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Why Do People Living at Higher Altitude Influence Death Rates for Selected Diseases and Conditions? An Ecologic Study Involving US Counties

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Abstract

Objective: Higher altitude has been associated with lower death rates for specific causes. This study will measure the association between altitude and selected causes of death and consider the effect other natural environmental factors have on these associations.

Methods: An ecologic study design involving 3,108 counties was used. Environmental variables included altitude and average daily sunlight, maximum air temperature, PM2.5, and precipitation. Age-adjusted mortality rates were considered for several causes of death.

Results: Counties with higher altitude have lower mortality rates for all causes, heart disease, cerebrovascular disease, tobacco-related cancer, non-tobacco-related cancer, and Alzheimer's disease, and higher for suicide and accidents. Diabetes and pneumonia/influenza are not associated with altitude. Counties at ≥ 2500 meters compared with < 500 meters have 6.05% higher sunlight, 30.47% lower air temperature, 55.53% lower PM2.5, and 49.50% lower precipitation. County-level mean mortality rates were 35.86% lower for all causes, 43.16% lower for heart disease, 35.67% lower for cerebrovascular disease, 51.47% lower for tobacco-related cancer, 25.14% lower for non-tobacco-related cancer, and 39.13% lower for Alzheimer's disease, and 93.89% higher for suicide. For accidents, the mean mortality rate was 30.97% higher through 2000-2499 meters, but the rates declined thereafter. Mean mortality rates are almost the same in the two altitude groups for pneumonia/influenza.

Conclusion: In adjusted models accounting for the environmental variables, altitude, average daily maximum air temperature, PM2.5, and precipitation positively correlate with each of the causes of death considered, whereas average daily sunlight negatively correlates with the causes of death.

Key words: *Altitude; Ambient air temperature; Mortality; PM2.5; Precipitation; Sunlight*

Introduction

Mortality rates are influenced by social and economic factors, lifestyle behaviors, clinical care, genetics, and the (industrial, social, and natural) environment. As part of the natural environment, higher altitude living has been associated with lower mortality rates for all causes [1]; heart disease and stroke [2-5]; cancer [6-8]; diabetes [9]; and Alzheimer's disease. [10] On the other hand, it has also been associated with higher coronary obstructive pulmonary disease, [3] suicide, [11-15] more severe pneumonia, [16] and accidents. [17,18]

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Various mechanisms have been proposed to explain the role of altitude with these outcome measures. In a study showing lower mortality from heart disease and stroke at higher altitude, the authors attributed it to climate conditions rather than classic cardiovascular disease risk factors. [5] It has also been suggested that high altitude living (and accompanying greater sun exposure) may contribute to cardiac health by promoting better vitamin D metabolism and new blood vessels, created as genes respond to lower oxygen. [3,19]

Researchers have hypothesized that physiological adaptive processes in response to hypoxia at higher altitude might explain lower mortality for a range of cancer types. [20] Living at higher altitude compared with less than 500 meters has been linked with better glucose homeostasis, which correlates with decreased odds of diabetes. [21] Air pollution may increase the risk for Alzheimer's disease. [22] Some researchers have also hypothesized that adapting to hypoxia can prevent dementia. [23]

It has been hypothesized that chronic hypobaric hypoxia (low blood oxygen associated with high altitude) promotes suicide by altering serotonin metabolism and brain bioenergetics. [24] Higher altitude living may increase the severity of pneumonia as the illness impairs the body's ability to absorb lower levels of oxygen into the bloodstream. [16] Finally, hypoxia associated with high altitude can cause fatigue, shortness of breath, and loss of consciousness, which may increase the chance of serious accidents. [18]

While the proposed mechanisms help us better understand associations between altitude and these health outcomes, some of the associations may be explained by natural environmental factors that are associated with altitude, like sunlight, ambient air temperature, fine particulate matter, and precipitation. The purpose of the current study is to measure the association between altitude and selected causes of death in the contiguous United States, as well as assess the influence other natural environmental factors have on these associations.

Methods

This study employed an ecologic design in which analyses are performed on county-level data, with 3,108 US counties or county equivalents (parishes, independent cities, etc.) across the contiguous United States represented.

Outcome Measures

Cause-specific mortality rates were obtained from the National Center for Health Statistics, 2013-2017. [25] Cause of death was coded according to the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10). [26] Specific causes considered in this study were all causes, heart disease, cerebrovascular disease, tobacco-related cancers (oral cavity and pharynx, esophagus, stomach, pancreas, respiratory system, cervix uteri, urinary bladder, and kidney and renal pelvis), non-tobacco-related cancers, diabetes, Alzheimer's disease, pneumonia/influenza, accidents, and suicide. Rates were age-adjusted to the 2000 US population. [27] Cause-specific rates were computed for individuals aged 40 years and older, except for all causes, accidents, and suicide, which were computed across the entire age span.

Natural Environmental Variables

Variables representing the natural environment included weighted altitude (m), average daily sunlight (KJ/m^2), average daily maximum air temperature (F), average fine particulate matter (ug/m^3), and average daily precipitation (mm). County-level estimates of altitude in meters above sea level were derived from the Geographic Names Information System from the United States Geological Survey. [28] To account for where most people in a county live, we use a weighted estimate of altitude, as done previously. [11] Sunlight, ambient air temperature, and precipitation for 2007-2011 were obtained through the North American Land Data Assimilation System, available through the CDC Wonder database [CDC WONDER [Internet]. [29] Average county-level daily density of fine particulate matter in micrograms per cubic meter (PM2.5) cover 2011-2014 and was obtained from the Environmental Public Health Tracking network. [30]

No ethical approval was sought or required for this study, which used publicly available datasets.

Statistical Techniques

County-level environmental variables and cause-specific age-adjusted mortality rates were described using statistical summary measures (mean, standard deviation, median, minimum, and maximum). Regression models estimated mean scores and mean differences for the counties according to altitude levels. Mean differences were compared among altitude groups using the Student-Newman-Keuls' multiple-range test. Simple and multiple regression models assessed associations between the cause-specific mortality rates and the environmental variables. The partial R^2 was also derived to measure the marginal contribution of each environmental variable when the other variables were already included in the model. Statistical significance was based on two-sided hypothesis tests at the 0.05 level. Statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC, USA, 2012). Graphs were created in Microsoft Excel, 2016.

Results

Summary measures of natural environmental and mortality variables across counties are presented for selected causes of death in Table 1. Measures range considerably across counties. Mean and median values tend to be similar for each of the variables (indicating the data are normally distributed), except for altitude, which is positively skewed.

	No.	Mean	SD	Median	Min	Max
Environmental Variables						
Weighted Altitude (m)	3106	414.32	487.36	263.09	-9.53	3471.44
Average Daily Sunlight (KJ/m^2)	3106	16398	1605	16103	12689	21191
Average Daily Max Air Temperature (F)	3106	65.38	9.28	64.83	38.36	87.47
Average Daily PM2.5	3108	9.02	1.97	9.40	3.00	19.70
Average Daily Precipitation (mm)	3106	2.72	0.91	2.98	0.24	7.07
Age-adjusted Causes of Mortality Rate						
All Cause	3105	818.72	147.72	808.40	257.60	1541.20
Heart Disease (Aged 40+)	3083	427.74	109.94	413.60	107.70	1280.40
Cerebrovascular Disease (Aged 40+)	2894	93.92	24.48	90.60	29.30	238.40
Tobacco-related Cancer (Aged 40+)	3031	183.40	41.72	183.40	41.50	539.70
Non Tobacco-related Cancer (Aged 40+)	3049	205.83	31.85	203.60	80.90	483.90
Diabetes (Aged 40+)	2727	58.43	27.09	53.40	13.40	315.20
Alzheimer's (Aged 40+)	2749	73.95	31.29	69.80	11.80	304.20
Pneumonia/Influenza (Aged 40+)	2544	40.18	16.97	36.60	9.50	235.40
Suicide	2347	17.94	7.08	16.60	5.10	68.20
Accidents	2961	56.53	18.40	53.70	16.70	185.80
Rates were age-adjusted to the US 2000 standard population per 100,000, 2013-2017. Tobacco-related cancers included oral cavity and pharynx, esophagus, stomach, pancreas, respiratory system, cervix uteri, urinary bladder, and kidney and renal pelvis. The summary natural environmental variable statistics have been reported previously (34).						

Table 1: *Descriptive measures of the county-level natural environmental and cause-specific mortality rates in the contiguous United States.*

Regression models were used to estimate means by altitude groupings for the selected environmental and cause-specific mortality. Average daily sunlight tends to increase with higher altitude and average daily maximum air temperature, PM2.5, and precipitation tend to decrease with higher altitude. Mortality rates for all causes, heart disease, cerebrovascular disease, tobacco-related cancer, non-tobacco-related cancer, and Alzheimer's disease tend to decrease with increasing altitude. Suicide and accident deaths tend to increase with higher altitude. Diabetes and pneumonia/influenza is not associated with altitude.

A comparison of the mean estimates in the ≥ 2500 meter group with the < 500 meter group yields a 6.05% increase for sunlight, 30.47% decrease for temperature, 55.53% decrease for PM2.5, and 49.50% decrease for precipitation. In addition, mean mortality rates decrease by 35.86% for all causes, 43.16% for heart disease, 35.67% for cerebrovascular disease, 51.47% for tobacco-related cancer, 25.14% for non-tobacco-related cancer, and 39.13% for Alzheimer's disease. Suicide rates increase by 93.89% and accident deaths increase 30.97% through 2000-2499 meters, but the rates decrease thereafter. Mean mortality rates are almost the same in the two altitude groups for pneumonia/influenza.

	Altitude < 500 meters	Altitude 500-999 meters	Altitude 1000-1499 meters	Altitude 1500-1999 meters	Altitude 2000-2499 meters	Altitude ≥ 2500 meters
	N = 2412	N = 367	N = 169	N = 88	N = 47	N = 23
Environmental Variables						
Average Daily Sunlight (KJ/m^2)	16271	16419	17236	17254	17725	17256
		149	965	983	1454	985
	A	A	B	B	B	B
Average Daily Max Air Temperature (F)	66.50	64.10	62.75	56.57	53.42	46.24
		-2.40	-3.75	-9.93	-13.08	-20.25
	A	A, B	B	C	D	E
Average Daily PM2.5	9.67	7.39	6.50	6.09	5.20	4.30
		-2.28	-3.17	-3.58	-4.47	-5.37
	A	B	C	C	D	E
Average Daily Precipitation (mm)	3.03	2.00	1.32	1.16	1.25	1.53
		-1.04	-1.71	-1.87	-1.79	-1.50
	A	B	C, D	C	C	D
Age-adjusted Causes of Death All Cause	833.96	795.89	763.26	728.22	724.95	534.93
		-38.07	-70.71	-105.74	-109.01	-299.03
	A	A, B	B, C	C	C	D
Heart Disease (Aged 40+)	440.15	407.51	384.19	348.55	323.65	250.17
		-32.64	-55.96	-91.60	-116.50	-189.99
	A	A, B	B, C	C, D	D	E
Cerebrovascular Disease (Aged 40+)	95.43	92.28	85.79	80.24	76.18	61.39
		-3.15	-9.64	-15.19	-19.25	-34.04
	A	A	A, B	B	B	C
Tobacco-related Cancer (Aged 40+)	190.15	174.44	151.74	134.19	116.60	92.28
		-15.70	-38.41	-55.96	-73.55	-97.87
	A	B	C	D	E	F
Non Tobacco-related Cancer (Aged 40+)	207.88	204.78	197.59	191.30	181.45	155.61
		-3.10	-10.29	-16.58	-26.43	-52.27
	A	A	A, B	B, C	C	D
Diabetes (Aged 40+)	57.33	67.91	64.60	53.59	59.37	40.24
		10.58	7.27	-3.74	2.04	-17.09
	A, B	B	B	A, B	A, B	A
Alzheimer's (Aged 40+)	74.67	76.08	66.28	63.22	57.56	45.45
		1.41	-8.40	-11.46	-17.11	-29.22
	A	A	A, B	A, B	A, B	B
Pneumonia/ Influenza (Aged 40+)	39.91	43.48	40.51	38.72	41.59	40.00
		3.57	0.59	-1.19	1.68	0.09
	A	A	A	A	A	A

Suicide	16.70	21.65	24.48	27.33	27.46	32.38
		4.96	7.78	10.63	10.77	15.69
	A	B	C	C	C	D
Accidents	54.69	65.39	62.63	60.90	71.63	54.73
		10.71	7.94	6.22	16.94	0.04
	A	B, C	A, C	A, C	B	A
Note: Mean difference scores are compared among groups using the Student-Newman-Keuls' (SNK) multiple-range test. Corresponding to the SNK test are capital letters, which identify whether significant differences exist in the estimates across the levels of altitude. There is a significant difference in means between groups if the letters differ. For example, with the all-cause mortality rate the difference in mean rates between the first and second altitude groups is significant, but there is no significant difference in mean rates between the second and third altitude groups.						

Table 2: *Means and mean differences across counties according to altitude grouping for natural environmental and cause-specific mortality rate variables in the contiguous United States.*

Regression slope and partial R-square estimates for the causes of death by the environmental variables are shown in Table 3.

	Unadjusted Models					**Adjusted Models for the Environmental Variables**				
Age-adjusted Causes of Death	Weighted Altitude (m)	Average Daily Sunlight (KJ/m^2)	Average Daily Max Air Temp (F)	Average Daily PM2.5	Average Daily Precipitation (mm)	Weighted Altitude (m)	Average Daily Sunlight (KJ/m^2)	Average Daily Max Air Temp (F)	Average Daily PM2.5	Average Daily Precipitation (mm)
All Cause	-0.08	0.01	6.15	24.89	53.32	0.09	-0.05	12.99	6.90	34.19
	6.71	2.03	14.93	10.98	10.74	2.75	6.97	14.93	0.43	1.51
Heart Disease (Aged 40+)	-0.07	0.01	4.58	18.09	39.51	0.05	-0.03	9.10	3.39	23.18
	8.05	2.02	14.88	10.29	10.59	1.45	7.22	14.88	0.19	1.36
Cerebrovascular Disease (Aged 40+)	-0.01	0.003	1.00	3.07	5.36	0.007	-0.004	1.54	0.75	2.12
	4.10	4.06	12.87	5.37	3.63	0.44	2.15	12.87	0.18	0.20
Tobacco-related Cancer (Aged 40+)	-0.036	-0.002	1.07	8.24	20.73	0.005	-0.01	2.63	1.38	11.18
	16.12	0.45	5.64	14.26	19.73	2.34	4.34	0.65	1.00	19.73
Non Tobacco-related Cancer (Aged 40+)	-0.01	0.00005	0.54	2.55	6.14	0.003	-0.01	1.48	-0.22	2.20
	3.35	0.00	2.46	2.39	3.00	0.08	2.35	1.48	0.02	3.00
Diabetes (Aged 40+)	0.002	0.002	0.46	-0.49	-1.74	0.011	-0.01	1.76	-1.45	-2.61
	0.10	1.04	2.42	0.11	0.31	0.95	1.93	2.42	0.73	0.37
Alzheimer's (Aged 40+)	-0.007	0.003	0.86	1.98	1.80	0.005	-0.003	1.36	0.49	-0.78
	0.77	3.06	6.21	1.28	0.98	0.21	0.28	6.21	0.04	0.03
Pneumonia/Influenza (Aged 40+)	0.001	0.0006	0.26	0.54	1.76	0.013	-0.003	1.00	-0.07	2.29
	0.06	0.32	1.92	0.31	0.75	3.34	0.94	1.92	0.73	0.73
Suicide	0.007	0.0001	-0.11	-1.48	-1.85	0.008	-0.001	0.27	-0.96	0.70
	20.14	0.08	2.04	14.74	5.21	20.14	1.28	0.59	2.20	0.75

Accidents	0.007	0.0007	0.13	-1.20	-0.71	0.017	-0.01	1.27	-1.52	2.44
	2.90	0.33	0.43	1.52	0.12	2.90	3.75	2.13	0.95	0.73
Note: R^2 is a measure of the proportion of the variance for a dependent variable that is explained by an independent variable or variables within a regression model. Partial R^2 measures the marginal contribution of a given independent variable when another variable or variable are already included in the model. Model R^2 is a measure of the cumulative partial R^2 values, increasing with each additional variable added to the model.										

Table 3: *Regression slope and partial R-square (%) estimates for the selected causes of death according to the environmental variables.*

All-Cause Mortality Rate

Adjusted slope estimates indicate that the negative association between altitude and the all-cause mortality rate seen before adjustment is explained by lower temperature, PM2.5 and precipitation, each of which correspond with higher altitude. Altitude is positively correlates with the all-cause mortality rate and sunlight negatively correlates with the all-cause mortality rate in the adjusted model. Average daily maximum temperature has the strongest association with the all-cause mortality rate followed by sunlight, altitude, precipitation, and then PM2.5.

Heart Disease Mortality Rate

Slope estimates shown here are similar to those for the all-cause mortality rate. In particular, the negative correlation between altitude and the heart disease mortality rate is explained by lower temperature, PM2.5 and precipitation at higher altitude. Altitude is positively associated with the heart disease mortality rate after accounting for temperature, PM2.5, and precipitation. In the adjusted model, sunlight is negatively associated and temperature, precipitation and PM2.5 are positively associated with the heart disease mortality rate.

Cerebrovascular Mortality Rate

Slope estimates tend to be smaller than, but patterns similar to, those observed for the heart disease mortality rates.

Tobacco-Related Cancer Mortality Rate

Adjusted slope estimates indicate that the negative association between altitude and the tobacco-related cancer mortality rate is explained by lower temperature, PM2.5 and precipitation that occurs at higher altitude. Altitude is slightly positively associated with the rate after adjustment. Sunlight has a stronger negative associated with the rate and temperature and precipitation continue to have positive associations with the rate, followed by PM2.5, after adjustment.

Non-Tobacco-Rated Cancer Mortality Rate

Slope estimates between the non-tobacco-related cancer mortality rates and the environmental variables are not as strong as with those involving the tobacco-related cancer mortality rates. The negative associations between altitude and the non-tobacco-related cancer mortality rate is explained by lower temperature, and to a smaller extent, precipitation. After adjustment, altitude is now only slightly positively associated with the rate. Sunlight has a negative association with the rate in the adjusted model. Temperature and precipitation continue to have positive association with the rate, whereas PM2.5 has no association, after adjustment.

Diabetes Mortality Rate

Temperature has the strongest direct positive association with the diabetes mortality rate. Adjusted slope estimates indicate that the diabetes mortality rate increases with higher altitude and temperature and decreases with sunlight. PM2.5 and precipitation have little association with the diabetes mortality rate.

Alzheimer's Mortality Rate

Temperature has a strong direct positive association with the Alzheimer's mortality rate. Although sunlight explains some of the variation in the Alzheimer's mortality rate across counties, its influence, along with that of altitude, PM2.5, and precipitation become negligible after accounting for temperature.

Pneumonia/Influenza Mortality Rate

Altitude has the strongest positive association with the pneumonia/influenza mortality rate in the adjusted model. Temperature is also positively associated with the rate. The other three environmental variables have very little influence on the variation in pneumonia/influenza across the counties.

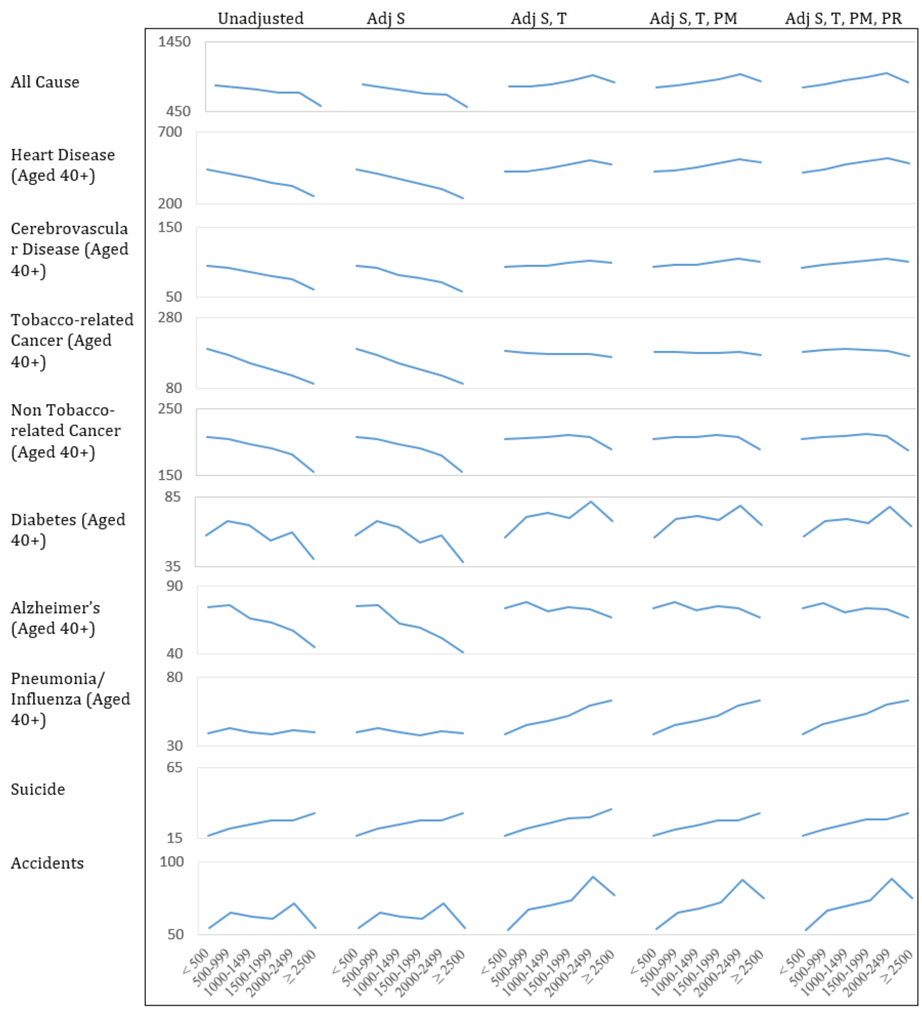
Suicide Rate

The strong positive association between altitude and suicide persists after adjusting for average daily sunlight, maximum air temperature, PM2.5, and precipitation. In the adjusted model, sunlight and PM2.5 have small negative associations with suicide. Temperature and precipitation have minimal effects on suicide.

Accident Mortality Rate

The accident mortality rate increases with higher altitude and temperature and decreases with more sunlight according to the adjusted estimates. The effects of PM2.5 and precipitation are minimal.

Cause-specific mean age-adjusted mortality rate estimates across counties are shown in Figure 1. Prior to adjustment for the natural environmental variables, negative associations appear for each of the causes of death, with exceptions for pneumonia/influenza, which is not associated with altitude, and suicide, which is positively associated with altitude. Adjustment for average daily sunshine had little effect on the estimated mean rates. However, the additional adjustment for average daily maximum air temperature had a large influence on the estimated mean rates, with this adjustment causing the estimated mean age-adjusted mortality rates to increase with higher altitude, or be close to flat. For pneumonia/influenza, the estimated mean age-adjusted mortality rates now increase with altitude after adjusting for temperature and the increasing estimated mean age-adjusted rates with altitude became even more pronounced for suicide and accidents, after adjusting for temperature. The additional adjustment for average PM2.5 and daily precipitation had little additional influence on the estimates.



Mean rates are age-adjusted to the US 2000 population, per 100,000. S: Average daily sunlight (KJ/m^2); T: average daily maximum air temperature (F); PM: average fine particulate matter (ug/m^3); and PR: average daily precipitation (mm).

Figure 1: *County-level cause-specific mean mortality rates by altitude, unadjusted and adjusted for average daily sunlight (S), max air temperature (T), PM2.5 (PM), and precipitation (PR).*

Discussion

This study shows the association between altitude and selected causes of death in the contiguous United States. Higher altitude living correlates with lower death rates from all causes, heart disease, cerebrovascular disease, tobacco-related cancer, non-tobacco-related cancer, diabetes, and Alzheimer's disease. These results are consistent with observations from previous studies. [1-10] However, higher altitude living does not correlate with death from pneumonia/influenza and is positively associated with suicide and accidents. Former research has also observed similar correlations with suicide and accident deaths, but found that higher altitude correlated with poor outcomes in more severe pneumonia. [11-18]

After accounting for average daily sunlight, maximum air temperature, PM2.5, and precipitation, altitude now positively correlates with each of the causes of death. The positive correlation between altitude and cancer mortality is consistent with another study. [32] Altitude does not generally contribute to the causes of death as much as temperature, except in the case of pneumonia/influenza, suicide, and altitude. At higher altitude the severity of pneumonia may be enhanced because the illness compromises being able to absorb lower levels of oxygen into the bloodstream. [16] Low blood oxygen associated with high altitude can also increase the risk of suicide by altering serotonin metabolism and brain bioenergetics. [24]

Average daily sunlight positively correlated with the selected causes of death, whereas after accounting for altitude and average daily maximum air temperature, PM2.5, and precipitation, it negatively with all the causes of death. Despite the adverse effects of too much sunlight (e.g., skin cancer, cataracts, premature aging of the skin), sunlight triggers vitamin D synthesis, which helps regulate the immune and neuromuscular systems and plays an important function in the life cycle of human cells. [33] Deficiency in vitamin D has been associated with increased risk of heart disease, breast cancer, colon cancer, prostate cancer, weight gain, depression, and suicide. [3, 19, 34, 35]

Average daily maximum air temperature has the strongest association with deaths from all causes, heart disease, cerebrovascular disease, Diabetes, and Alzheimer's. In the United States, hot ambient air temperature is associated with a larger number of deaths each year than any other weather condition, including cold temperature. [36] A study involving 14 countries found that 7.7% of mortality is attributed to extreme hot and cold ambient air temperature. [37] A review article found that high ambient air temperature linked to greater risk mental health-related admissions, emergency department visits, and suicides. [38] Another review article found that hot weather correlated with increased risk of unintentional injuries and accidents in high-income countries. [39] Research has also associated hotter ambient air temperature with greater risk for injuries, violent crime, and suicide. [17]

PM2.5 has a smaller correlation with the causes of death than the other environmental variables. On the other hand, average daily precipitation had the strongest correlation with tobacco- and non-tobacco-related cancer deaths among the environmental variables. This result may be partly explained by more a positive association between average daily precipitation and % adult smokers (r = 0.40), % adult obesity (r = 0.25), and % adult physical inactive (r = 0.29). Several studies have, in turn, linked smoking, obesity, and physical inactivity with various types of cancer. In addition, extreme precipitation can contaminate water quality (i.e., runoffs that may contain heavy metals, pesticides, nitrogen, and phosphorus), which may link to cancer. [40]

A limitation of the ecologic study design used in this paper is that measurements represent the county versus individual level. As a result, ecologic fallacy may be an issue. However, individuals within each county are expected to be affected similarly by the natural environmental variables considered. Although average daily maximum air temperature had a strong negative association with each of the causes of death rates, the influence of ambient air temperature on health is complicated because of our climate-controlled homes, cars, and workplaces. Most results were statistically significant, as expected because of the large number of counties evaluated in this study. However, some of the significant estimated effects sizes might not be of practical importance. The natural environmental variables are largely unmodifiable, such that behavior change would largely require moving. Finally, the cross-sectional, population-level data does not allow us to draw conclusions about causal-effect relationships.

Conclusions

Counties with higher altitude have lower age-adjusted mortality rates for all causes, heart disease, cerebrovascular disease, tobacco-related cancer, non-tobacco-related cancer, and Alzheimer's disease, and higher for suicide and accidents. Diabetes and pneumonia/influenza are not associated with altitude. The benefit of higher altitude in terms of some of these health outcomes is explained by other environmental variables associated with altitude, primarily lower average daily maximum air temperature. The adverse effect of altitude on suicide and accidents is not explained by the other environmental variables. Further study of the mechanisms that explain this latter observation is warranted. In addition, because average daily maximum temperature is the primary environmental factor associated with most of the causes of death considered, a better understanding of the way this variable adversely effects health is important. For example, is it a function of increased metabolic expenditure required by the body to cope with excessive ambient air temperatures and/or because of the association temperature has with certain social, economic, and health behavior variables, which, in turn, impact these health outcomes?

Ethical approval

Institutional review board approval was not required as the study used publicly available datasets.

Competing interests

None declared.

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