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ORIGINAL ARTICLE

Association of environmental and behavioural factors with cardiovascular disease mortality

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Abstract

Aims Recognizing the rising concern of environmental impacts on health, the study aims to explore how specific environmental factors such as air pollution, humidity, and temperature variations contribute to the prevalence of cardiovascular disease (CVD) mortality, emphasizing the role of air quality, climate variables, and lifestyle factors in the disease mortality specifically.

Methods and results Analysis of province-level data on CVD mortality in Turkey from 2010 to 2019, assessing the correlations with environmental and lifestyle factors like particulate matter, sulfur dioxide, meteorological variables, and smoking and alcohol consumption. The study employs the SAS TRAJ procedure and Ordinal Logistic Regression for statistical analysis. The multiplicity correction was done through Benjamini–Hoechberg false discovery rate (FDR) approach. As expected, both smoking and alcohol consumption were found to be significantly associated with CVD mortality (odds ratio (OR): 1.10, 95% CI: 1.08, 1.11, P-value < 0.0001). While median Air Pressure and Humidity were among the most significant markers with OR of 1.10 indicating an increasing CVD mortality, their variability metrics such as coefficient of variation (CV) showed significant protective effects with OR of 0.37 and 0.89, respectively. Temperature and its variability seemed to be protective overall.

Conclusions Our research highlights the significant influence of environmental factors on cardiovascular health, especially air pressure and humidity, beyond the known factors such as smoking and alcohol consumption. These findings suggest the need for comprehensive public health strategies that address both environmental and lifestyle risk factors to effectively reduce the burden of cardiovascular diseases.

Keywords Air pollution; Cardiovascular diseases; CVD mortality; Environmental markers; Epidemiology; Public health

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Introduction

The circulatory system, including the cardiovascular system, is a vital network of organs and vessels responsible for transporting oxygen, nutrients, and waste products throughout the body. This system's efficient functioning is crucial for maintaining overall health. However, the prevalence of circulatory system diseases, such as coronary artery disease, heart failure, stroke, peripheral artery disease, and hypertension, poses significant health challenges globally and regionally. The World Health Organization (WHO) identifies cardiovascular diseases (CVD) as the leading cause of death worldwide, accounting for approximately 32% of all global deaths.[1] In the United States, cardiovascular diseases contribute to around 836 546 deaths annually.[2]

Globally, CVDs, encompassing heart, vascular brain diseases, and blood vessel diseases, are responsible for over 17.9 million deaths per year.[1] These diseases are influenced by various risk factors, including lifestyle choices like smoking, physical inactivity, and unhealthy diets, as well as medical conditions such as diabetes, high blood pressure, and high cholesterol.[3] The management and prevention of these diseases are therefore pivotal in reducing the global health burden. In September 2011, WHO announced a global action plan to reduce the risk of premature death from cardiovascular diseases by 25% by 2025 (The WHO Global NCD action plan 2013–2020). Following the WHO target, American Heart Association and World Heart Federation published a modeling study called 'Heart of 25 by 25'.[4] They point out that if the rising trend in risk factors of premature deaths continues, majority of the countries would fall short of the WHO's goal of a 25% reduction. However, giving the fact that the majority of cardiovascular diseases are preventable, they emphasized that if a number of risk factors could actually be modified, it would lead to dramatic changes making possible to reach the WHO goal. Therefore, it is crucial to understand risk factors to aggressively address them by population-wide strategies.

Environmental factors are one of the major preventable mortality causes which constituted almost 24% of deaths globally in 2016 according to WHO.1 Recent studies have highlighted the impact of environmental factors, particularly air pollution, on circulatory system diseases. The Global Burden of Disease (GBD) study estimates that approximately 9.0 million total deaths are directly attributable to environmental pollution, with a significant portion due to ambient and household air pollution.[5,6] The role of nonchemical environmental factors, such as temperature, noise, and socioeconomic factors, in exacerbating cardiovascular events has also been recognized.[6]

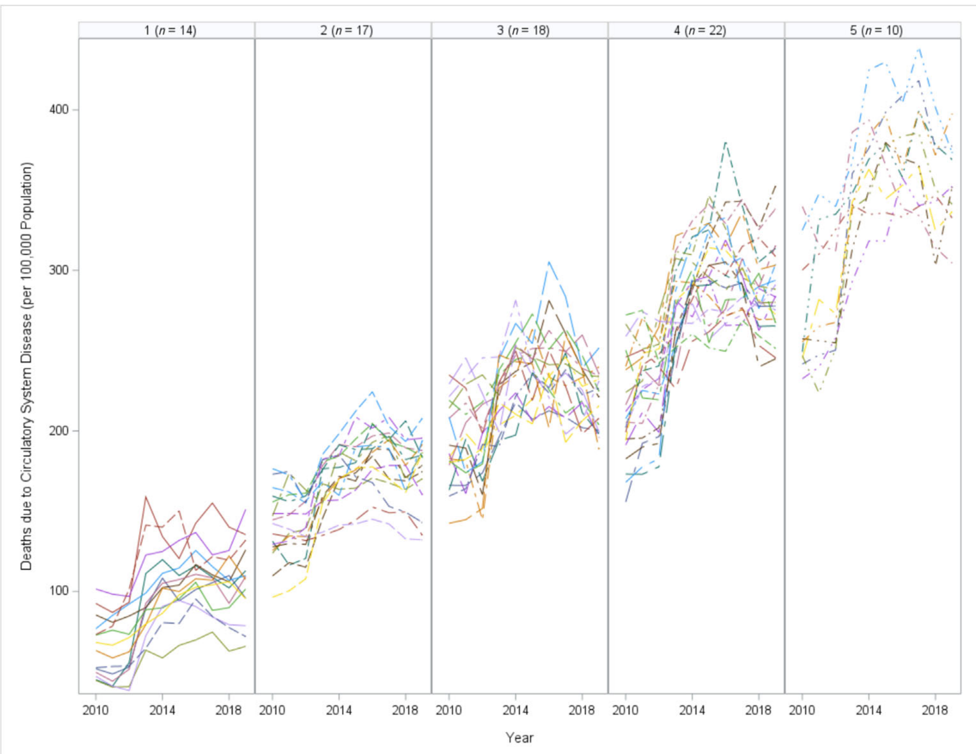
The sources of air pollution, both natural phenomena and human activities, significantly contribute to the global burden of circulatory diseases. The adverse health effects of particulate matter (PM), particularly <2.5 μm in size (PM 2.5) and ultrafine particles, have been well-documented in epidemiological studies.[7-10] PM10 and PM2.5 have been associated with adverse health outcomes for respiratory and cardio-cerebrovascular diseases.[11] According to WHO, almost the entire global population (99%) breathes unhealthy levels of PM.1 Studies suggest that the health risks of PM10 are linked to its carbonaceous fraction and metals.[12,13] Furthermore, the impact of temperature variations on cardiovascular diseases has been extensively studied, revealing a correlation between extreme temperatures and increased mortality rates.[14-17]

Effective management and preventive strategies must consider these broader environmental determinants to mitigate the impact of circulatory system diseases. This study aims to provide comprehensive insights into the change profiles of cardiovascular disease (CVD) mortality and the associations of preventable risk factors with CVD, employing trajectory analyses and regression models.

Materials and methods

The province-level CVD death trajectories are the primary outcome variable of this study. The annual deaths due to CVD for 81 provinces of Turkey were obtained for years 2010 through 2019. The annual death rates were computer--based on the

Figure 1 Profiles of circulatory system mortality by SAS TRAJ procedure.



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province population for each year and expressed as deaths per 100,000 population.

The list of predictors includes particulate matter-10 (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), air pressure, humidity, rainy days in a year, maximum-average-minimum temperatures, wind speed as well as total sunlight, sun radiation, and electromagnetic field. These markers were represented as the medians of the measurements between 2010 and 2019. To investigate the impact of the environmental variations on our response variables, we also defined variation markers as the standard deviations and coefficient of variables of these markers from 2010 to 2019. Our predictors included smoking, alcohol consumption, and exposure to second-hand smoke.

To describe the change of CVD mortality over time, we employed the SAS TRAJ procedure developed by Jones et al.[18] By comparing the goodness of fit statistics, a three-level categorization was found to best describe the change profiles. As these change-profiles are of ordered-nature (e.g., low, intermediate, and high), we employed an ordinal logistic regression approach modeling the likelihood of being in a higher ordinal category for each unit-increase in the predictor.

A total of 33 markers were investigated. To control for the multiple-testing issue, we followed the Benjamini–Hochberg false discovery rate (FDR) technique.[19] For a better graphical representation of the significant predictors on the same panel, we standardized both the response variable as well as the predictor to have mean zero and variance one. All analyses were conducted using SAS (R) Version 9.4 (Cary, North Carolina, USA).

Results

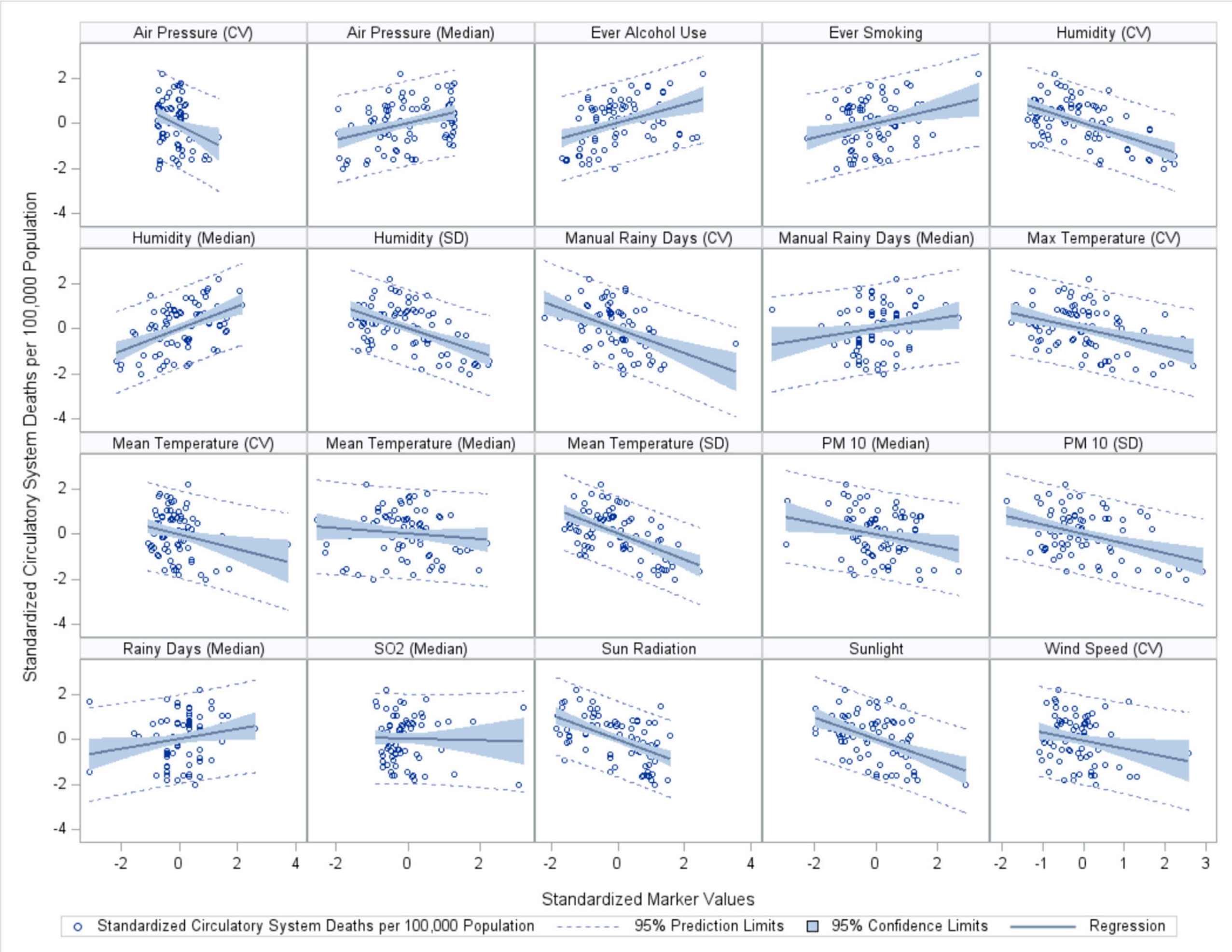
In the assessment of province-specific CVD mortality profiles over a period from 2010 to 2019, we identified 5 main trajectories as depicted by *Figure 1*, showing an ordinal level of increase in the CVD mortality burden.

The comprehensive results of the study, detailed in *Table 1* and illustrated in *Figure 2*, reveal the intricate associations between a range of environmental and lifestyle factors and cardiovascular disease (CVD) mortality. The study investigates over 25 significant predictors, each analysed in terms of both central tendency (median) and variability (coefficient of variation [CV] and standard deviation [SD]). These predictors include factors like air pressure, humidity, rainy days, and various temperature measures, along with lifestyle factors such as alcohol and smoking habits. Positive associations (indicating increased CVD mortality risk) are found with

Table 1 Predictors significantly associated with cardiovascular disease mortality in univariable models

Predictor	OR (95% CI)	*P*-value	FDR Corrected *P*-value
Air pressure (CV)	0.37 (0.17, 0.81)	0.0127	0.014806
Air pressure (median) (per 10 units)	1.10 (1.08, 1.12)	<0.0001	2.86E-18
Ever alcohol use	1.10 (1.08, 1.11)	<0.0001	4.53E-31
Ever smoking	1.10 (1.08, 1.13)	<0.0001	3.33E-17
Exposure to smoke at home	0.92 (0.90, 0.95)	<0.0001	1.354E-9
Humidity (CV)	0.89 (0.87, 0.90)	<0.0001	4.96E-56
Humidity (median)	1.11 (1.09, 1.13)	<0.0001	2.44E-37
Humidity (SD)	0.79 (0.77, 0.82)	<0.0001	2.27E-47
Manual rainy days (CV)	0.96 (0.95, 0.97)	<0.0001	1.55E-23
Manual rainy days (Median)	1.18 (1.12, 1.24)	<0.0001	2.67E-10
Manual rainy days (SD)	0.48 (0.40, 0.58)	<0.0001	8.68E-14
Maximum temperature (CV)	0.93 (0.91, 0.94)	<0.0001	2.7E-22
Maximum temperature (SD)	0.64 (0.60, 0.70)	<0.0001	3.59E-27
Mean temperature (CV)	0.99 (0.98, 0.99)	<0.0001	4.86E-7
Mean temperature (median)	0.91 (0.87, 0.95)	<0.0001	9.379E-6
Mean temperature (SD)	0.38 (0.33, 0.43)	<0.0001	4.25E-55
Minimum temperature (CV) (per 1000 units)	1.08 (1.04, 1.12)	<0.0001	0.000065
Minimum temperature (median)	0.95 (0.92, 0.98)	0.0006	0.000761
Minimum temperature (SD)	0.42 (0.37, 0.48)	<0.0001	4.61E-41
Particulate matter-10 (CV)	0.99 (0.98, 0.99)	<0.0001	0.000022
Particulate matter-10 (median)	0.97 (0.96, 0.98)	<0.0001	6.79E-13
Particulate matter-10 (SD)	0.87 (0.85, 0.89)	<0.0001	7.13E-36
Rainy days (CV)	0.92 (0.91, 0.93)	<0.0001	1.2E-45
Rainy days (median)	1.22 (1.16, 1.28)	<0.0001	5.71E-15
Rainy days (SD)	0.68 (0.61, 0.77)	<0.0001	2.35E-10
SO_2 (median)	0.98 (0.97, 0.99)	0.0005	0.000671
SO_2 (SD)	0.97 (0.96, 0.99)	0.0004	0.00048
Sun radiation (per 10 units)	0.90 (0.89, 0.91)	<0.0001	2.75E-51
Sunlight (per 50 units)	0.84 (0.82, 0.84)	<0.0001	1.33E-40
Total electromagnetic exposure (per 500 units)	0.95 (0.87, 0.98)	0.0127	0.014806
Wind speed (CV)	0.98 (0.97, 0.99)	<0.0001	0.000055
Wind speed (SD)	0.56 (0.32, 0.97)	0.0401	0.045128

Figure 2 Predictors significantly associated with circulatory system mortality.



several median-level environmental and lifestyle factors. In contrast, negative associations (suggesting a protective effect) are noted with the variability in environmental conditions like air pressure and humidity.

This intricate analysis, supported by the representative 16 plots in *Figure 2*, emphasizes the complex and multifaceted nature of cardiovascular health, influenced by both steady-state and fluctuating environmental conditions, alongside individual lifestyle choices. The study's findings offer valuable insights for developing nuanced public health strategies and interventions aimed at reducing CVD mortality.

We have also constructed multivariable models controlling the effects of smoking and alcohol consumption and the results are provided in *Table* 2. These multivariable models suggest similar findings as in the univariable models suggesting that the association of the key environmental markers is independent of the smoking and alcohol consumption profiles of the provinces.

Discussions

The results of this study provide a comprehensive analysis of the factors influencing cardiovascular disease (CVD) mortality in Turkey over a decade (2010–2019). The study's findings are significant in understanding the complex interplay between environmental factors, lifestyle choices, and cardiovascular health. The identification of five main trajectories in province-specific CVD mortality profiles underscores the varying impact of these factors across different regions.

A key finding of this study is the significant association between various environmental factors and CVD mortality. The study highlights the role of air quality, as indicated by particulate matter (PM10), sulfur dioxide (SO2), and other pollutants, in influencing cardiovascular health. The negative associations found with the variability in environmental conditions like air pressure and humidity suggest that not just the levels of these factors but also their fluctuations are important in determining cardiovascular risk.

Table 2 Predictors significantly associated with cardiovascular disease mortality in multivariable models controlling for smoking and alcohol consumption

Predictor	OR (95% CI)	*P*-value	FDR corrected *P*-value
Air pressure (CV)	0.34 (0.16, 0.77)	0.0089	0.013245
Air pressure (median)	1.07 (1.05, 1.10)	<0.0001	2.115E-8
Exposure to smoke at home	0.91 (0.88, 0.93)	<0.0001	3.09E-12
Humidity (CV)	0.90 (0.89, 0.91)	<0.0001	1.22E-39
Humidity (median)	1.09 (1.08, 1.11)	<0.0001	1.41E-25
Humidity (SD)	0.82 (0.79, 0.84)	<0.0001	4.55E-32
Manual rainy days (CV)	0.96 (0.95, 0.97)	<0.0001	1.74E-23
Manual rainy days (median)	1.18 (1.12, 1.24)	<0.0001	3.61E-10
Manual rainy days (median)	1.22 (1.16, 1.29)	<0.0001	7.67E-13
Manual rainy days (SD)	0.51 (0.42, 0.62)	<0.0001	1.03E-10
Maximum temperature (CV)	0.94 (0.92, 0.96)	<0.0001	1.24E-11
Maximum temperature (median)	0.93 (0.89, 0.98)	0.0068	0.010508
Maximum temperature (SD)	0.70 (0.64, 0.76)	<0.0001	8.19E-16
Mean temperature (median)	0.85 (0.81, 0.89)	<0.0001	2.22E-11
Mean temperature (SD)	0.41 (0.35, 0.46)	<0.0001	9.7E-39
Minimum temperature (CV) (per 1000 unit)	1.10 (1.05, 1.14)	<0.0001	0.000064
Minimum temperature (median)	0.89 (0.86, 0.93)	<0.0001	1.377E-9
Minimum temperature (SD)	0.46 (0.41, 0.53)	<0.0001	1.01E-28
Particulate matter-10 (CV)	0.985 (0.98, 0.99)	0.0005	0.000831
Particulate matter-10 (Median)	0.98 (0.97, 0.98)	<0.0001	2.24E-9
Particulate matter-10 (SD)	0.89 (0.87, 0.91)	<0.0001	8.93E-21
Rainy days (CV)	0.93 (0.92, 0.94)	<0.0001	1.87E-38
Rainy days (median)	1.23 (1.17, 1.30)	<0.0001	1.58E-15
Rainy days (SD)	0.76 (0.67, 0.85)	<0.0001	0.000012
SO_2 (Median)	0.985 (0.98, 0.99)	0.0269	0.037221
SO_2 (SD)	0.97 (0.96, 0.99)	0.0008	0.001256
Sun radiation (per 10 units)	0.90 (0.89, 0.92)	<0.0001	1.23E-43
Sunlight (per 50 units)	0.82 (0.80, 0.84)	<0.0001	1.77E-44
Total electromagnetic exposure (per 500 units)	0.79 (0.73, 0.84)	<0.0001	5.22E-12
Wind speed (CV)	0.995 (0.98, 0.99)	0.0308	0.039669

The study underscores the impact of air quality, particularly PM10, on CVD mortality. This finding aligns with Brook et al.,[20] who discuss the negative health effects of air pollution. Furthermore, the study by Pope and Dockery (2006) provides further evidence on the health effects of fine particulate matter, reinforcing our findings on PM10. However, our study results suggest a protective association of median PM-10 levels, contrasting with the general consensus on the harmful effects of particulate matter,[21,22] which would need to be explored further in future prospective studies. Our analysis also suggests a possible threshold effect or regional variations in particulate matter composition that might influence its impact on health.[22]

Lifestyle factors such as smoking and alcohol consumption were also found to be significant predictors of CVD mortality. The positive associations with these factors align with existing literature, reinforcing the need for public health interventions focusing on lifestyle modifications.

The intricate nature of the associations found in this study indicates that public health strategies aimed at reducing CVD mortality should be multifaceted. Interventions need to address both environmental and lifestyle factors. Policies aimed at improving air quality, alongside campaigns promoting healthier lifestyles, could be effective in reducing the burden of cardiovascular diseases.

Epidemiologic evidence suggests that there is a strong U-shaped (or V-shaped) relationship between temperature and all-cause mortality. According to this hypothesis, mortality is typically very low in a mild temperature environment and progressively increases at extreme lower and higher outdoor temperatures.[14,23] In the boreal hemisphere, a greater effect of colder temperatures on mortality risk is observed in the more-southern regions, while a greater effect of warmer temperatures on mortality is reported in the more-northern regions.[24] Overall, these results indicate that the threshold temperature associated with lower mortality risk differs in according to the climate of a location and increases from cold to hot climates. Such evidence supports the hypothesis that there is an acclimation of humans in different weather conditions. In this study, we have shown that the variation in temperature represented through standard deviation and coefficient of variation was overall protective.

The strength of this study lies in its comprehensive approach, considering a wide range of environmental and lifestyle factors over a significant period. The use of advanced statistical methods, such as the SAS TRAJ procedure and ordinal logistic regression, adds robustness to the findings. However, the study is limited by its focus on a single country, which may affect the generalizability of the results. Additionally, the observational nature of the study means that causal relationships cannot be definitively established. Our available data was also limited for some of the environmental markers such as CO, which was available only for 50 of the 81 provinces, which greatly limited their use in our univariable and definitely in our multivariable models.

Future research could focus on longitudinal studies in diverse geographical settings to validate these findings. Investigating the mechanisms through which environmental factors influence cardiovascular health could also provide deeper insights. Additionally, exploring the effectiveness of specific public health interventions based on these findings would be valuable.

This study contributes significantly to our understanding of the factors influencing cardiovascular disease mortality. The findings highlight the need for comprehensive public health strategies that address both environmental and lifestyle factors to effectively combat the burden of cardiovascular diseases.

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Conflict of interest

The authors have no relevant conflict of interest.

Data availability statement

As the death records data utilized in this report were granted access only to the corresponding author, we do not have the permission to share these data components; however, we can share the environmental data upon request.

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