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THE IMPACT OF CLIMATE CHANGE ON CHRONIC RESPIRATORY DISEASES IN SAUDI ARABIA: THE MEDIATING ROLE OF AIR POLLUTION

Ayub Maezi Alharbi[1], Farra Aidah Jumuddin[2*], Raed Falah Ayesh[3], Abdullah Ali Rashed[4], Salman Alhumaidi Alanazi[5]

[1]Public Health in Environmental Health, Lincoln University College, Selangor, Malaysia.
[2]Lincoln University College, Selangor, Malaysia. Email: farraaidah@lincoln.edu.my
[3]Epidemiology, Qassim Health Cluster, Saudi Arabia.
[4]Public Health, Ministry of Health, Saudi Arabia.
[5]Public Health, Hail Health Cluster, Saudi Arabia.

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Corresponding Author: Farra Aidah Jumuddin (farraaidah@lincoln.edu.my)

ABSTRACT

The prevalence of chronic respiratory diseases (CRD) in Saudi Arabia exhibits a persistent and increasing pattern over the past few years. Several factors can affect the prevalence of CRD. Therefore, this study aims to examine the effect of air pollution and climate change on the prevalence of CRD in Saudi Arabia. The study uses the autoregressive distributed lag (ARDL) estimator to estimate the long-term and short-term effects of air pollution and climate change on the prevalence of CRD. The study uses data from 1990 to 2023. The dependent variable is CRD prevalence, which is extracted from the Global Burden of Disease (GBD) database. The independent variables include air pollution (AP) and the heating index (HI), which are obtained from the World Bank database. The Stata software is used for data analysis, and a 5% level of significance is used. The empirical analysis reveals a statistically significant effect of AP on the prevalence of CRD in both the long and short terms. A one-standard-unit increase in AP leads to a 1.92% and 0.75% increase in the prevalence of CRD in the long and short run, respectively. HI significantly affects the prevalence of CRD in the long run by about 0.96%. Persistent and higher levels of AP and HI contributed to the increase in prevalence of CRD in Saudi Arabia.

KEYWORDS: Chronic Respiratory Disease, Air Pollution, Climate Change, Saudi Arabia.

1. INTRODUCTION

Chronic respiratory diseases (CRD) refer to general illnesses that affect the human respiratory system, specifically the airways and lungs (Momtazmanesh et al. 2023). CRD include asthma, chronic obstructive pulmonary disease (COPD), chronic bronchitis, and others. It has been classified as among the top non-communicable causes of death and disability-adjusted life years (DALYs) and accounts for about 4.1 million deaths and about 105 million DALYs in 2023 across the world (GBD 2024). The corresponding figures for Saudi Arabia indicate that CRD accounted for approximately 2,500 mortality cases and 18,600 DALYs in 2023. Alqahtani (2022) indicated that CRD was the leading cause of death in Saudi Arabia in 2019. Such statistics burden the health system, including hospitalisations, reduced quality of life, and economic costs (Vos et al. 2020; Syamlal et al. 2020).

There is a growing concern that the change in climate may hinder efforts to manage respiratory illnesses and increase the prevalence of CRD (D'Amato et al. 2014; Andualem et al. 2025). Climate change is described as the long-term shifts and changes in temperature, weather patterns, and the occurrences of extreme events like floods and dust (IPCC 2022; Tran et al. 2023). Previous research also indicated that the burning of fossil fuels, deforestation, desertification, aridity, industrial and production processes, and urbanisation were among the top causes of global climate change (D'Amato et al. 2014; IPCC 2022; Pacheco et al. 2021; Halpin et al. 2025).

The literature has suggested different contributing factors to the increased risk and prevalence of CRD. These include, but are not limited to, AP, dust or sand storms, heatwaves, occupational chemical exposure, and tobacco smoking (Xu et al. 2025; Andualem et al. 2025; Scheerens et al. 2022; Anenberg et al. 2012). Rojas-Rueda et al. (2021) and Halpin et al. (2025) showed that AP is one of the most common and principal factors that adversely influence humans' respiratory health. Thus, the country's public health will be at increased risk when climate change worsens (Anenberg et al. 2012).

The climate of Saudi Arabia is considered a fertile environment for respiratory infections because it is characterised by unique features, including extreme heat (> 45°C), low rainfall, and frequent sandstorms due to its desert nature. The substantial economic development and fast urbanisation are highly dependent on the consumption of fossil fuels also affects air quality (Rojas-Rueda et al. 2021). Meo et al. (2013) indicated that sandstorms cause severe CRD, lung illness, and sleep disturbance. In the same way, Alyami et al. (2025) revealed that the population residing in high-traffic or industrial areas has a higher likelihood of developing CRD, such that these areas are characterised by increased levels of NO_2 and $PM_{2.5}$. Moreover, Saudi literature indicates a gradual increase in CRD prevalence, particularly asthma, COPD, and others (Mohamed Hussain et al. 2018; Alomary et al. 2022; IPCC 2022). However, the link between CRD prevalence and climate change, as well as air pollution, was. Most existing studies are short-term or episodic analyses (e.g., hospital admissions during a dust storm or heatwave), but they do not investigate the temporal connections (Al-hajji and Al-Qahtani 2025; Alyami et al. 2025; Meo et al. 2013). This highlights the presence of a significant knowledge gap regarding how air pollutants and climate change events affect the prevalence of CRDs in Saudi Arabia over time. Therefore, this study aims to examine the impact of climate change and air pollution on the prevalence of CRDs in Saudi Arabia.

2. RESEARCH METHODS

2.1 Study variables

This research utilises data from 1990 to 2023 extracted from the GBD and the World Bank databases. Table 1 illustrates the study variables and their sources. The selection of the study variables is restricted by the availability during the study period. The outcome variable is the overall age-standardised prevalence of CRD in percentage units. Figure 1 illustrates the trend in CRD prevalence in Saudi Arabia over the study period. The figure shows that the prevalence of CRD exhibited an increasing trend from 1990 to 2000 and then began to decrease until 2005. From 2006 onwards, it exhibited a consistently increasing trend until 2023.

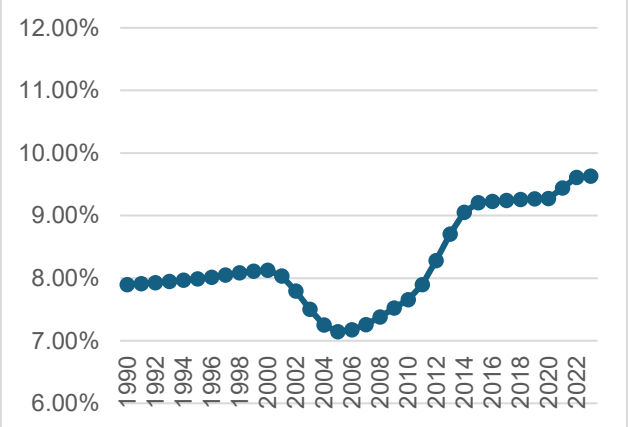

Figure 1: Historical records of the prevalence of chronic respiratory diseases in Saudi Arabia (1990 – 2023).

Table 1: Descriptive statistics of the study variables.

	CRD	AP	HI
Mean	8.3	0.000	24.442
Median	8.0	-0.055	22.745
Maximum	9.6	2.529	41.990
Minimum	0.71	-2.334	7.700
SD	0.8	1.581	9.881
Skewness	0.415	-0.005	0.129
Kurtosis	1.884	1.579	1.909
Jarque-Bera	2.741	2.862	1.781
Probability	0.254	0.239	0.411

AP: Air pollution, which is a composite score that is derived from conducting PCA of $PM_{2.5}$, CO_2 emissions, and NO_2 extracted from the World Bank.
CRD: Prevalence of chronic respiratory disease collected from GBD.
HI: Heating index, measured in degrees Celsius (°C) and collected from the World Bank.
SD: Standard deviation.

The first independent variable is air pollution (AP), which is obtained by conducting principal component analysis (PCA) to derive the standardised composite score of AP using $PM_{2.5}$, NO_2, and CO_2 emissions. These indicators explained about 80.8% of the first principal component (COMP-1), as indicated in Table A1 in the Appendix. The average score is zero because it represents the standardised value from the three elements. Climate change is measured by the heating index (HI), with an average value of 24.442 °C, and a minimum and maximum score of 7.700 °C and 41.990 °C, respectively. All study variables followed the normal distribution as evidenced by the insignificant Jarque-Bera test.

2.2 Estimation Framework

The current study considers the prevalence of CRD as a function of AP and HI () that can be modelled in the following form:

(1)

where the subscript represents the period and represents the intercept that measures the average prevalence of CRD when there are no AP and HI. The coefficients and represent the effects of AP and HI, respectively. The error terms are defined by.

The first step in data analysis involves assessing the stationarity of the study variables. This step is conducted by implementing unit root tests such as Phillips and Perron (1988) (PP) test and the Zivot and Andrews (2002) test with structural breaks, as shown in Table 2. The PP test indicates that the AP is nonstationary and reaches its stationarity at its first difference, highlighting that it is integrated of order one I(1). Meanwhile, the PP test reveals that HI is a stationary time series and thus it is integrated of order zero, I(0). On the other hand, the results of the Zivot-Andrews test indicate that CRD is a nonstationary series and it becomes stationary at its first difference after accounting for the structural break, which is found to be in the year 2006, coded as 1 for the year 2009 and 0 otherwise.

Table 2: Results of the stationarity tests.

Variable	PP Test	p-value	Zivot-Andrews Test	p-value	Result
AP					
Level	– 2.607	0.279	– 3.978[(a)]	0.386	I(1)
1st difference	– 7.679	0.000	– 8.290[(b)]	0.000	
HI					
Level	– 5.889	0.000	– 6.219[(b)]	0.000	I(0)
CRD					
Level	– 1.301	0.870	– 4.295[(a)]	0.209	I(1)
1st difference	– 1.518	0.802	– 5.358[(b)]	0.000	

[(a)]: break year is 2002. [(b)]: break year is 2009.

Having established the integration order for all time-series variables, the next step is to estimate the dynamic nexus among them. The study employs the autoregressive distributed lag (ARDL) time series model because it is powerful for small sample sizes and when the variables exhibit mixed orders of integration (I(0) and I(1)) and the dependent variable is I(1). The study also defined a year dummy for the break year of 2009. The model also allows for estimating long-term and short-term associations (Pesaran and Shin 1999; Pesaran et al. 2001). All statistical analyses are conducted using Stata version 17, with a 5% level of significance considered.

3. RESULTS AND DISCUSSION

The estimation results obtained using the ARDL model are presented in Table 3. We report the estimated coefficients along with their standard errors, critical values, and p-values. The error correct term (ECT) is – 0.258, which is within the acceptable ECT values and statistically significant (p-value < 0.001). It indicates that about 25.8% of the deviation from the long-term equilibrium is being corrected in the next period. The ARDL bound testing reveals a statistically significant result, indicating that the variables are cointegrated and exhibit significant long-term connections (F = 11.72, which exceeds the 1% tabulated F-value). These results confirm that the CRD and environmental variables converge to the long-term linkage.

Table 3: Estimation result of the ARDL model.

	Coefficient	S.E.	t-statistic	p-value
Long-run relationship				
AP	1.921*	0.396	4.851	0.000
HI	0.960*	0.287	4.342	0.000
Short-run relationship				
AP	0.752*	0.038	3.45	0.000
HI	0.053	0.061	0.869	0.386
DU2009	– 0.089*	0.034	2.618	0.009
ECT	– 0.258*	0.026	– 9.897	0.000
Bound Testing F	11.725*			

* Indicates a statistically significant effect at the 5% level.
Δ: Difference operator; ECT: error correction term; S.E.: standard error.

The analysis reveals that AP and CRD are significantly associated at 1% level of significance at both the long and short terms. In the long term, a one-unit increase in the standardised score of AP is associated with a 1.921% increase in the prevalence of CRD. This effect remains statistically significant in the short term, demonstrating that CRD increases by about 0.752% as a result of increasing AP by one standardised unit. The findings indicate that higher concentrations of CO_2 emissions, $PM_{2.5}$, and NO_2 increased the prevalence of CRD in Saudi Arabia, which is consistent with literature (Rojas-Rueda et al. 2021; Alyami et al. 2025; Halpin et al. 2025; Mebrahtu et al. 2023; de Miguel-Díez et al. 2019; Safiri et al. 2022). For example, one study confirms that sustained exposure to $PM_{2.5}$ significantly raises the risk of developing COPD (Xing et al. 2025). Alman et al. (2016) also indicated that the likelihood of CRD prevalence is significantly linked with the higher levels of $PM_{2.5}$ in the United States. Furthermore, Huang et al. (2021) suggested that long-term exposure to air pollutants increases the risk of CRD and airway inflammation and reduces lung function. In line with prior findings (Xing et al. 2025). A simulation-based study in the Alasha region of Saudi Arabia suggests that PM10 has a modest impact on respiratory health. At the same time, higher same-day $PM_{2.5}$ levels are associated with increased respiratory visits (Al-hajji and Al-Qahtani 2025). Nevertheless, Alangari et al. (2015) highlighted that sandstorms with higher $PM_{2.5}$ concentrations did not contribute to acute asthma episodes in Riyadh.

Regarding the impact of climate change, the analysis reveals a statistically significant relationship between HI and CRD. In the long term, a 1°C increase in HI is associated with a 0.96% increase in the prevalence of CRD. However, this effect is not artistically significant in the short term. In line with our findings, a systematic literature review and meta-analysis of studies in Ethiopia indicated that high-heat conditions can directly affect individuals with respiratory ailments: inhalation of hot air can cause bronchoconstriction and airway irritation, exacerbating conditions of CRDs, such as asthma and COPD (Andualem et al. 2025). Lin et al. (2009) reported that the risk of COPD hospitalisation rose by 7.6%, due to a 1°C increase in temperature above 29°C, which is also congruent with several previous studies (D'Amato et al. 2014; Mirsaeidi et al. 2016; Tran et al. 2023; Hansel et al. 2016; Margolis 2021; Silveira et al. 2023). A systematic literature review has shown that the increase in extreme weather events elevates the incidence of asthma, particularly among children and women subjects (Makrufardi et al. 2023). Previous research has also suggested that a 1 °C rise in global temperature results in an approximately 5% increase in asthma risk, particularly among older adults or in high-latitude regions (Cong et al. 2017; Xu et al. 2023). Therefore, our findings confirm the existing literature, which suggests that an increasing HI reflects the broader trend of a warming climate, correlated with a higher prevalence of CRD in the long term.

The coefficient of the dummy indicator for the year 2009 is statistically significant, which corresponds to the major dust storm that occurred in March of the same year, which caused a marked increase in air pollution and a higher rate of respiratory disease infections (Notaro et al. 2013; Alharbi et al. 2013).

4. CONCLUSION

The present study disentangled the relationship between environmental factors and public health in Saudi Arabia, demonstrating that elevated levels of air pollution and climate change indicators elevate the prevalence of CRD in the country. The study presented a novel finding in the literature by employing a time series model using an ARDL estimator on Saudi public health and environmental data, which helps identify the amount of change in AP and HI over both the long and short terms.

The current study helps formulate or adapt policies to minimise the negative effects of AP and climate change on the prevalence of CRD in Saudi Arabia. Such policies could include air quality management and controlling greenhouse gas emissions by encouraging green industrial activities. Therefore, policymakers could benefit from this finding and contribute to achieving the ambitious "Saudi Vision 2030", established in 2016, that aims to improve health and foster green initiatives.

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Appendix

Table A1: Results of PCA for air pollution.

Eigenvalues					
No.	Value	Difference	Proportion	Cumulative Value	Cumulative Proportion
Comp-1	2.4250	2.0597	0.8083	2.4250	0.8083
Comp-2	0.3653	0.1558	0.1219	2.7904	0.9301
Comp-3	0.2096	---	0.0699	3.00	0.9999
Eigenvectors (loadings):					
Variable	PC1	PC2	PC3		
CO2	0.5834	0.4827	0.6532		
PM2.5	0.5559	0.8236	0.1121		
NO2	0.5921	0.2977	0.7489		