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Research Article

Why is High Altitude Living Associated with Lower Premature Death and Better Quality of Life? An Ecologic Study Involving US Counties

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Abstract

The current study identifies direct and indirect associations between altitude and premature death and poor quality of life health outcomes. An ecologic study design was used, involving 3,108 counties in the contiguous US. Statistical measures estimated the association between county-level altitude and selected health outcomes. Higher altitude was associated with less premature death and better quality of life, but these associations were explained by higher average daily sunlight and lower average daily maximum air temperature, PM2.5 and precipitation, which correlate with higher altitude. After accounting for the environmental variables, higher altitude was then associated with more premature death and poorer quality of life. In an adjusted model, the amount of variation in a summary health outcomes index explained by altitude was 3.9%, average daily sunlight was 2.1%, maximum air temperature was 21.0%, and precipitation was 3.5%. The effect of PM2.5 was negligible. The model was extended to also include smoking status, income, insurance status, children in poverty, income ratio, single-parent households, violent crime rate, and injury death rate, whereupon the amount of variation in the health outcomes index explained by altitude was 0.7%, average daily sunlight was 0.6%, maximum air temperature was 0.9%, and precipitation was 0.5%. Taken together, better health is associated with lower altitude and average daily maximum air temperature, PM2.5, and precipitation, but higher average daily sunlight. The effects of these environmental variables on the health outcomes index are largely explained by the mediating influence of the social and economic variables considered.

Introduction

Years of potential life lost is a summary measure of premature death. This health indicator provides a way to weight deaths that occur in younger ages, quantifying the social and economic loss stemming from premature death. Other health outcomes that have social and economic implications include poor or fair health, poor physical health days, poor mental health days, and low birthweight. Poor physical and mental health contributes to on-the-job productivity loss and unemployment [1-5]. Low birthweight has potential social and economic consequences, as these children are more likely to have disabilities, hospitalizations, brain damage, impaired language development, require special education classes, and to experience chronic health problems and have a greater risk of being in lower economic classes later in life [6].

Several studies have shown that premature death and quality of life health outcomes are impacted by education, income, health insurance, poverty, income ratio, single-parent households, violent crime and injury [7-12]. In addition, the natural environment may influence premature death and quality of life health outcomes, both directly and indirectly through their effect on these variables (i.e., education, income, etc.). However, little is known about the role the natural environment plays in this context. An understanding of this role may better inform policy and intervention programs and, thereby, lower premature death and improve quality of life health outcomes.

The purpose of this study was to identify direct and indirect associations between altitude and premature death and poor quality of life health outcomes.

Materials and Methods

The current study involved an ecologic design in which the variables being assessed represented 3,108 counties in the contiguous United States. Analyses were performed on measurements taken on the county-level data. The study was intended to generate hypotheses that may be assessed more definitively with longitudinal data. IRB approval was not required as the study used publicly available datasets.

County-level premature death, quality of life, and social and economic data were compiled by a Robert Wood Johnson Foundation program called County Health Rankings & Reports: Building a Culture of Health, County by County [13]. The study also involved county-level environmental data, available through the Environmental Public Health Tracking Network, the United States Geological Survey's National Elevation Dataset programs and the Wonder Online Databases supported by the Centers for Disease Control and Prevention [13–15].

Premature Death and Poor Quality of Life Health Outcomes

Five health outcomes were considered in this study: premature death, poor or fair health, poor physical health days, poor mental health days, and low birthweight. Premature death was measured as years of potential life lost before age 75 years per 100,000 person-years, available from the National Center for Health Statistics mortality files, 2016-2018. Poor or fair health represented the percentage of adults reporting fair or poor health; poor physical health days represented the average number of physically unhealthy days reported in the past 30 days; and poor mental health days represented the average number of mentally unhealthy days reported in the past 30 days. Each of these measures were age-adjusted and was available from the Behavior Risk Factor Surveillance System, 2017. Age-adjustment involved weighting the age-group specific estimates to the 2000 US population [16]. Low birthweight represented the percentage of live births with low birthweight (< 2,500 grams), and was available from the National Center for Health Statistics –Natality Files, 2012-2018.

A health outcomes index was created to provide a summary of the five health outcomes. To calculate the index, each measure was first standardized using z-scores. This allowed for combining multiple measures of different scales. The index score was then a weighting of the standardized scores for the five variables. The county with the lowest aggregated z-score was healthiest. The weights were based on those used by states in 2020 County Health Ranks: Ranked Measure Sources and Years of Data: 0.5 for premature death, 0.1 for poor or fair health, 0.1 for poor physical health days, 0.1 for poor mental health days, and 0.2 for low birthweight [13].

Natural Environmental Variables

Five natural environmental variables were included in this study: 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). Altitude was estimated in meters above sea level for each county, based on data from the Geographic Names Information System from the United States Geological Survey [17]. In some counties with mountainous areas, most people live in the valleys. To obtain a measure of altitude reflecting where most of the people live, a weighted estimate of altitude was derived. Weighted altitude has been used in a previous study relating altitude to suicide [18]. Average county-level daily sunlight, maximum air temperature and precipitation represent the combined years 2007-2011. These data were obtained through the North American Land Data Assimilation System, available through the CDC Wonder database [CDC WONDER [Internet] [15]. Average county-level daily density of fine particulate matter in micrograms per cubic meter (PM2.5) cover 2011-2014, obtained from the Environmental Public Health Tracking network [19].

Social and Economic Variables

The county-level social and economic factors considered in this study were % adults with some college, median household income, % uninsured, % children in poverty, income ratio (ratio of household income at the 80th percentile to income at the 20th percentile), % single-parent households, violent crime rate, and injury death rate. The Robert Wood Johnson program obtained these data from various sources. Percent some college, income ratio, and % single-parent households of adults data was obtained from the American Community Survey, 5-year estimates, 2014-2018; median household income and % children in poverty was obtained from Small Area Income and Poverty Estimates, 2018; % uninsured was obtained from Small Area Health Insurance Estimates, 2017; violent crime rate was obtained from uniform crime reporting, FBI, 2016; and injury death rates were obtained from National Center for Health Statistics mortality files, 2014-2018.

Statistical Techniques

County-level data was described for each variable using summary statistical measures (mean, standard deviation, median, minimum, and maximum). The health outcome index was correlated with the natural environmental and social and economic variables using the Pearson Correlation Coefficient. Correlations were also estimated between each of the five premature death and quality of life health outcomes and social and economic factors with the natural environmental variables. The assumption of linearity between variables was assessed graphically (data not shown). Unadjusted and adjusted correlation coefficients were estimated. 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 statistics for premature death and quality of life, environmental, social and economic variables are presented in Table 1.

The health outcomes index is a weighted overall measure of the premature death and quality of life variables. A lower index score represents better health. This measure is correlated separately with each of the variables in the table. The correlations indicate that counties experiencing better health (lower health outcomes index) have higher altitude and lower sunlight, temperature, PM2.5, and precipitation. Counties experiencing better health also have higher % some college and median household income and a lower % uninsured, % children in poverty, income ratio, % single-parent households, violent crime rate, and injury death rate.

Health outcomes and social and economic factors are correlated with the environmental variables in Table 2.

Although better health is associated with higher altitude, after accounting for higher temperature and lower PM2.5 and precipitation, which are associated with higher altitude, higher altitude now correlates with poorer health, as reflected by each of the health indicators. The adjusted correlations also tend to show better health for each of the indicators in counties with more sun, lower average daily maximum air temperature, PM2.5, and precipitation.

Table 1. Summary Information for Premature Death and Quality of Life Health Outcomes, Environmental, Social, and Economic Factors for Counties in the Contiguous United States

	No.	Mean	SD	Median	Min	Max	Correlation with the Health Outcome Index
Premature Death and Quality of Life Health Outcomes							
Years of potential life lost before age 75 per 100,000 population (age-adjusted)	2827	8574	2584	8328	2731	29138	0.941
Percentage of adults reporting fair or poor health (age-adjusted)	3108	17.95	4.74	17.00	8.00	41.00	0.844
Average number of physically unhealthy days reported in past 30 days (age-adjusted)	3108	3.99	0.70	3.90	2.40	6.60	0.856
Average number of mentally unhealthy days reported in past 30 days (age-adjusted)	3108	4.17	0.60	4.20	2.50	6.30	0.805
Percentage of live births with low birthweight (< 2,500 grams)	3011	8.16	2.06	8.00	3.00	24.00	0.731
Health Outcomes Index	2825	0.02	0.86	-0.06	-1.82	4.68	1.000
Natural Environmental Factors							
Weighted Altitude (m)	3106	414.3	487.4	263.1	-9.5	3471.4	-0.143
Average Daily Sunlight (KJ/m^2)	3106	16398.3	1605.0	16102.9	12689.0	21191.1	0.292
Average Daily Maximum Air Temperature (F)	3106	65.4	9.3	64.8	38.4	87.5	0.458
Average PM2.5 (ug/m^3)	3108	9.0	2.0	9.4	3.0	19.7	0.208
Average Daily Precipitation (mm)	3106	2.7	0.9	3.0	0.2	7.1	0.278
Social and Economic Factors							
% Some College	3108	57.89	11.83	58.00	15.00	100.00	-0.618
Median household income	3108	52659	13822	50514	25385	140382	-0.723
% Uninsured, everyone	3108	11.42	5.11	11.00	2.00	34.00	0.327
% Children in Poverty	3108	21.20	8.90	20.00	3.00	68.00	0.833
Income Ratio	3106	4.52	0.76	4.40	2.50	12.00	0.537
% Single-Parent Households	3107	32.33891	10.65447	32	0	87	0.658
Violent Crime Rate	2935	251.3874	191.8668	204	0	1820	0.331
Injury Death Rate	3015	86.63184	25.10892	84	22	320	0.616

Rates were age-adjusted to the 2000 US adult population. To calculate the Health Outcomes Index, each measure was first standardized using z-scores. This allowed for combining multiple measures of different scales. The index score was then a weighting of the standardized scores for the five variables. The county with the lowest aggregated z-score is healthiest. The weights were based on those used by states in 2020 County Health Ranks: Ranked Measure Sources and Years of Data: 0.5 for premature death, 0.1 for poor or fair health, 0.1 for poor physical health days, 0.1 for poor mental health days, and 0.2 for low birthweight [13]. The summary natural environmental variable statistics have been reported previously [20].

Table 2. Premature Death and Quality of Life Health Outcomes and Social and Economic Factors According to Selected Environmental Measures

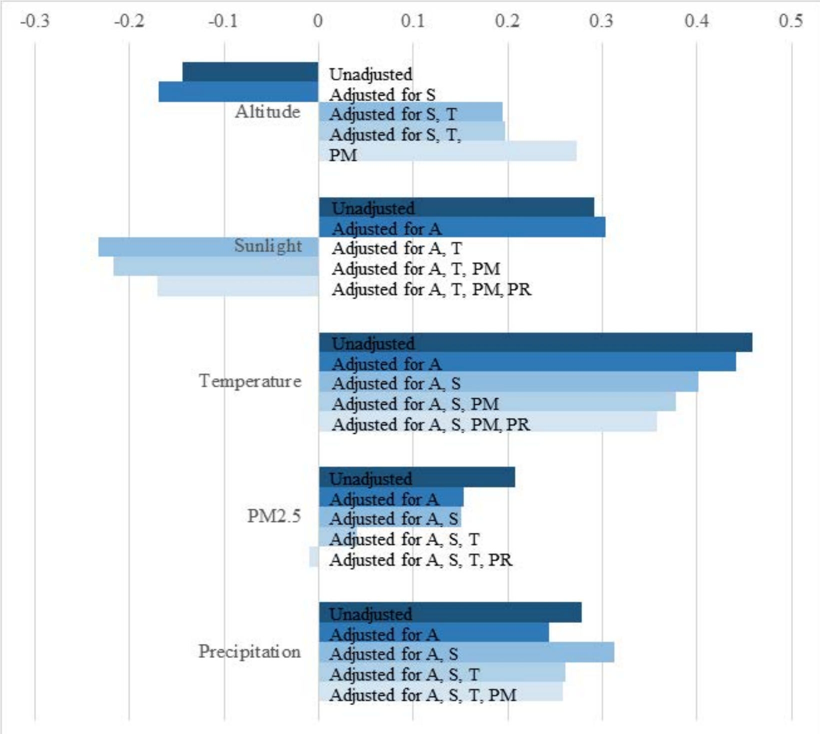
	Pearson Correlation Coefficient – unadjusted (row 1) and adjusted (row 2)				
Label	Weighted Altitude (m)	Average Daily Sunlight (KJ/m²)	Average Daily Max Air Temp (F)	Average Daily PM2.5	Average Daily Precipitation (mm)
Years of potential life lost before age 75 per 100,000 population (age-adjusted)	-0.10	0.20	0.35	0.12	0.35
	0.21	-0.20	0.33	-0.07	0.17
Percentage of adults reporting fair or poor health (age-adjusted)	-0.20	0.42	0.59	0.28	0.24
	0.22	-0.13	0.38	0.03	0.16
Average number of physically unhealthy days reported in past 30 days (age-adjusted)	-0.18	0.23	0.40	0.31	0.35
	0.27	-0.13	0.28	0.10	0.29
Average number of mentally unhealthy days reported in past 30 days (age-adjusted)	-0.23	0.17	0.37	0.40	0.46
	0.28	-0.09	0.23	0.17	0.38
Percentage of live births with low birthweight (< 2,500 grams)	-0.06	0.36	0.42	0.20	0.24
	0.24	0.05	0.17	0.08	0.27
% Some College	0.11	-0.29	-0.40	-0.16	-0.14
	-0.16	-0.10	-0.27	0.00	-0.10
Median household income	0.04	-0.15	-0.28	-0.02	-0.10
	-0.21	0.24	-0.35	0.14	-0.12
% Uninsured, everyone	0.11	0.61	0.57	-0.14	-0.19
	0.20	-0.08	0.44	-0.26	-0.10
% Children in Poverty	-0.14	0.36	0.46	0.14	0.19
	0.14	-0.06	0.27	-0.08	0.18
Income Ratio	-0.18	0.28	0.35	0.15	0.19
	-0.01	0.08	0.07	-0.03	0.15
% Single-Parent Households	-0.27	0.26	0.36	0.24	0.25
	-0.10	0.12	0.02	0.02	0.13
Violent Crime Rate	-0.14	0.31	0.32	0.20	0.12
	-0.04	0.19	-0.05	0.12	0.07
Injury Death Rate	0.22	0.05	0.01	-0.20	-0.04
	0.25	-0.15	0.19	-0.18	0.15

Counties with higher altitude correlate with higher % some college, % uninsured, and injury death rate, but lower % children in poverty, income ratio, % single-parent households, and violent crime rate. However, after accounting for higher sunlight and lower temperature, PM2.5 and precipitation at higher altitude, higher altitude is associated with higher % uninsured, % children in poverty, and injury death rate, and lower % some college, median household income, % single-parent households, and violent crime. The primary environmental factor associated with these social and economic variables is average daily maximum air temperature. In the adjusted models, temperature has the largest association with % some college (negative), median household income (negative), % uninsured (positive), and % children in poverty (positive); precipitation has the largest association with income ratio (positive) and % single-parent households (positive); sunlight has the largest association with violent crime (positive); and altitude has the largest association with injury death rate (positive).

Correlations between the health outcomes index and the environmental variables are shown in Figure 1. Each of the correlated estimates change as we sequentially adjust for the environmental variables. For example, the correlation involving the altitude and the health outcomes index goes from negative to positive with the adjustment of temperature. In other words, better health experienced at higher altitude is primarily explained by cooler temperatures, which correspond with higher altitude. After accounting for sunlight, temperature, PM2.5, and precipitation, altitude now correlates with poorer health. In the adjusted model, sunlight is associated with better health. Higher temperature and precipitation remain correlated with poorer health in the fully adjusted models. PM2.5 shows little correlation with health in the fully adjusted models.

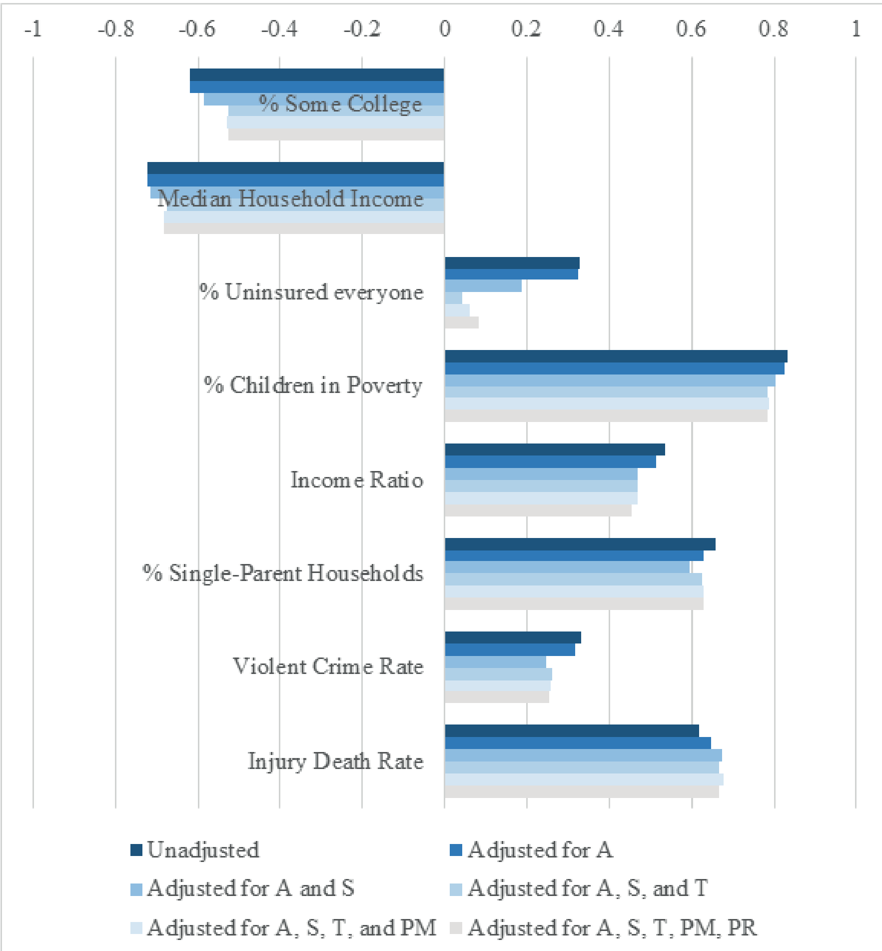
Correlation estimates between the health outcomes index and the social and economic factors are potentially confounded by the environmental factors. For example, since

Figure 1. Pearson Correlation Coefficients Measuring the Association between the Health Outcomes Index and Natural Environmental Variables



A: weighted alititude (m); S: average daily sunlight (KJ/m²); T: average daily maximum air temperature (F); PM: average fine particulate matter (ug/m³); and PR: average daily precipitation (mm).

Figure 2. Pearson Correlation Coefficients Measuring the Association between the Health Outcomes Index and the Social and Economic Factors



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ambient air temperature correlates with % some college and independent of that relationship correlates with the health outcomes index, it is a possible confounder. Correlations between the health outcomes index and the social and economic factors are shown in Figure 2.

Although adjustment for the environmental variables tend to dampen the correlation estimates between the health outcomes index and the social and economic factors, these estimates remain fairly strong, with the possible exception of % uninsured.

Finally, in a multiple regression model, the health outcomes index was regressed on the environmental variables. In the fully adjusted model, average daily PM2.5 was insignificant ($p = 0.5872$). Altitude, temperature, and precipitation positively correlated with the health outcomes index (poorer health) and sunlight negatively correlated with the health outcomes index (better health). The amount of variation in the health outcomes index explained by altitude was 3.9%, average daily sunlight was 2.1%, maximum air temperature was 21.0%, and precipitation was 3.5%. Assuming the social and economic factors mediate the association between the environmental factors and the health outcomes index, including these variables in the model should dampen the associations. Indeed, in the full model that includes the environmental, social and economic factors, the amount of variation in the health outcomes index explained by altitude was 0.7%, average daily sunlight was 0.6%, maximum air temperature was 0.9%, and precipitation was 0.5%.

Discussion

The current study described the effect of altitude on premature death and poor quality of life through its relationship with sunlight, ambient air temperature, PM2.5, and precipitation. The direct influence of the natural environmental variables on premature death and poor quality of life health outcomes persisted after adjustment for their simultaneous effects. However, almost all of their association with premature death and poor quality of life appears to be mediated by selected social and environmental factors.

Higher altitude was associated with lower premature death and better quality of life outcomes. Lower premature death and better quality of life outcomes at higher altitude may be due to biological changes that take place in the body at higher altitude and/or natural environmental factors associated with higher altitude, such as more moderate ambient air temperature. After accounting for average daily sunlight, maximum air temperature, PM2.5, and precipitation, higher altitude correlated with higher premature death and poorer quality of life outcomes. However, this does not mean that there are no health benefits to higher altitude living beyond the influence of the other environmental variables.

Some have hypothesized that there are health benefits to higher altitude living associated with positive adjustments the body makes to hypoxia [21-25]. Hypoxia is a condition where the body or part of the body has inadequate oxygen supply at the tissue level. Hypoxia occurs at altitudes above sea level, but physiological responses are small below 1,500 meters (0-5,000 feet) for healthy individuals, compromised because of memory issues from 1,500 to 3,500 meters (5,000 -11,400 feet), and visual sensitivity at night falls 10% at 1,500 meters and 30% at 3,000 meters [26]. Chronic hypoxia alters serotonin metabolism and brain bioenergetics [27]; certain illnesses may impair the body's ability to absorb lower levels of oxygen into the bloodstream [28]; and hypoxia can cause fatigue, shortness of breath, and, in extreme cases loss of consciousness, which increase the risk of serious injury [29]. Hypoxia among women at altitudes ≥ 2500 meters decreases birth weight by altering maternal glucose and lipid metabolism [30].

Higher average daily sunlight was associated with more premature death and poorer quality of life outcomes. However, sunlight strongly correlates with altitude, ambient air temperature, and precipitation. After accounting for altitude, ambient air temperature, PM2.5, and precipitation, higher average daily sunlight then correlated with lower premature death, poor or fair health days, and physically and mentally unhealthy days. Although public health messages tend to focus on the hazards of too much sun (i.e., destroying vitamin A in the skin such that skin aging is accelerated, increasing the risk of skin cancer, causing cataracts, and reactivating some viruses), sunlight exposure boosts the body's vitamin D supply and it also has other beneficial health effects (i.e., increase endorphins, decrease autoimmune diseases, increase gene repair, helps treat skin disorders like psoriasis, etc.) [31]. Although a World Health Organization (WHO) report linked 0.1% of the global burden of disease (in terms of disability-adjusted life years [DALYs]) to excessive exposure to ultraviolet radiation, the report also indicated that a reduction of ultraviolet radiation to very low levels would cause an increase of approximately 3.3 billion DALYs globally [32].

Higher average daily maximum air temperature had the strongest association with greater premature death and lower quality of life outcomes among the natural environmental variables. Research has shown that hot temperatures are related to more deaths each year in the United States than from any other weather condition [33]. According to a 30 year average (1989-2018), there are approximately 4.5 more heat-related deaths than cold-related deaths [33]. A literature review identified several studies associating higher ambient air temperature with more overall and cause-specific morbidity (e.g., cardiovascular and respiratory diseases) [34]. A multi-country study estimated that 7.7% of mortality is attributed to non-optimal ambient air temperature [35]. One review found that high ambient air temperatures resulted in greater risk of mental health-related admissions, emergency department visits, and suicides [36]. Another review confirmed that hot weather increases the risk of unintentional injuries and accidents in high-income countries [37]. Research has further linked hotter ambient air temperature with increased risk for injuries, violent crime, suicide, and low birth weight infants [38, 39].

Compared with the other environmental factors considered in this study, PM2.5 tended to have a small influence on premature death and poor quality of life outcomes. However, its negative association with the average number of physically and mentally unhealthy days reported in the past 30 days, more so for the latter, is worth noting. Previous research has associated particulate matter pollution with morbidity from respiratory diseases, coronary obstructive pulmonary disease, asthma, and pneumonia [40]. Research has also shown that high levels of fine particulate matter in the air correlate with higher rates of death from homicide and legal intervention, unintended accidents, and suicide [38]. Further, there is some research linking exposure to fine particulate matter with lower cognition and well-being [41, 42].

After adjustment for altitude, average daily maximum air temperature and PM2.5, precipitation correlated with more premature death, poor or fair health days, physically and mentally unhealthy days, and live births with low birthweight. Extreme precipitation events may increase the risk of automobile accidents, unintentional injuries, and suicide [38, 43-46]. Extreme precipitation can also compromise water quality (i.e., runoffs that may include heavy metals, pesticides, nitrogen, and phosphorus), hurting ecosystems and the public's health [47]. Although precipitation positively correlated with low birth weight infants, in countries with relatively low precipitation, where more precipitation is particularly helpful for crops, precipitation has been shown to decrease low birth weight infants [39, 48].

The associations between the natural environmental variables (altitude, sunlight, ambient air temperature, and precipitation) and the health outcomes index became negligible after including the social and economic variables in the model. Because these variables tended to be associated with both the environmental variables and the health outcome index, they are potential mediators. For example, the amount of variation in the health outcomes index explained by average daily maximum air temperature was 21.0%. However, temperature was also associated with several variables that influence premature death and quality of life (e.g., education, income, children in poverty, single-parent households, violent crime, and injury). Indeed, when these variables were included in the model, only 0.9% of the amount of variation in the health outcomes index was explained by a direct effect of temperature.

A limitation of this study is that the data reflects county-level measurements rather than individual level information. Hence, ecologic fallacy may exist in our estimated correlations. In addition, to fully capture the effect of extreme ambient air temperatures on people's health is impossible because of our climate-controlled homes, cars, and workplaces. However, the environmental variables are experienced at similar levels among individuals within counties.

We should also note that the large number of counties assessed produced generally significant results, some of which may not be of practical importance. In addition, the natural environmental variables are generally not modifiable, hence may be less clinically important. Finally, the data are not longitudinal such that we are not able to draw conclusions about causal-effect relationships. Yet, for some variables the causal direction is clear.

Conclusion

This study attempted to explain why higher altitude living correlates with better health. The beneficial effect of altitude on the selected health indicators considered in this study is primarily explained by higher altitude being associated with lower temperature, PM2.5, and precipitation. Sunlight is positively associated with better health after adjusting for the other environmental variables. The study further considered select social and economic variables, which were found to be associated with both the environmental and health outcome variables. After accounting for these variables, associations between the environmental and health outcome measures became insignificant. Hence, the social and economic variables considered fully explain the association between the environmental variables related to altitude (temperature, PM2.5, precipitation, and sunlight) and the health outcome measures.

Funding Statement

None

Data Availability

All relevant data within the paper can be accessed through the public domain, with references provided.

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