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RESEARCH ARTICLE

Is Life Expectancy Really Better at Higher Altitude Living? An Ecologic Study Involving US Counties

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Abstract

Introduction: This study explores the extent to which the correlation between higher altitude and better life expectancy can be explained by sunlight, air temperature, fine particulate matter, precipitation, and selected health behaviors.

Methods: An ecologic study design was used with 3,108 counties in the contiguous US. Multiple data sources were accessed and assessed using descriptive statistics and regression techniques.

Results: Life expectancy positively correlates with higher altitude and lower average daily sunlight, maximum air temperature, fine particulate matter, and precipitation. However, after accounting for lower average daily maximum air temperature, fine particulate matter, and precipitation, which correlate with higher altitude, higher altitude and lower average daily sunlight now associate with poorer life expectancy. After accounting for lower temperature and other natural environmental factors, counties with better overall health behaviors tend to have lower altitude and average daily maximum air temperature and precipitation, but higher sunlight. A negative association between life expectancy and fine particulate matter is small. In the fully adjusted model, the amount of variation in life expectancy explained by altitude is 1.4%, average daily sunlight is 6.8%, maximum air temperature is 15.1%, fine particulate matter is 0.2%, and precipitation is 2.7%. After also including the health behavior index in the model, these percent contributions become 1.0%, 0.5%, 1.9%, 0.0%, and 0.5%, respectively.

Conclusions: After accounting for higher sunlight and lower ambient air temperature, fine particulate matter, and precipitation that occur at higher altitudes, altitude correlates with lower life expectancy. The effects of these natural environmental variables on life expectancy are largely mediated by the health behaviors considered.

Keywords: Altitude, sunlight, ambient air temperature, PM2.5, precipitation, health behaviors, life expectancy

Introduction

Life expectancy is an important marker of health status. Life expectancy has shown marked improvement globally, increasing from 52.6 years in 1960 to 72.0 years in 2016 [1]. In the United States, life expectancy has increased more than 30 years from 1900 (47.3 years) through 2016 (78.6 years) [2, 3]. Although individuals tend to attribute much of the improvement in life expectancy to advances in and better access to healthcare [4], 23-25 of the 30 year improvement in the United States has been linked to accomplishments in public health [5, 6]. Promoting disease prevention through healthy behaviors (e.g., not smoking, being physically active, and safe sex practices) is an important emphasis area of public health.

It is well established that life expectancy is influenced by lifestyle behaviors, clinical care, genetics, and working, social, and economic factors. In addition, our natural environment also contributes to life expectancy. For example, higher altitude living has been associated with lower overall death rates [7]. Specifically, higher altitude living has been related to lower death rates for heart disease and stroke, cancer, diabetes, and Alzheimer's disease [8-16]. However, it has also been linked to higher death rates for coronary obstructive pulmonary disease (COPD), suicide, more severe pneumonia, and accidents [7, 13, 17- 25].

The link between life expectancy and altitude is not well understood. While altitude may directly correlate with life expectancy, it may also indirectly influence life expectancy through its association with health behaviors, which, in turn, impact life expectancy. In addition, environmental variables that correlate with altitude such as sunshine, ambient air temperature, particulate matter in the air 2.5 microns or less in width (PM2.5), and precipitation, may indirectly associate with life expectancy by their influence on health behaviors, but

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also directly influence life expectancy. Accounting for these variables may explain the greater life expectancy observed at higher altitude living.

The purpose of this study was to identify the extent to which the correlation between higher altitude and superior life expectancy can be explained by other natural environmental factors (sunlight, air temperature, PM2.5, precipitation) and health behaviors.

Materials and Methods

An ecologic study design was used to assess life expectancy, natural environment, and health behavior variables measured on the county level for 3,108 US counties. Analyses were conducted on county-level data. The study is exploratory in nature. No ethical approval was sought or required for this study, which used publicly available datasets.

Life Expectancy and Health Behavior Variables

County-level life expectancy and health behavior data were compiled by the Robert Wood Johnson Foundation program called County Health Rankings & Reports: Building a Culture of Health, County by County [26]. The data were obtained from various sources and time periods. County-level life expectancy was derived from the National Center for Health Statistics mortality files data, 2016-2018. County-level health behavior variables were % adult smokers, % adult obesity, % physically inactive, % limited access to exercise opportunities, Food Environment Index, % excessive drinking, % driving deaths with alcohol involved, sexually infected transmissions, and teen birth rate. The % of adults who currently smoke and the % excessive drinking were obtained from the Behavior Risk Factor Surveillance System, 2017. The % of adult obesity and the % physically inactive were obtained from the United States Diabetes Surveillance System, 2016. The % access to exercise opportunities was obtained from the Business Analyst, Delorme map data, ESRI, & US Census Tigerline files, 2010 and 2019. The Food Environment Index was obtained from Map the Meal Gap, 2017, and USDA Food Environment Atlas, 2015. It is an index of factors that contribute to a healthy food environment, from 0 (worst) to 10 (best). It accounts for distance an individual lives from the grocery store or supermarket, locations of health food purchases with communities, and inability to access healthy food because of cost. The % alcohol-impaired driving death was obtained from the Fatality Analysis Reporting System, 2014-2018. The % sexually transmitted infection was obtained from the National Center for HIV/AIDS, Viral Hepatitis, STD, and TB Prevention, 2017. The teen birth rate was obtained from the National Center for Health Statistics – Natality Files, 2012-2018.

The health behaviors index is a weighted measure of the selected health behavior variables. A higher index score represents poorer health behaviors. To calculate the Health Behavior 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 greatest aggregated z-score has the poorest health. The weights were based on those used by states in 2020 County Health Ranks: Ranked Measure Sources and Years of Data: 0.33 for % adult smokers, 0.17 for % adults with obesity, 0.07 for Food Environment Index, 0.08 for % physically inactive, 0.03 for % limited access to exercise opportunities, 0.08 for excessive drinking, 0.08 for % driving deaths with alcohol involved, 0.08 for sexually infected transmission, and 0.08 for teen birth rate [26].

Natural Environmental Variables

Analyses involved five natural environmental variables: 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 natural environmental data were 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, which they obtained from the North American Land Data Assimilation System [27-28].

Weighted altitude in meters above sea level was estimated for each county. People living in mountainous areas tend to live in the valleys. Hence, a weighted measure of altitude was derived to represent the altitude where most of the population live. 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 [27]. 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 [29].

Statistical Techniques

Summary statistics were derived and reported for each variable across counties. County-level life expectancy was correlated with the environmental and health behavior variables using the Pearson Correlation Coefficient. County-level life expectancy and the health behavior variables were each correlated with the environmental variables. Both Pearson correlation coefficients and partial correlation coefficients were derived. The partial correlation coefficients represent the correlation of each environmental variable with life expectancy after accounting for the other environmental variables. Multiple regression assessed the association between life expectancy and the environmental variables, adjusting for the health behavior index. 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

County-level summary statistics for life expectancy, natural environmental factors, and selected health behaviors are presented in Table 1. The number of counties providing information on each variable is included. Mean scores vary considerably across the counties. Life expectancy is correlated with this measure, along with each of the individual health behavior and natural environmental variables. The correlations indicate that counties experiencing better life expectancy have higher altitude and lower average daily sunlight, maximum air temperature, PM2.5, and precipitation. Counties experiencing higher life expectancy also have lower % adult smokers, % adults with obesity, food environment index, % physically inactive, % limited access to exercise opportunities, sexually infected transmissions, and teen birth rate. Counties with higher life expectancy have a lower health behavior index (i.e., better health behaviors).

Life expectancy and health behaviors are correlated with the environmental variables in Table 2. Correlation coefficients are both unadjusted and adjusted to account for the presence of the other environmental factors in the table. As shown in Table 1, counties with higher life expectancy have higher altitude and lower average daily sunlight, maximum air temperature, PM2.5, and precipitation. However, after accounting for higher temperature and other environmental factors associated with higher altitude, higher altitude is now associated with poorer life expectancy. The adjusted correlations also show greater life expectancy in counties with more sun, lower average daily maximum air temperature, PM2.5, and precipitation.

Counties with higher altitude correlate with lower % adult smokers, % adult obesity, % physically inactive, sexually infected transmissions, and health behavior index. However, after accounting for lower temperature and other natural environmental factors correlated with higher altitude, higher altitude is associated with higher % adult smokers, poorer food environment index, % physically inactive, % limited access to exercise opportunities, and teen birth rate. The adjusted correlations indicate that the health behavior index improves with lower altitude and higher average daily sunlight and lower average daily maximum air temperature and precipitation.

Correlations between life expectancy and the environmental variables is shown in Figure 1. Each of the correlations changes

Table 1: Summary information for life expectancy, environmental, and health behaviors for counties in the contiguous United States

	No.	Mean	SD	Median	Min	Max	Correlation with Life Expectancy
Life Expectancy	3040	77.43	2.91	77.5	61.6	90.10	
Environmental Variables							
Altitude (m) – weighted	3106	414.3	487.4	263.1	-9.5	3471.4	0.242
Average Daily Sunlight (KJ/m^2)	3106	16398.3	1605.0	16102.9	12689.0	21191.1	-0.152
Average Daily Maximum Air Temperature (F)	3106	65.4	9.3	64.8	38.4	87.5	-0.388
Average PM2.5 (ug/m^3)	3108	9.0	2.0	9.4	3.0	19.7	-0.305
Average Daily Precipitation (mm)	3106	2.7	0.9	3.0	0.2	7.1	-0.314
Health Behaviors							
% Adult Smokers	3108	17.4	3.6	17.0	6.0	41.0	-0.727
% Adult Obesity	3108	32.9	5.4	33.0	12.0	58.0	-0.500
% Physically Inactive	3011	27.5	5.7	27.0	10.0	50.0	-0.581
% Limited access to exercise opportunities	3108	8.5	8.2	6.0	0.0	72.0	-0.100
Food Environment Index 0 (best) – 10 (worst)	3089	2.5	1.1	2.3	0.0	10.0	-0.489
% Excessive Drinking	3108	17.5	3.2	18.0	8.0	29.0	0.541
% Driving deaths with alcohol involved	3108	28.2	14.8	27.0	0	100.0	0.038
Sexually infected transmissions	3083	397.6	271.2	326.7	35.8	6120.3	-0.302
Teen Birth Rate	2967	29.9	14.1	28.0	2.0	103.0	-0.683
Health Behavior Index (higher is worse)	2898	0.015	0.579	-0.017	-1.943	3.721	-0.763

To calculate the Health Behavior 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 greatest 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: 0.33 for % adult smokers, 0.17 for % adults with obesity, 0.07 for Food Environment Index, 0.08 for % physically inactive, 0.03 for % limited access to exercise opportunities, 0.08 for excessive drinking, 0.08 for % driving deaths with alcohol involved, 0.08 for sexually infected transmission, and 0.08 for teen birth rate [26]. The summary natural environmental variable statistics have been reported previously [41].

Table 2: Life expectancy and health behaviors according to the natural environmental factors

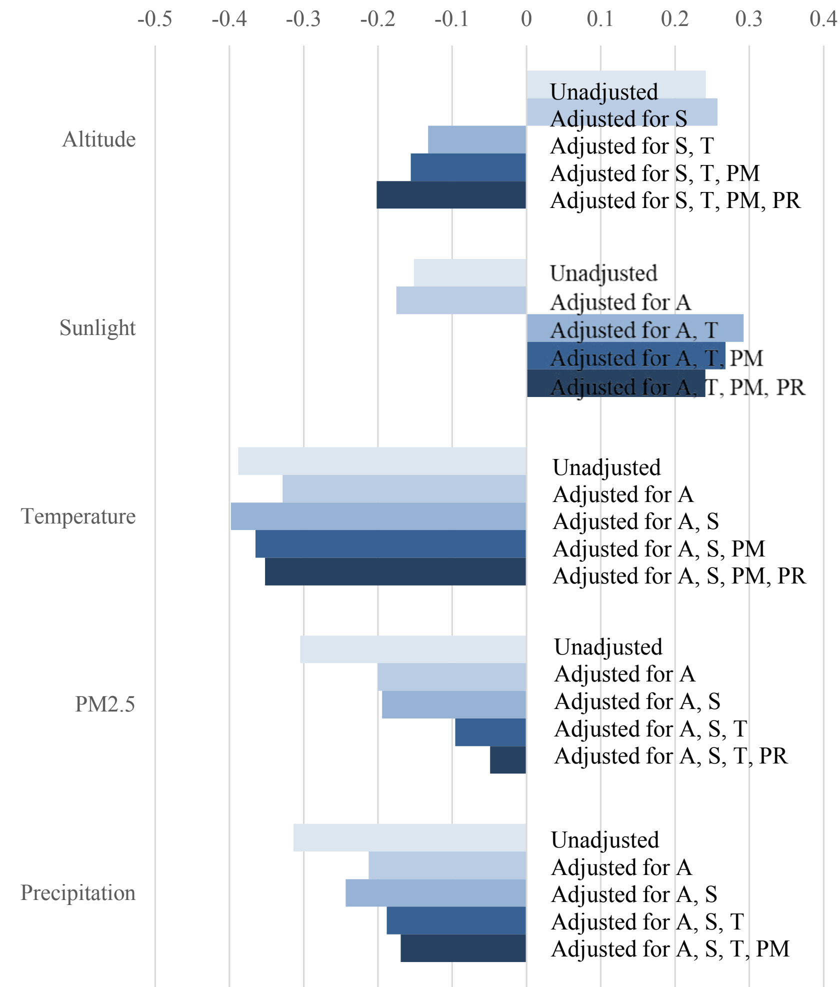
Health Behaviors	Altitude (m) – weighted	Average Daily Sunlight (KJ/m²)	Average Daily Max Air Temp (F)	Average Daily PM2.5	Average Daily Precipitation (mm)
Life Expectancy	0.24	-0.15	-0.39	-0.3	-0.31
	-0.31	0.26	-0.39	-0.07	-0.22
% Adult Smokers	-0.27	-0.04	0.23	0.31	0.40
	0.20	-0.28	0.31	0.04	0.25
% Adult Obesity	-0.33	-0.02	0.23	0.26	0.24
	-0.04	-0.21	0.23	0.01	-0.01
% Physically Inactive	-0.30	0.15	0.40	0.26	0.29
	0.10	-0.24	0.35	-0.04	0.13
% Limited access to exercise opportunities	-0.07	0.13	0.26	0.00	0.04
	0.11	-0.21	0.30	-0.08	0.03
Food Environment Index 0 (best) – 10 (worst)	0.03	0.34	0.36	-0.04	-0.00
	0.15	-0.06	0.25	-0.08	0.09
% Excessive Drinking	0.03	-0.34	-0.43	-0.17	-0.22
	-0.35	0.13	-0.33	-0.01	-0.29
% Driving deaths with alcohol involved	0.07	-013	-0.19	-0.14	-0.11
	-0.10	0.03	-0.10	-0.07	-0.10
Sexually infected transmissions	-0.16	0.29	0.32	0.13	0.06
	-0.11	0.13	0.00	0.05	-0.03
Teen Birth Rate	-0.05	0.38	0.49	0.09	0.03
	0.24	-0.22	0.42	-0.05	0.00
Health Behavior Index	-0.27	0.08	0.32	0.23	0.27
	0.10	-0.26	0.34	-0.04	0.10

Pearson correlation coefficients (row 1) and partial correlation coefficients (row 2). The partial correlation coefficients represent the correlation of each environmental variable with life expectancy, after accounting for the other environmental variables.

when we account for the other environmental variables. For example, the correlation for life expectancy and altitude goes from positive to negative after adjusting for temperature. In other words, the superior life expectancy at higher altitude is primarily explained by cooler temperatures, which correspond with higher altitude. The negative association between life expectancy and altitude after adjusting for temperature becomes even stronger with adjustment for PM2.5 and precipitation, each of which decrease with higher altitude. Sunlight after adjusting for temperature is associated with greater life expectancy. Counties with higher average daily maximum temperature, PM2.5, and precipitation have lower life expectancy, both before and after adjustment.

In a multiple regression model, life expectancy was regressed on the environmental variables. In the fully adjusted model, counties with higher life expectancy had lower altitude, average daily maximum air temperature, PM2.5, and precipitation, but higher average daily sunlight. The amount of variation in life expectancy explained by altitude was 1.4%, average daily sunlight was 6.8%, maximum air temperature was 15.1%, PM2.5 was 0.2%, and precipitation was 2.7%. Because the health behavior variables will mediate the association between the environmental variables and life expectancy, including these variables in the model should make the direct association between the environmental variables and life expectancy appear negligible. In the full model that includes the health behavior index, the amount of variation in life expectancy explained by altitude was 1.0%, average daily sunlight was 0.5%, maximum air temperature was 1.9%, and precipitation was 0.5%.

Life expectancy ranking by US state is shown in Table 3. Since high altitude is associated with factors that contribute to better life expectancy, it is not surprising that life expectancy adjusted for altitude caused states like Colorado, Utah, and Wyoming to fall in ranking 11, 7, and 8 places, respectively. On the other hand, adjustment for altitude increased the life expectancy ranking for Florida by 6 places. Additional adjustment for average daily sunlight, which is positively associated with life expectancy, caused the sunshine state Florida to subsequently fall back 6 places in ranking. If we further adjust for average daily maximum temperature, PM2.5, and precipitation, Florida improves in life expectancy ranking 13, 1, and 4 places, respectively. After accounting for all five natural environmental differences among the counties within the US states, the greatest increase in ranking is in Texas and the greatest decrease in ranking is in California.



A: altitude (m) - weighted; 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 1: Pearson correlation coefficients measuring the association between life expectancy and the natural environmental factors

Discussion

The current study shows that higher altitude living correlates with better life expectancy. This is consistent with previous studies showing that higher altitude living correlates with lower death rates from heart disease and stroke, cancer, diabetes, Alzheimer's disease, and all causes combined [7-16]. However, the positive correlation between altitude and life expectancy becomes negative and only 1.4% of the variation in life expectancy is explained by altitude after adjusting for the other natural environmental factors. In other words, higher average daily sunlight and lower average daily maximum air temperature, PM2.5, and precipitation, which are associated with higher altitude, explain much of the association between altitude and life expectancy. Physiological challenges resulting from hypoxia may also contribute to the negative effect of higher altitude on life expectancy in the adjusted model [17, 25, 30, 31]. Greater risk of COPD, suicide, pneumonia, and accidents has been linked to higher altitude living [7, 13, 17- 25]. On the other hand, health benefits may occur at higher altitude as the body makes positive adjustments to hypoxia [13, 32-35].

Average daily sunlight negatively correlates with life expectancy. However, after accounting for altitude, ambient air temperature, PM2.5, and precipitation, higher average daily sunlight is positively associated with life expectancy. Although excessive sun exposure can accelerate skin aging and cause skin cancer and cataracts, it is an excellent source of vitamin D, which has many well established health benefits [36]. The World Health Organization (WHO) has estimated globally that 3.3 billion disability-adjusted life years (DALYs) occur from very low levels of exposure to ultraviolet radiation, as opposed to 0.1% from very high levels of ultraviolet radiation [37].

Among the natural environmental variables, average daily maximum air temperature has the strongest association with life expectancy. In the United States, hot ambient air temperatures are related to a greater number of deaths each year than any other weather condition [38]. A study of 384 locations in 14 countries estimated that 7.7% of mortality is attributed to non-optimal ambient air temperature [39]. Research has also shown that in high-income countries, hot air temperature increases the risk of accidents and unintentional

Table 3: Life expectancy ranking by state after adjustment for environmental variables

Rank	Unadjusted	Altitude (m) - weighted	Average Daily Sunlight (KJ/m²)	Average Daily Max Air Temp (F)	Average Daily PM2.5	Average Daily Precipitation (mm)	Change in Ranking
1	Rhode Island	Rhode Island	Rhode Island	Connecticut	Rhode Island	Rhode Island	0
2	Connecticut	Connecticut	Connecticut	Rhode Island	Connecticut	Connecticut	0
3	Massachusetts	Massachusetts	Massachusetts	Nebraska	Washington	Washington	4
4	Minnesota	Minnesota	Minnesota	Washington	Minnesota	Nebraska	8
5	Colorado	New Jersey	Washington	Minnesota	Nebraska	Minnesota	-1
6	California	California	New Jersey	New Jersey	Massachusetts	Massachusetts	-9
7	Washington	Washington	New York	Colorado	New Jersey	New Jersey	1
8	New Jersey	New York	North Dakota	Massachusetts	Colorado	Colorado	-3
9	North Dakota	North Dakota	Vermont	Iowa	North Dakota	New York	1
10	New York	Wisconsin	Wisconsin	New York	New York	Iowa	5
11	Wyoming	Vermont	New Hamp	DC	Iowa	Florida	18
12	Nebraska	Nebraska	Iowa	North Dakota	DC	DC	9
13	Wisconsin	Iowa	California	Texas	Vermont	North Dakota	-4
14	Vermont	New Hamp	Nebraska	Wyoming	Wyoming	Vermont	0
15	Iowa	Oregon	Oregon	California	Florida	Wyoming	-4
16	Oregon	Colorado	DC	Florida	Texas	Texas	19
17	Idaho	DC	Maine	Wisconsin	Wisconsin	New Hamp	2
18	Utah	Maryland	Colorado	Vermont	New Hamp	Oregon	-2
19	New Hamp	Wyoming	Maryland	Oregon	Oregon	Wisconsin	-6
20	Montana	Idaho	Wyoming	Idaho	Montana	Maryland	4
21	DC	Maine	Idaho	Maryland	Maryland	Montana	-1
22	Nevada	Delaware	Pennsylvania	Illinois	Kansas	Kansas	10
23	Arizona	Florida	Montana	Pennsylvania	Idaho	California	-17
24	Maryland	Montana	Delaware	Montana	California	Pennsylvania	3
25	Maine	Utah	Michigan	New Hamp	Pennsylvania	Idaho	-8
26	Delaware	Pennsylvania	Illinois	Kansas	Arizona	Arizona	-3
27	Pennsylvania	Michigan	South Dakota	Arizona	South Dakota	Illinois	3
28	Michigan	Illinois	Utah	Utah	Illinois	Delaware	-2
29	Florida	Arizona	Florida	Delaware	Delaware	South Dakota	2
30	Illinois	Nevada	Virginia	Virginia	Utah	Utah	-12
31	South Dakota	South Dakota	Kansas	South Dakota	Virginia	Virginia	3
32	Kansas	Virginia	Nevada	North Carolina	Maine	Maine	-7
33	New Mexico	Kansas	Arizona	Michigan	Michigan	North Carolina	3
34	Virginia	Texas	Indiana	Indiana	North Carolina	Michigan	-6
35	Texas	North Carolina	Ohio	Nevada	Nevada	Missouri	4
36	North Carolina	Indiana	North Carolina	Maine	Missouri	Nevada	-14
37	Indiana	Ohio	Texas	Missouri	New Mexico	New Mexico	-4
38	Ohio	New Mexico	Missouri	Ohio	Indiana	Indiana	-1
39	Missouri	Missouri	New Mexico	New Mexico	Ohio	Georgia	1
40	Georgia	Georgia	Georgia	Georgia	Georgia	Louisiana	2
41	South Carolina	South Carolina	South Carolina	Louisiana	Louisiana	Ohio	-3
42	Louisiana	Louisiana	West Virginia	Oklahoma	Oklahoma	Oklahoma	2
43	West Virginia	Oklahoma	Louisiana	South Carolina	Arkansas	Arkansas	2
44	Oklahoma	West Virginia	Oklahoma	Arkansas	South Carolina	South Carolina	-3
45	Arkansas	Arkansas	Tennessee	West Virginia	West Virginia	West Virginia	-2
46	Tennessee	Tennessee	Arkansas	Tennessee	Tennessee	Tennessee	0
47	Alabama	Alabama	Kentucky	Alabama	Alabama	Alabama	0
48	Kentucky	Kentucky	Alabama	Kentucky	Mississippi	Mississippi	1
49	Mississippi	Mississippi	Mississippi	Mississippi	Kentucky	Kentucky	-1

injuries [40]. However, in the United States the direct effect of extreme ambient air temperature on life expectancy is mitigated by climate controlled vehicles, workplaces, and homes. The negative association between higher average daily maximum air temperature and lower life expectancy is likely explained by higher ambient air temperatures being related to less physical activity and more obesity [41, 42].

PM2.5 has a negative correlations with life expectancy. However, the correlation with life expectancy and the health behavior variables becomes small after adjusting for the other environmental variables. Nevertheless, research has shown that particulate matter pollution is associated with higher death rates from cardiovascular disease, homicide and legal intervention, unintended accidents, and suicide [43, 44].

The negative association between average daily precipitation and life expectancy persists after adjusting for the other environmental variables. Although extreme precipitation can cause automobile accidents, unintentional injuries, and suicide [45-48], and impair water quality (i.e., runoffs that may include heavy metals, pesticides, nitrogen, and phosphorus) [49], some of this result may be explained by precipitation influencing health behaviors that, in turn, effect life expectancy. The results show that average daily precipitation positively correlates with certain behaviors, including % adult smokers and % physically inactive.

In a model simultaneously accounting for the natural environmental variables, the amount of variation in life expectancy explained by average daily maximum air temperature was 15.1%. Average daily sunlight explained 6.8% of the variation, average daily precipitation explain 2.7% of the variation, and altitude explained 1.4% of the variation. The amount of variation explained by PM2.5 was only 0.2%. However, after including the health behavior index, all of these percent contributions to variation in life expectancy became very small. In the fully adjusted model, average daily maximum air temperature only directly explained 1.9% of the variation in life expectancy.

The cross-sectional, population-level data used in this study means that measures of association were on the group level and not the individual level. Hence, ecologic fallacy may influence the results. However, the environmental variables are experienced at similar levels among individuals within counties. Although a strong negative correlation was observed between average annual maximum air temperature and life expectancy the full impact of ambient air temperature was compromised by our climate-controlled homes, cars, and workplaces. In addition, the large number of counties considered resulted in mostly significant results. Some of the significant associations may not be of practical importance. Further, the fact that the natural environmental variables are primarily unmodifiable, response to the findings of this study may require people to move their residency. Finally, the cross-sectional ecologic data limit our being able to make statements about causality. Nevertheless, causal direction is clear in some situations, like higher altitude associates with cooler ambient air temperature, which, in turn, is more conducive with physical activity.

Conclusion

Higher altitude associates with better life expectancy. Other natural environmental and health behavior variables also associate with life expectancy. Once sunlight, ambient air temperature, PM2.5, and precipitation are accounted for, altitude correlates with worse life expectancy. Chronic hypoxia likely contributes in complex ways to this result. Average daily sunlight positively correlates with life expectancy, and average daily maximum air temperature, PM2.5, and precipitation negatively correlate with life expectancy. Ambient air temperature has the strongest negative association with life expectancy. The direct effects of these natural environmental variables on life expectancy are small, but appear to primarily influence life expectancy indirectly through their association with selected health behaviors.

Declarations

Ethical approval: IRB approval was not required as the study used publicly available datasets.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used in this study are available from the public domain. These datasets are described, with their sources referenced in the Methods section of this paper.

Competing interests

The author has no conflicts of interest to declare.

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Authors’ contributions

Conceptualization, data retrieval and analysis, and writing the manuscript was performed by the author.

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