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Research Article

The Relationship Between High Altitude and Cardiovascular Mortality Rates

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Abstract

Aim: This study aims to determine whether there is a significant correlation between altitude and cardiovascular disease (CVD) mortality rates using publicly available data from 81 provinces in Türkiye.
Material and Method: The data in this study were obtained from publicly available provincial data of the Turkish Statistical Institute (TUIK). The data were analyzed using Spearman correlation and linear regression via SPSS 25.0. The significance threshold was set at $p < 0.05$.
Results: A statistically significant negative correlation was observed between altitude and cardiovascular mortality rates ($r = -0.220$, $p = 0.048$). Regression analysis, however, indicated that altitude alone explained only 1.9% of the variance in CVD death rates (Adj. $R^2 = 0.019$, $p = 0.224$).
Conclusion: While there is a weak but statistically significant inverse relationship between altitude and cardiovascular mortality rates in Türkiye, altitude alone is not a strong predictor. Further multifactorial studies are needed to elucidate additional environmental and socioeconomic contributors.

Keywords: Altitude, Cardiac, Vascular Diseases, Mortality

INTRODUCTION

Cardiovascular diseases (CVD) encompass all disorders affecting the heart and vascular system and include many clinical conditions such as ischemic heart disease, stroke, hypertension-related diseases, heart failure, and peripheral artery diseases. According to 2023 data from the World Health Organization (WHO), this group of diseases causes approximately 17.9 million deaths worldwide each year, ranking first among global causes of mortality. Approximately 85% of these deaths occur due to major cardiovascular events such as myocardial infarction and stroke (1). In this context, understanding and preventing the causes of CVD is of great importance for public health policies.

In recent years, studies on the environmental determinants of cardiovascular disease mortality have increased. The effects of factors such as air pollution, climate conditions, noise levels, socioeconomic factors, and the altitude of settlements on health have increasingly begun to be investigated (2,3,5). Among these variables, the possible effects of living at high altitude on cardiovascular health are particularly noteworthy. High-altitude environments are physiologically characterized by low atmospheric pressure and reduced oxygen density. Although this creates hypoxic stress in the body, some studies suggest that this stress may produce cardioprotective effects through adaptive physiological responses over the long term (6). Evidence indicating that living at high altitude may have protective effects has been explained through various mechanisms. Chronic hypoxia increases the production of erythropoietin, raising the number of red blood cells and thereby enhancing oxygen-carrying capacity. In addition, some studies have shown that blood pressure regulation changes at high altitude, endothelial functions are altered, and metabolic efficiency improves (7). It is also suggested that socioecological factors such as lower obesity rates, decreased physical inactivity, and reduced air pollution in high-altitude regions may indirectly reduce the risk of CVD (8,9).

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However, there is no consensus on the health effects of high altitude. Some studies have reported that hypoxia-related complications may increase—especially at very high altitudes (>2,500 m) or in individuals with chronic conditions—and that altitude may even be a risk factor for events such as heart attack or stroke (10,11). Therefore, it should not be overlooked that the effects of altitude interact with many factors such as an individual's health status, genetic predispositions, and the effectiveness of regional health systems.

Türkiye presents a unique geographical structure in the context of these discussions. The country's topography varies significantly from east to west and north to south, and there are considerable altitude differences between its provinces (12). For instance, while provinces such as Erzurum, located in the Eastern Anatolia Region, are situated at altitudes exceeding 1,800 meters, major cities such as Istanbul, Izmir, and Adana are located near sea level. In addition to this topographical diversity, there are substantial disparities in socioeconomic development and access to healthcare services across Türkiye's provinces. For these reasons, Türkiye offers a suitable natural laboratory for examining the relationship between altitude and cardiovascular mortality at the ecological level.

The main purpose of this study is to investigate whether there is a statistically significant relationship between the average altitude of the provinces in Türkiye and mortality rates due to cardiovascular diseases. Secondly, the study aims to assess how strongly altitude can predict the differences in cardiovascular mortality between provinces. In this context, correlation analyses will be conducted between the altitude variable and mortality rates, and the explanatory power of altitude will be evaluated using the simple linear regression method. The results of the study will also contribute to the ongoing discussion of whether altitude alone is a sufficient explanatory factor or whether it should be evaluated alongside other environmental and socioeconomic variables.

MATERIAL AND METHOD

This ecological study was conducted using publicly available provincial data from the Turkish Statistical Institute and national health databases (13). The dataset includes 81 provinces, their average altitudes (in meters), and proportional mortality rates due to cardiac and vascular diseases.

All data were analyzed in a computer environment using SPSS 25.0 package program. In cases where normality conditions could not be provided in determining the relationship between continuous variables, Spearman Correlation test was used. Correlation coefficient interpretation was evaluated as (Weak = 0.01-0.49; Medium = 0.50-0.69; High = 0.70-1.00) (14). Regression Analysis was performed to evaluate the effect of altitude in predicting cardiovascular disease mortality rate. Autocorrelation was evaluated with Durbin-Watson in regression analyses. In the study, statistical significance level was accepted as $p < 0.05$.in significance tests.

RESULTS

The dataset included provinces ranging in altitude from 3 meters (İzmir, Kocaeli) to 1,890 meters (Erzurum) (Table 1).

Table 1. Provinces according to altitude

Province	Altitude	Mortality Rate	Province	Altitude	Mortality Rate	Province	Altitude	Mortality Rate
Erzurum	1890	0.340	Kütahya	950	0.391	Kırklareli	209	0.360
Ardahan	1870	0.363	Mardin	938	0.357	Bursa	155	0.404
Kars	1768	0.317	Tunceli	914	0.353	Osmaniye	150	0.314
Hakkari	1748	0.312	Uşak	906	0.367	Düzce	146	0.354
Van	1727	0.291	Siirt	902	0.386	Balıkesir	139	0.447
Ağrı	1640	0.289	Iğdır	860	0.382	İstanbul	120	0.311
Bayburt	1556	0.335	Ankara	850	0.338	Hatay	85	0.126
Bitlis	1500	0.353	Gaziantep	843	0.287	Manisa	74	0.395
Muş	1404	0.313	Çorum	801	0.420	Aydın	64	0.388
Şırnak	1350	0.337	Kastamonu	798	0.399	Edirne	42	0.400
Yozgat	1301	0.404	Eskişehir	782	0.319	Antalya	39	0.372
Sivas	1285	0.379	Bolu	725	0.378	Sakarya	31	0.358
Nevşehir	1250	0.346	Çankırı	723	0.389	Adana	23	0.387
Niğde	1229	0.353	Kırıkkale	700	0.430	Bartın	19	0.367
Erzincan	1214	0.384	Diyarbakır	670	0.324	Sinop	12	0.379
Gümüşhane	1153	0.338	Adıyaman	669	0.109	Tekirdağ	10	0.341
Bingöl	1151	0.358	Tokat	640	0.391	Trabzon	10	0.363
Kayseri	1071	0.340	Kilis	640	0.278	Zonguldak	10	0.367
Elazığ	1067	0.348	Muğla	625	0.346	Mersin	6	0.344
Karaman	1038	0.350	Kahramanmaraş	568	0.135	Rize	6	0.362
Isparta	1035	0.394	Batman	525	0.352	Giresun	5	0.387
Afyonkarahisar	1021	0.417	Artvin	520	0.384	Yalova	5	0.328
Konya	1016	0.364	Şanlıurfa	518	0.329	Samsun	4	0.427
Kırşehir	978	0.456	Bilecik	500	0.391	Çanakkale	3	0.502
Aksaray	975	0.366	Amasya	392	0.427	Kocaeli	3	0.331
Malatya	964	0.292	Denizli	354	0.397	Ordu	3	0.366
Burdur	950	0.402	Karabük	258	0.421	İzmir	2	0.356

Proportional mortality rates due to cardiovascular diseases ranged from 0.109 (Adıyaman) to 0.502 (Çanakkale) (Table 2).

Table 2. Order of highest to lowest mortality rate from cardiovascular disease

Province	Altitude	Mortality Rate	Province	Altitude	Mortality Rate	Province	Altitude	Mortality Rate
Çanakkale	3	0.502	Iğdır	860	0.382	Muğla	625	0.346
Kırşehir	978	0.456	Sivas	1285	0.379	Mersin	6	0.344
Balıkesir	139	0.447	Sinop	12	0.379	Tekirdağ	10	0.341
Kırıkkale	700	0.430	Bolu	725	0.378	Erzurum	1890	0.340
Samsun	4	0.427	Antalya	39	0.372	Kayseri	1071	0.340
Amasya	392	0.427	Bartın	19	0.367	Gümüşhane	1153	0.338
Karabük	258	0.421	Zonguldak	10	0.367	Ankara	850	0.338
Çorum	801	0.420	Uşak	906	0.367	Şırnak	1350	0.337
Afyonkarahisar	1021	0.417	Aksaray	975	0.366	Bayburt	1556	0.335
Yozgat	1301	0.404	Ordu	3	0.366	Kocaeli	3	0.331
Bursa	155	0.404	Konya	1016	0.364	Şanlıurfa	518	0.329
Burdur	950	0.402	Trabzon	10	0.363	Yalova	5	0.328
Edirne	42	0.400	Ardahan	1870	0.363	Diyarbakır	670	0.324
Kastamonu	798	0.399	Rize	6	0.362	Eskişehir	782	0.319
Denizli	354	0.397	Kırklareli	209	0.360	Kars	1768	0.317
Manisa	74	0.395	Sakarya	31	0.358	Osmaniye	150	0.314
Isparta	1035	0.394	Bingöl	1151	0.358	Muş	1404	0.313
Bilecik	500	0.391	Mardin	938	0.357	Hakkâri	1748	0.312
Kütahya	950	0.391	İzmir	2	0.356	İstanbul	120	0.311
Tokat	640	0.391	Düzce	146	0.354	Malatya	964	0.292
Çankırı	723	0.389	Bitlis	1500	0.353	Van	1727	0.291
Aydın	64	0.388	Niğde	1229	0.353	Ağrı	1640	0.289
Adana	23	0.387	Tunceli	914	0.353	Gaziantep	843	0.287
Giresun	5	0.387	Batman	525	0.352	Kilis	640	0.278
Siirt	902	0.386	Karaman	1038	0.350	Kahramanmaraş	568	0.135
Artvin	520	0.384	Elazığ	1067	0.348	Hatay	85	0.126
Erzincan	1214	0.384	Nevşehir	1250	0.346	Adıyaman	669	0.109

Spearman correlation analysis revealed a statistically significant negative relationship between altitude and cardiovascular mortality rates ($r = -0.220$, $p = 0.048$), suggesting that provinces at higher altitudes tended to have lower CVD death rates (Figure 1).

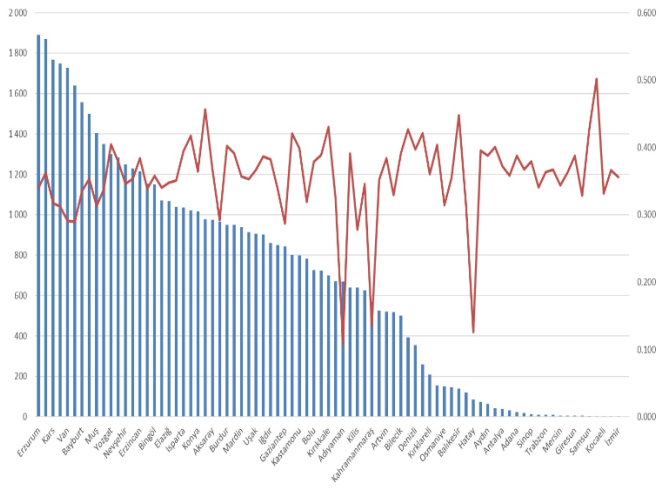

Figure 1. Scatter plot of altitude vs. cardiovascular mortality rates.

In the regression model established to evaluate the factors predicting cardiovascular disease death rates, no autocorrelation was detected (Durbin-Watson = 2.229). It was observed that the model explained 1.9% of the variance in cardiovascular mortality rates; however, the model was not statistically significant ($F = 1.505(1)$; Adj. $R^2 = 0.019$; $p = 0.224$) (Table 3).

Table 3. Linear regression results.

Variable	B	Std. Error	Beta	t	p	95.0% CI	
						Lower	Upper
(Constant)	0.367	0.011		34.082	<0.001	0.345	0.388
Altitude	-1.51×10^{-6}	0.001	-0.137	-1.227	0.224	-1961.51×10^{-6}	1958.49×10^{-6}

DISCUSSION

This study shows a statistically significant inverse relationship between altitude and cardiovascular mortality in Turkish provinces. These findings are consistent with previous studies suggesting that high-altitude environments may have a protective effect on cardiovascular health (15,16).

However, the weak correlation and insignificant regression results emphasize that altitude is only one of many environmental and social determinants of cardiovascular mortality. According to TÜİK data, cardiovascular diseases are the leading cause of death in Türkiye and rank first among all causes (13). Therefore, all conditions that may be associated with cardiovascular diseases should be investigated. Cardiovascular diseases can be influenced by many biological, psychological, and environmental factors (17,18). Access to healthcare, dietary habits, socioeconomic status, air pollution levels, and genetic predisposition may all play crucial roles (19,20). Future studies should include multivariate models that integrate additional demographic, behavioral, and environmental variables.

The reasons for lower cardiovascular mortality rates at higher altitudes may be explained by a combination of physiological, environmental, and lifestyle factors. At high altitudes, atmospheric pressure and oxygen concentration decrease, resulting in hypoxia (low oxygen levels). The body develops a series of adaptive responses when exposed to hypoxia. Hypoxia stimulates the release of the hormone erythropoietin, which increases the production of red blood cells. This enhances the oxygen-carrying capacity of the blood, allowing more oxygen to reach the tissues. Chronic hypoxia causes the coronary arteries to dilate and new capillaries to form, encouraging more oxygenated blood flow to the heart muscle. Cells also optimize their energy production processes under hypoxic conditions, increasing their efficiency in oxygen use. These adaptations may protect against cardiovascular disease by improving the heart's ability to cope with hypoxic stress (21).

A lower prevalence of obesity and metabolic syndrome has been observed in individuals living at high altitudes (22). This may be partly attributable to the increased basal metabolic rate and appetite suppression associated with high-altitude living. Reduced obesity rates also contribute to lower cardiovascular risk factors such as hypertension, type 2 diabetes, and dyslipidemia. Individuals living at higher altitudes have been reported to have lower total cholesterol and LDL (low-density lipoprotein) levels and higher HDL (high-density lipoprotein) levels (23,24). This favorable lipid profile contributes to a reduced risk of atherosclerosis and, therefore, to the prevention of cardiovascular disease. Geographic conditions and lifestyle at higher altitudes may also encourage individuals to lead more active lives. Increased physical activity improves cardiovascular health, lowers blood pressure, and reduces overall cardiovascular risk factors (25,26).

Air pollution may increase the risk of cardiovascular disease by inducing oxidative stress and inflammation (27). Generally, air pollution levels are lower at higher altitudes. Reduced pollution may mitigate cardiovascular risk by decreasing chronic inflammation and oxidative stress. Additionally, the duration and intensity of sunlight exposure increase at higher altitudes, which may positively affect cardiovascular health by boosting vitamin D synthesis. Vitamin D deficiency has been associated with hypertension and other cardiovascular risk factors (28). Communities living at higher altitudes may also have stronger social ties and support systems, which can reduce stress and, in turn, cardiovascular risk (29).

However, living at high altitudes may offer potential benefits as well as potential disadvantages in terms of cardiovascular risk. Many provinces at high altitudes in Türkiye also overlap with regions characterized by low socioeconomic development, limited access to healthcare, and lower education levels (30). Socioeconomic disadvantage is a significant determinant that affects both the burden of disease and the ability to benefit from available healthcare services. Therefore, these populations may still be at greater risk for cardiovascular mortality (31). Ignoring this complex structure when evaluating altitude in isolation may lead to misleading interpretations. Although air pollution levels are generally lower in high-altitude regions, this generalization may not apply to all provinces. For instance, local factors such as solid fuel use in rural areas may negatively impact air quality.

Eating habits also vary by region (32). In some high-altitude areas, animal fat and salt consumption may be higher, increasing the risk of hypertension and atherosclerosis. Conversely, in other provinces, traditional diets rich in fiber and low in processed foods may provide protective effects against cardiovascular disease (33).

There are some limitations to our study. Variables such as demographic (age distribution, gender ratio), socioeconomic (income level, education level), healthcare access, lifestyle factors (smoking, exercise, diet), environmental variables (air quality, food security), and genetic predispositions should all be evaluated together. The study is cross-sectional in nature; thus, a causal relationship between altitude and cardiovascular mortality cannot be established. Mortality data obtained from national statistics may contain errors due to regional differences in reporting or classification. In future research, the use of longitudinal, individual-level data and more comprehensive models could help overcome these limitations and provide more accurate insights.

CONCLUSION

There exists a weak but statistically significant inverse correlation between altitude and cardiovascular mortality in Türkiye. However, altitude alone does not adequately explain the variability in mortality rates across provinces. Lower cardiovascular disease-related mortality at higher altitudes is likely attributable to a combination of physiological adaptations to hypoxia, healthier metabolic profiles, increased physical activity, lower air pollution, and other environmental and lifestyle factors. Given the complexity of these relationships and individual-level differences, more definitive conclusions require further research. These findings suggest that public health policies should consider a broader range of regional factors when addressing the burden of cardiovascular disease.

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