cold were the largest contributor, whereas extreme heat and extreme cold had smaller effects. Despite gains in life expectancy, lifespan inequality increased, indicating that improvements were not evenly distributed across the older population. The study highlights that while rising longevity continues, extreme temperatures remain a significant factor influencing the survival of older adults.

The modelling study by García-León et al. (2024) assessed temperature-related mortality across 1,368 European regions, combining city-specific exposure response functions with demographic projections to estimate present and future risks. Between 1991 and 2020, about 407,538 deaths annually were linked to non-optimal temperatures, with cold-related deaths (363,809) far exceeding heat-related deaths (43,729). Projections under a 3 °C warming scenario suggest an additional ~55,000 deaths per year by 2100, driven largely by rising heat-related mortality and ageing populations, reducing the cold-to-heat ratio from 8.3:1 to 2.6:1. The study highlights strong regional disparities, with eastern Europe most affected by cold and southern Europe by heat, underscoring the need for localized adaptation strategies to protect vulnerable populations.

The study by Barakzai and Burney (2021) attempted to look into the influence of high temperatures on mortality in Pakistan. Using 20 years of climate and mortality data (2000-2019) and applying a Generalized Linear Model with a Quasi-Poisson link, the authors studied how fluctuations in maximum temperature influence death rates. Their findings reveal that an increase in monthly maximum temperature from medium to high levels increases the relative risk of mortality by 11%, whereas a fall below medium temperatures decreases deaths by 23%. The ideal temperature range is 25-30 °C, as proposed by the study beyond which the mortality risk increases steadily.

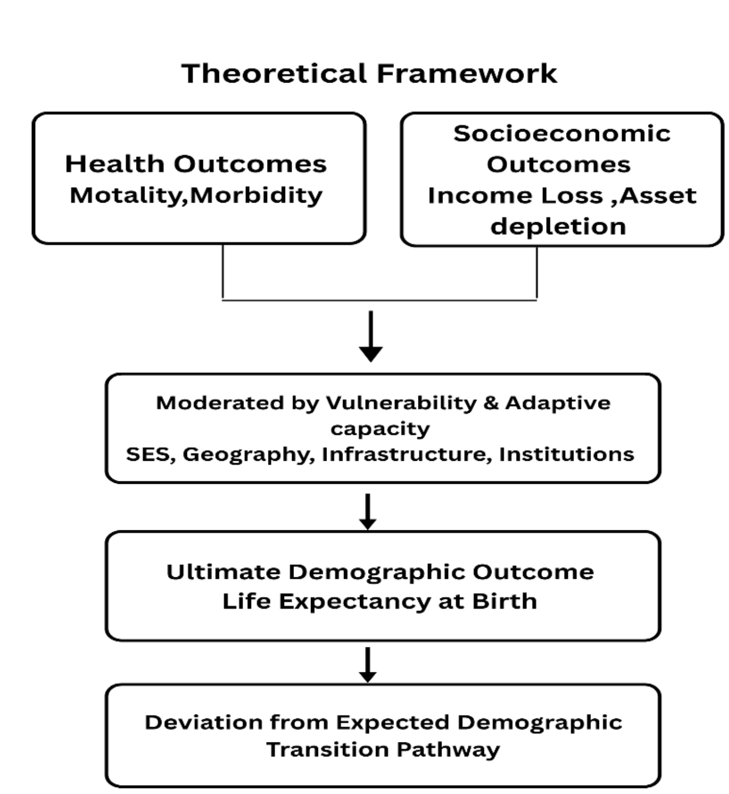
In addition, the study “Changing Climate Patterns and Women Health: An Empirical Analysis of District Rawalpindi, Pakistan” aims to investigate how changing climatic conditions affect women’s health outcomes in the region. The objective was to determine the specific vulnerabilities women suffer due to heatwaves, floods, excessive rainfall, and rising temperatures. This research relied on primary survey data from women in Rawalpindi to examine the relation between climate variability and health status. The findings highlight that women are disproportionately impacted by climate change experiencing higher risks of illness, malnutrition, reproductive health complications and mental stress, thereby emphasizing the urgent need for gender-sensitive climate adaptation and health policies in Pakistan.

3. Theoretical Framework & Empirical Background:

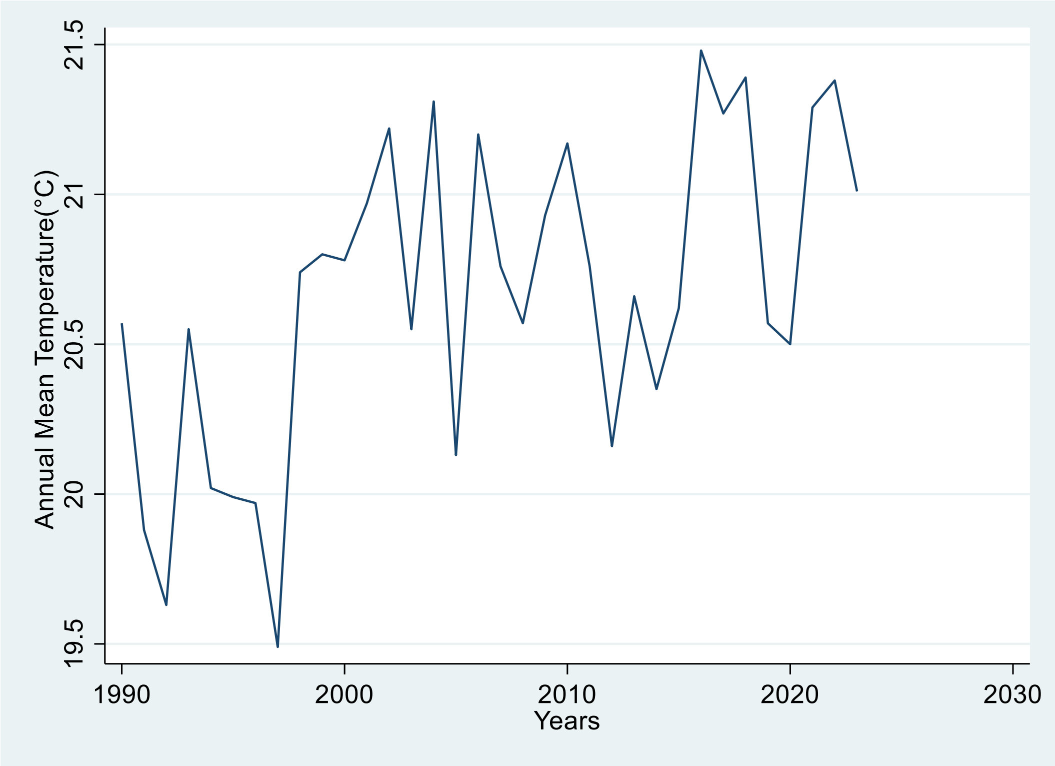
This study is grounded in an integrated theoretical model proposing that temperature dynamics influence life expectancy through a multi-layered causal architecture. We posit that temperature acts as a critical exogenous factor that can shift a population’s position relative to the Preston curve, disrupting the typical relationship between economic development and longevity. The effect operates through proximate biophysical pathways conceptualized via the Causal Web Model of environmental epidemiology, wherein temperature serves as a node amplifier that intensifies strands leading to mortality. These include direct physiological stress from extreme heat, indirect ecological effects such as expanded vector-borne disease transmission, and systemic impacts on food security and water quality. The magnitude of these effects, however, is not uniform; it is fundamentally moderated by the dimensions of the Climate–Health

Vulnerability Framework (IPCC Risk Paradigm) namely, differential population exposure, pre-existing sensitivity, and adaptive capacity. We hypothesize the strongest adverse associations where high exposure and sensitivity converge with low adaptive capacity.

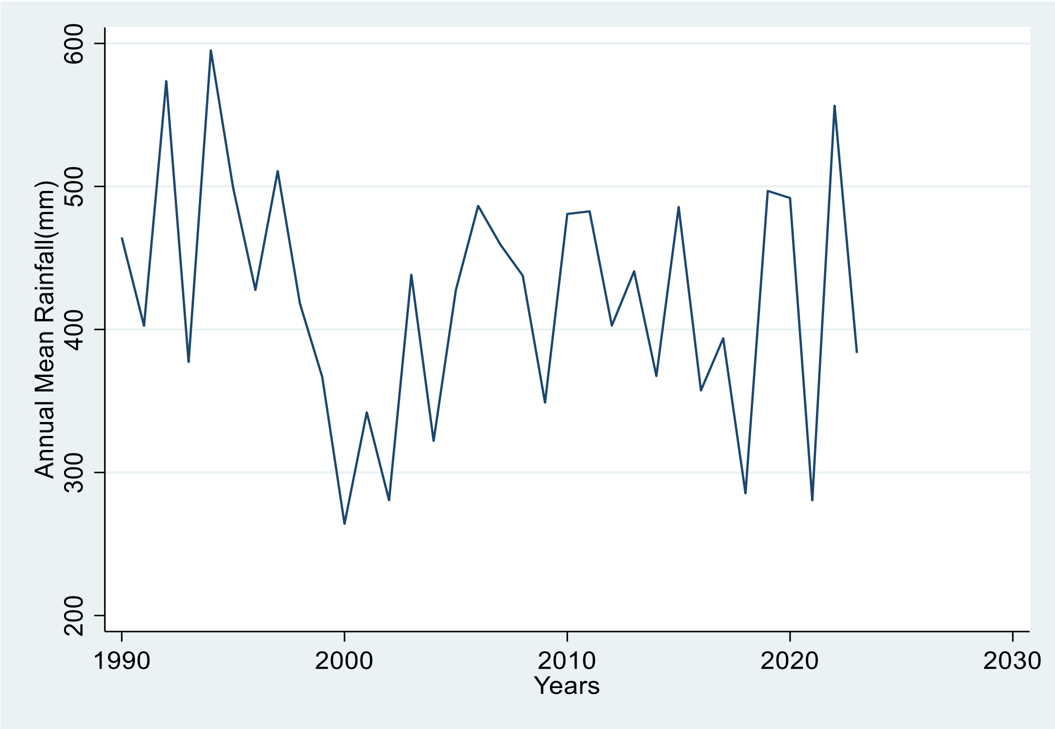
Underpinning this entire nexus is the structural mechanism articulated by the Fundamental Cause Theory (Link & Phelan), which positions socioeconomic resources as a primary determinant of health outcomes. We theorize that climate change acts as a risk amplifier for pre-existing inequality. Higher socioeconomic groups can deploy flexible resources; knowledge, wealth, and power to mitigate their exposure, reduce their sensitivity, and enhance their adaptive capacity against temperature-related hazards. Conversely, lower socioeconomic groups lack this protective buffer, leading to a disproportionate mortality burden from temperature shocks. Consequently, the aggregate relationship between temperature and life expectancy is not merely biophysical but is intrinsically mediated by societal inequality. This integrated framework guides our investigation beyond a simple aggregate correlation, directing it toward analyzing the contingent, unequal, and fundamentally multi-causal nature of how climate variability shapes demographic outcomes across and within populations.



1. Average annual temperature in Pakistan from 1990 to 2023



2. Average annual rainfall in Pakistan from 1990 to 2023



3. Average annual life expectancy in Pakistan from 1990 to 2023

The trends in Pakistan's yearly, mean temperature, rainfall, and life expectancy(total, female, and male) between 1990 to 2023 are depicted in figures 1-3.

Figure 1 displays the mean annual temperature for Pakistan from 1990 to 2023. It can be analyzed that temperature follows a clear upward trend, indicating the effects of climate change over time. Starting around 19.6°C in 1990, the temperature fluctuates but gradually increases, reaching approximately 21.3°C in 2023. The general pattern indicates a warming trajectory but these variations may point to short-term climatic variability. The substantial increase of almost 1.7 °C over the course of three decades could have detrimental effects on Pakistan's agriculture, water resources, public health, and heat related mortality. Furthermore, this trend aligns with global climatic patterns (Roy, 2024).

Meanwhile, it can be observed in figure 2 that precipitation patterns show strong fluctuations; therefore, rainfall variability lacks a clear trend.

The overall life expectancy in Pakistan has sharply increased from almost 60 years in 1990 to nearly 66 years by 2020, although some major fluctuations are observed in a few years. [Figure 3]. Throughout the study period, female life expectancy has continuously exceeded both overall and male life expectancy, starting from 61 years and reaching around 70 years till 2020. This may occur due to the biological resistance of women or reduced exposure to health hazards. Additionally, in 1990, the life expectancy for men was 58 years; by 2020, it had progressively increased to 66 years, but it still lower than that of women.

3.1 Research Gap:

Our proposed study fills in a major gap in the existing body of research by looking at more than just a few specific pathways such as heatwaves, mortality, dengue incidence or nutritional impacts to provide thorough national level analysis that explicitly quantifies the aggregate effect of temperature dynamics on life expectancy at birth across all administrative units of Pakistan. In contrast to sectoral studies that concentrate on single mechanism (Khan Barakzai & Burney, 2021), (Sharif, Shahzad, & Batool, 2024) or Ajaz and Majeed (2018) whose insights were limited to one district and one gender, our research uses a longitudinal, demographic decomposition framework to isolate the contribution of climate factors to life expectancy. Moreover, past research rarely addresses gender differences even though climatic influences on health sometimes vary dramatically between men and women in Pakistan. An additional novelty resides in the use of a comprehensive, long-term dataset that spans multiple decades-an empirical scope that has not been applied in other climate health research for Pakistan. This holistic approach provides policy makers with a consistent metric of climate-induced population risk that is currently lacking from both scholarly and policy debate in Pakistan, thereby bridging academic and decision- making authorities.

4. Data and Methodology

The present research analyzes time series data for Pakistan from 1990 to 2023 to determine how climate change affects life expectancy. To assess gender-specific impacts, the study employs independent regressions with male and female life expectancy at birth as dependent variables. The World Development Indicators 2025 provides data about life expectancy at birth, life expectancy at birth for males, and life expectancy at birth for females. Life expectancy at birth, according to the World Bank (2025), is the number of years that a newborn infant would live if prevailing mortality patterns at the time of its birth persisted throughout its life.

The independent climate variables in our analysis are temperature and rainfall (Roy, 2024). Data on temperature and rainfall were obtained from World Bank Climate Change Knowledge Portal 2025. Temperature is defined as the annual average mean surface air temperature (°C), whereas rainfall is measured as the annual total precipitation(mm). The ERA5 reanalysis dataset, which is accessible via the site, provided the data for this investigation. Compared to more conventional observational datasets like CRU, ERA5 was selected because to its greater accuracy, higher spatial resolution (0.25°), and more recent updates. For the years 1990-2023, Pakistan's annual mean temperature and yearly precipitation were retrieved.

Econometric Methodology

Assume a dependent variable Y_t and a vector of regressors $X_{1t}, X_{2t}, \dots \dots, X_{nt}$. The unrestricted ARDL(p, q_1,q_2,…..,q_n) model is written as:

$$Y_t = \alpha_o + \Sigma_{i=1}^{p} \phi_i Y_{t-i} + \Sigma_{j=1}^{n} \Sigma_{k=1}^{qj} \beta_{jk} X_{jt-k} + \varepsilon_t$$

The model is re-parameterized into the Error Correction Model(ECM) form for bounds testing:

$$\Delta Y_t = \delta_o + \lambda_1 Y_{t-1} + \Sigma_{j=1}^{n} \lambda_{2j} X_{jt-1} + \Sigma_{i=1}^{p-1} \psi_i \Delta Y_{t-i} + \Sigma_{j=1}^{n} \Sigma_{k=o}^{qj-1} \gamma_{jk} \Delta X_{jt-k} + \mu_t$$

Where λ_1 and λ_{2j} capture the long-run relationship

ψ_i and γ_{jk} represent short-run dynamics

μ_t is the error term

In our study, the dependent variable is life expectancy, while the regressors are temperature and rainfall. So, the following simple regression form can be used to express our model:

$$LE_t = \alpha_o + \beta_1 Temp + \gamma_1 Rain + \varepsilon_t$$

Where LE is life expectancy, Temp is temperature and Rain is rainfall respectively. Time period is denoted by t and ε_t is the error term.

Many macroeconomic time series have unit roots and are non-stationary, as demonstrated by Nelson and Plosser (1982). Regressions on such series may therefore produce spurious and misleading results if the unit root issue is not resolved. Therefore, the first step in our analysis requires checking the stationarity of data. Among the various tests available, we use the Augmented Dickey-Fuller (ADF) test to determine whether the variables in the model are stationary. The regression equation below provides the foundation of the ADF test:

$$\Delta Y_t = \delta Y_{t-1} + \Sigma_{j=1}^{q} \phi_j \Delta Y_{t-j} + \varepsilon_t$$

Where ΔY_t is the first difference of the series, Y_{t-1} is the lagged value of the variable, and ΔY_{t-j} are the lagged differences included to remove autocorrelation. The null hypothesis assumes that the variable has a unit root and is therefore non-stationary whereas, the alternative hypothesis states the opposite (the series is stationary). If the calculated t-statistic of the coefficient β is greater than the critical value, we reject the null hypothesis and conclude that the series is stationary. However, if the t-statistic is less than the critical value, we fail to reject the null hypothesis and infer that the series contains a unit root and is therefore non-stationary.

Autoregressive Distributed Lag (ARDL) Model

Following confirmation of the stationarity of the data, we look at whether life expectancy, temperature, and rainfall have a long-term relationship. We use the Autoregressive Distributed Lag (ARDL) model created by Pesaran, Shin, and Smith (2001). for this purpose. The ARDL method works well with small sample sizes and can be used when the variables have mixed orders of integration I(0) and I(1). The ARDL specification can be written as follows:

$$LE_t = \alpha_o + \Sigma_{i=1}^{p}\beta_i LE_{t-i} + \Sigma_{j=0}^{q}\gamma_j Temp_{t-j} + \Sigma_{k=0}^{r}\delta_k Rain_{t-k} + \varepsilon_t$$

The next step is to re-parameterize the ARDL into the Unrestricted Error Correction Mechanism Model (UECM) since it enables us to analyze both short-run and long-run dynamics.

$$\Delta LE_t = \alpha_o + \Sigma_{i=1}^{p-1}\phi_{1i\Delta} LE_{t-i} + \Sigma_{j=0}^{q-1}\theta_{1j}\Delta Temp_{t-j} + \Sigma_{k=0}^{r-1}\theta_{2k}\Delta Rain_{t-k} + \pi_1 LE_{t-1} + \pi_2 Temp_{t-1} + \pi_3 Rain_{t-1} + \varepsilon_t$$

Where ϕ_{1i}, θ_{1j} and θ_{2k} represent short-run dynamics

π_1, π_2 and π_3 capture the long-run relationship

Bounds Testing for Cointegration

Now, applying the ARDL bounds test further allows us to reach the conclusion of whether there exists a long-run relationship between dependent and independent variables or not. The null and alternative hypotheses for this test are as follows:

$H_o: \pi_1 = \pi_2 = \pi_3 = 0$ (there is no long-run relationship)

$H_1: At\ least\ one\ of\ \pi_1, \pi_2, \pi_3 \neq 0$ (the long-run relationship is present)

Subsequently, the decision regarding the existence of a long-run relationship will be based on the computed F-statistic and the decision rule proposed by (Pesaran et al., 2001).

Long-Run ARDL Model

If the bounds testing procedure confirms cointegration, the long-run ARDL relationship between life expectancy and independent variables is expressed as:

$$LE_t = \theta_o + \theta_1 Temp_t + \theta_2 Rain_t + \nu_t$$

The long-run coefficients θ_1 and θ_2 are derived from the estimated UECM parameters using the Pesaran et al. (2001) transformation.

$$\theta_1 = -\frac{\pi Temp}{\pi LE}, \quad \theta_2 = -\frac{\pi Rain}{\pi LE}$$

Where πLE is the coefficient on LE_{t-1} and π_{Temp} and π_{Rain} are the coefficients on the lagged levels of temperature and rainfall respectively. These ratios represent the long-run elasticities of life expectancy with respect to temperature and rainfall.

5. **Results and Discussion**

The study's empirical findings are presented in this section. All the analysis has been done using STATA. The descriptive statistics for the three main variables utilized in this study—temperature, rainfall, and life expectancy at birth (total, female, and male) are shown in Table 1. The table displays the number of observations, mean, standard deviation, minimum, and maximum values for each variable throughout the sample period. The total number of observations for the dataset is 34. The average life expectancy at birth is 63.43 years, with women having a much longer life expectancy than men. The rainfall shows significant variability, ranging from 264.12 mm to 595.11 mm, while the average annual temperature is 20.67°C, with very little fluctuation across observations.

Table 1: Descriptive Statistics

Variables	**Observations**	**Mean**	**Std. Dev.**	**Min**	**Max**
Life Expectancy at birth	34	63.428	2.445	59.728	67.649
Life Expectancy at birth of Females	34	65.173	3.135	60.826	70.163
Life Expectancy at birth of Male	34	61.904	1.813	58.833	65.332
Temperature	34	20.667	.528	19.49	21.48
Rainfall	34	422.013	84.445	264.12	595.11

Unit Root Test:

Table 2 presents the results of Augmented Dickey Fuller (ADF) unit root tests. Life expectancy is not stationary at level; however, it becomes stationary after taking the first difference at 1% level of significance suggesting that it is integrated of order 1 or I(1). The life expectancy at birth of males and females shows similar results, with both being integrated of order 1 at the 1% level of significance. Temperature and rainfall, on the other hand, are stationary at level at 1% level of significance indicating that they are I(0). The Autoregressive Distributed Lag (ARDL) model is deemed suitable for this research since the variables have heterogeneous order of integration, with some being I(0) and others being I(1).

Table 2: ADF Unit Root Test

Variables	**At Level**	**First Difference**	**Order of Integration**
Life Expectancy	-0.122 (0.9472)	-6.391 (0.0000)***	I(1)
Life Expectancy at birth of Male	-0.403 (0.9096)	-6.171 (0.0000)***	I(1)
Life Expectancy at birth of Female	0.031 (0.9610)	-6.331 (0.0000)***	I(1)
Temperature	-3.551 (0.0068)***	---	I(0)
Rainfall	-6.019 (0.0000)***	---	I(0)

P-values are written in brackets.

ARDL Bounds Test:

The Akaike Information Criteria (AIC) were used to determine the variables' optimal lag lengths (lowest AIC value). As indicated in Table 3, the ARDL bounds test was used to determine whether life expectancy and climatic factors had a long-run relationship. There is no indication of cointegration because the F-statistics for male life expectancy (1.559) and total life expectancy (2.262) are both below the 5% lower bound value (3.79). For female life expectancy, the F-statistic (4.627) falls between the lower and upper bounds (3.79 and 4.85) respectively yielding an inconclusive result. Therefore, the bounds test confirm that there is no long-run association for overall and male life expectancy and only short-run relationships are considered in subsequent analysis.

Table 3: Bounds Test

Variables	**F-statistic**	**I(0)**	**I(1)**	**Conclusion**
Life Expectancy	2.262	3.79	4.85	No cointegration
Life Expectancy at birth Male	1.559	3.79	4.85	No cointegration
Life Expectancy at birth Female	4.627	3.79	4.85	Inconclusive

Following Pesaran et al. (2001) if: F-statistics>upper bound I(1) →cointegration exists, F-statistic<lower bound I(0)→no cointegration, F-statistic is between the lower and upper bound →inconclusive result.

ARDL Short-run Dynamics:

Table 4 displays the model's short-run coefficients, which are estimated using the ARDL method. The findings show that life expectancy is highly persistent because its own first lag is positive and statistically significant at the 1% level (coefficient = 0.82, p-value<0.01), indicating that an increase in life expectancy of one year in the prior year corresponds to an increase of 0.82 years in the current yearIn short-run, temperature has a positive and significant effect on life expectancy. If all else stays the same, a 1°C increase in temperature results in an approximate 0.59-year increase in life expectancy. This result is consistent with earlier studies that found a statistically insignificant but positive correlation between life expectancy and CO2 emissions in many nations (Mazhar et al., 2023; Delavari et al., 2016; Ali et al., 2014; Bayati et al., 2013). Additionally, a number of studies that have looked at the relationship between ambient temperature and mortality have found that mortality associated to cold tends to be higher than mortality related to hot (García-León et al., 2024; Lloyd et al., 2024). According to some other research, life expectancy and ambient temperature have a U-shaped association (Zhang et al., 2018; Liu et al., 2021; Odhiambo Sewe et al., 2018). If data covering a longer time period were available, Pakistan might show a similar U-shaped pattern. However, the lagged temperature value is statistically insignificant, meaning that life expectancy is only affected by the temperature of the current time. Although there is a positive correlation between rainfall and life expectancy, but this relationship is not statistically significant (Roy, 2024). These prevailing results may suggest that rainfall's effect can be mitigated by other variables such as a country's health spending, literacy rate and availability of medical facilities. Therefore, it can be concluded that rainfall variability may not have a major influence on population health in nations with strong social safety nets since the negative effects can be lessened by improved infrastructure, healthcare and adaptability.

Since the bounds test confirmed that the relationship is valid only in short run, further long -run analysis was not conducted. This indicates the absence of a long-term effect and explains why U-shaped association between life expectancy and temperature is not clearly observed. If data covering a longer time period were available, Pakistan might show a similar U-shaped pattern.

Table 4: ARDL(3 1 0) Short-run Coefficients

Short-run Coefficients from ARDL Model			
Regressors	**Dependent Variable: Life Expectancy**	**Dependent Variable: Life Expectancy Female**	**Dependent Variable: Life Expectancy Male**
Life Expectancy(L1)	.8156716 (0.000)***	.9388696 (0.000)***	.7093459 (0.003)***
Life Expectancy(L2)	-.2308114 (0.361)	-	-.3704637 (0.172)
Life Expectancy(L3)	.3454368 (0.131)	-	.2041421 (0.449)
Temperature	.5882148 (0.005)***	.6988546 (0.000)***	.5145925 (0.017)**
Temperature(L1)	.0089673 (0.959)	.0236662 (0.873)	-.0228265 (0.904)
Rainfall	.0013687 (0.199)	.002359 (0.011)**	.0004487 (0.690)
C	-8.177787 (0.046)**	-11.6693 (0.003)***	-3.131902 (0.480)

Note: L1, L2 and L3 represent the first, second and third lags of life expectancy, respectively(e.g. L1=LE_{t-1}, L2=LE_{t-2} and L3=LE_{t-3}). Similarly, L1 for temperature refers to its first lag(T_{t-1}).

The short-run results for female and male life expectancy, reported in the third and fourth columns of the table, closely resemble those obtained for overall life expectancy. The positive and statistically significant initial lag shows that life expectancy exhibits a strong pattern of persistence in both gender-specific models, indicating that advancements in prior years continue to affect current results. In all three models, temperature continues to have a positive and statistically significant short-term correlation with life expectancy, supporting its significance as a population health determinant. A key difference, however, emerges in the case of rainfall: while rainfall is not significant in the models for total or male life expectancy, it becomes statistically significant for females, though with a very small coefficient (0.002359). This suggests that rainfall has a slight but favorable short-term impact on female life expectancy, which may be due to gender-specific variations in environmental exposure or sensitivity.

These conclusions are only valid in the short term. The lack of long-term correlations between life expectancy, temperature, and rainfall in Pakistan may indicate that institutional and socioeconomic factors dominate in determining long-term health outcomes. Climate variables have short-term effects, but structural changes, adaptation, and more powerful determinants like healthcare, income, and pollution management obscure their long-term consequences.

Diagnostics

The robustness of the computed ARDL model is confirmed by the diagnostic tests. While the Breusch-Pagan/Cook–Weisberg test reveals no indication of heteroskedasticity (p-value=0.1594), the Breusch-Godfrey LM test demonstrates no serial correlation (p-value=0.8775). The model's accurate specification is further confirmed by the Ramsay RESET test (p-value=0.8666). Furthermore, because the recursive residuals fall below the 5% border constraints, the CUSUM stability plot shows that the calculated coefficients hold steady throughout time. Overall, the diagnostic findings support the ARDL model's reliability.

6. Conclusion

The consequences of climate change differ greatly, depending on geographical circumstances, socioeconomic conditions and adaptive capacity. Using time series data from 1990 to 2023, this study investigated the effects of climate change, particularly temperature and rainfall, on life expectancy at birth in Pakistan. The ARDL model was applied since the variables showed a mixed order of integration. The bounds test revealed that there was no long-term relationship because the F-statistic was below the lower bound at the 5% level of significance. Only short-run dynamics were captured by the estimated coefficients from the ARDL model. Additionally, if all other variables stay the same, life expectancy rose by roughly 0.59 years for every 1°C increase in temperature. In the short run, rainfall had a positive but statistically insignificant effect on life expectancy.

Some policy suggestions based on this study are that the government should invest in climate mitigation strategies. Access to better healthcare facilities should be improved to guarantee that individuals receive treatment and medication on time, and infrastructure should be resilient to prevent water damage.

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