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Relationship between Ambient Temperature and Mental Health in the USA †

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Abstract: Climatic variables such as temperature have been shown to correlate with demand for mental health services in other countries. An attempt by the present study to replicate this correlation using existing USA treatment data on mental health was not substantiated. Using annual state-level data from 2007 through 2015, the rate of mental health service utilization per 1000 population was correlated with average temperature and precipitation, while adjusting for Gross Domestic Product (GDP), unemployment, and urbanization. No statistically significant correlation was found.

Keywords: climate; impact; health; temperature; precipitation; unemployment rate; urbanization; gross domestic product; behavioral health

1. Introduction

It is clear that the ambient temperature impacts public health (e.g., [1]), and global climate change and local effects such as urban heat island will therefore have subsequent health impacts. Rising temperatures, in particular, are a cause of concern and are likely to increase both morbidity [2] and mortality [3], especially in vulnerable populations. However, the impacts of temperature on behavioral health (substance abuse and mental health) have not received as much attention as those on physical health. A number of Australian and Canadian studies indicate that rising temperatures can also lead to exacerbation of behavioral health issues, causing increases in, for example, emergency room visits due to mental health [4,5]. Researchers have begun to develop a framework to understand the relationship between temperature and mental health [6]. An Australian study [7] quantified the temperature threshold for triggering mental-illness-related emergency visits during extreme heat events. Another study [8] focused on such impacts on women.

Interestingly, very little attention appears to have been paid to the issue of environmental impacts on substance use and mental health disorders in the USA. This is especially remarkable given the exposure of parts of the USA to extreme temperatures, such as the southwestern USA and most (if not all) of the major cities that are subject to urban heat island effects. This paper is an attempt to establish the relationship between differences in climate across states and over time within states and the utilization of mental health services. Unlike other studies, this paper uses available official treatment data on mental health collected across states over time. The choice to use these state-level data presents as a viable alternative to using primary data, which are usually collected to conduct this type of research. The state and federal governments have been supporting the collection of the mental health treatment data and thus it would be worthwhile to test their potential for use.

2. Methods

We begin an analysis of this relationship in the USA by examining and correlating climatic data for US states with the rate of mental health service utilization per 1000 population, which is commonly called the *penetration rate*. For the purposes of this study, we focus on mental health services and reserve substance abuse instances for a future study. For all 50 USA states as well as the District of Columbia, we attempt to correlate temperature and select economic indicators against a mental health indicator (i.e., penetration rate) using multiple linear regression analysis. We started by including all independent variables in the equation and systematically excluding variables suspected to be correlated with another variable (for example, using all temperature variables and excluding one variable at a time or using a combination of variables) and/or reducing the number of variables in the equation.

Data Sources: The data used for the analysis come from a variety of sources as described below.

2.1. Climate Data

Climatic data were obtained from the National Oceanic and Atmospheric Administration (NOAA)'s National Centers for Environmental Administration, which contains the *Climate at a Glance* resource [9]. As discussed in the next subsection, we were constrained since mental health data are available only at the state level, and only year-long averages are provided for the years 2007 through 2015. We therefore collected corresponding climate data for the same years, with annually averaged data for each state and the District of Columbia. Reference [9] provided state-wide minimum temperature, maximum temperature, average temperature, and precipitation.

2.2. Mental Health Data

The mental health data are collected annually from the State Mental Health Authorities (SMHAs) in all 50 states, the District of Columbia, and the eight U.S. territories through the Uniform Reporting System (URS) [10]. For this study, data from the territories are excluded. Data collection is supported and funded by the Substance Abuse and Mental Health Services Administration (SAMHSA) within the U.S. Department of Health and Human Services (DHHS).

Official mental health data in the URS are the only treatment data from publicly-funded mental health programs under the auspices of the SMHAs. Data are reported using standard protocol. Data reporting from the states started in 2003, but the first complete data set from all the states is available only beginning in 2007. For the purposes of this study, the penetration rate (or treated prevalence rate) is the dependent variable. It is the ratio of the number of individuals who received mental health treatment services to the total number of state population. The numerator is the unique count of individuals who received a mental health service from the SMHA during a 12-month reporting period, and the denominator is the state population, expressed per 1000 population. An individual who received a service during the reporting period is counted only once in the numerator, although the person may have received different types of services many times during the year. Some confounding factors may affect a state's penetration rates over time or between states. These factors include but are not limited to the state's reporting capacity, characteristics of the state's mental health service delivery system, funding levels, state-identified priority populations receiving publicly-funded mental health services, etc.

2.3. GDP, % Urban, and Unemployment Data

Recognizing that climate variables are not the only factors that can affect the rate at which mental health services are received, we also consider both economic variables and living environment. The economic proxy variables are per capita real gross domestic product (GDP) and unemployment rate—averaged both statewide and annually—for the same years for which mental health data are available (2007–2015). The statewide per capita real GDP (in chained 2009 dollars) is from the USA Bureau of Economic Analysis [11], while the unemployment rate (in %) is from the USA Bureau of Labor Statistics [12]. Meanwhile, the living environment is characterized as the percentage of a statewide population that lives in an urban area, defined here as a community of at least 50,000 people by the USA Census Bureau [13]. Since the last national census was taken in 2010 (it is normally done every 10 years), we used the 2010 value and assumed that the percent of a state's population that lives in such urban areas did not change over the period 2007–2015. For all other variables, however, we considered annual averages over the same time periods.

As stated above, we gathered data for all 50 states plus the District of Columbia, which contains the city of Washington, DC. Rather than showing tables for all 50 states and the District of Columbia, Table 1 presents the data for three representative states: Arizona, Ohio, and Minnesota. These three states are in dramatically different climate zones. According to the climate zones defined by the US Department of Energy Building America Program [14], Arizona is largely in the "Hot-Dry" zone, Ohio is largely in the "Cold" zone, and Minnesota is mostly in the "Cold/Very-Cold" zone. The diversity of climate zones in the USA contributes to the difficulty in establishing quantitative relationships between health indicators (like the penetration rates used here) and climate variables, given that individual states can be very different in other ways besides climate.

Table 1. Annual data (2007–2015) for three representative USA states.

ARIZONA								
Year	**Ave. Temp. * (°C)**	**Min. Temp. * (°C)**	**Max. Temp. * (°C)**	**Precipitation (cm)**	**Per Capita Real GDP ($)**	**Percent Urban (%)**	**Unemploy-ment Rate (%)**	**Penetration Rate per 1000 Population**
2007	16.44	8.50	24.39	27.91	$44,168		3.9	23.35
2008	15.89	7.94	23.83	31.27	$41,800		5.9	22.32
2009	16.17	8.11	24.17	17.86	$38,232		10.0	24.44
2010	15.78	8.06	23.44	35.33	$37,935	89.81	10.4	25.63
2011	15.72	7.72	23.78	24.46	$38,257		9.5	25.34
2012	16.72	8.56	24.89	24.28	$38,559		8.2	28.86
2013	15.83	7.94	23.67	30.81	$38,303		8.0	29.27
2014	16.83	8.89	24.72	28.12	$38,427		7.0	23.85
2015	16.56	8.89	24.17	36.55	$38,414		6.0	23.03
AVERAGES	16.22	8.29	24.12	28.51	$39,344	89.81	7.7	25.12
OHIO								
Year	**Ave. Temp. * (°C)**	**Min. Temp. * (°C)**	**Max. Temp. * (°C)**	**Precipitation (cm)**	**Per Capita Real GDP ($)**	**Percent Urban (%)**	**Unemploy-ment Rate (%)**	**Penetration Rate per 1000 Population**
2007	11.28	5.50	17.00	104.55	$44,399		5.6	26.97
2008	10.33	4.61	16.11	112.01	$43,548		6.5	28.01
2009	10.28	4.72	15.89	92.71	$41,593		10.3	29.49
2010	10.94	5.28	16.61	93.37	$42,667	77.92	10.1	30.77
2011	11.28	5.94	16.61	142.11	$44,192		8.7	31.45
2012	12.22	6.33	18.17	94.69	$44,896		7.2	31.63
2013	10.50	5.17	15.83	105.89	$45,254		7.6	33.08
2014	9.56	3.94	15.17	97.94	$46,385		5.6	34.46
2015	10.89	5.22	16.61	109.27	$46,826		4.9	35.80
AVERAGES	10.81	5.19	16.44	105.84	$44,418	77.92	7.4	31.30
MINNESOTA								
Year	**Ave. Temp. * (°C)**	**Min. Temp. * (°C)**	**Max. Temp. * (°C)**	**Precipitation (cm)**	**Per Capita Real GDP ($)**	**Percent Urban (%)**	**Unemploy-ment Rate (%)**	**Penetration Rate per 1000 Population**
2007	5.78	0.06	11.56	74.19	$51,351		4.6	16.61
2008	4.11	−1.78	10.06	69.44	$51,234		5.5	31.37
2009	4.50	−1.17	10.17	67.01	$48,884		7.8	34.13
2010	6.06	0.28	11.78	84.94	$50,148	73.27	7.3	36.87
2011	5.56	−0.11	11.28	61.85	$50,875		6.5	39.25
2012	7.33	1.33	13.39	66.47	$51,272		5.8	41.45
2013	4.06	−1.61	9.72	73.69	$51,999		4.9	38.47
2014	3.72	−1.89	9.33	73.96	$53,005		4.0	37.01
2015	6.39	0.67	12.11	74.83	$53,380		3.8	39.04
AVERAGES	5.28	−0.47	11.04	71.82	$51,350	73.27	5.6	34.91

* "Ave. Temp." = Average Temperature, "Min. Temp." = Minimum Temperature, "Max. Temp." = Maximum Temperature.

3. Results

Table 2 presents all the collected data for the 50 states and the District of Columbia (DC), averaged over the years 2007–2015. This allows a side-by-side comparison of the displayed variables: average temperature, minimum temperature, maximum temperature, precipitation, real GDP per capita,

% urban population, unemployment rate, and finally the penetration rate per 1000 people (our variable that indicates the rate at which behavioral health services are availed).

Table 2. Average statewide data for the years 2007–2015.

State	Ave. Temp. (°C)	Min. Temp. (°C)	Max. Temp. (°C)	Precipitation (cm)	Per Capita Real GDP ($)	% Urban Population	Unemployment Rate (%)	Penetration Rate per 1000 Population
ALABAMA	17.46	11.05	23.88	140.57	$36,496	59.04	7.69	21.24
ALASKA	−2.54	−6.75	1.67	94.31	$69,488	66.02	7.14	27.42
ARIZONA	16.22	8.29	24.12	28.51	$39,344	89.81	7.66	25.12
ARKANSAS	16.04	10.02	22.06	136.38	$35,232	56.16	6.93	24.62
CALIFORNIA	15.12	8.01	22.23	46.58	$53,871	94.95	8.94	17.17
COLORADO	7.83	0.13	15.54	45.93	$50,752	86.15	6.28	18.74
CONNECTICUT	10.07	4.50	15.64	122.11	$65,003	87.99	7.19	24.57
DELAWARE	13.55	8.07	19.03	113.88	$63,336	83.30	6.44	10.45
FLORIDA	21.87	16.02	27.72	132.49	$39,238	91.16	7.66	14.29
GEORGIA	17.81	11.41	24.21	124.84	$43,195	75.07	7.96	16.00
HAWAII	23.42	19.27	27.55	108.22	$49,805	91.93	5.30	11.28
IDAHO	6.67	0.06	13.30	58.59	$35,193	70.58	6.36	8.68
ILLINOIS	11.32	5.69	16.96	109.31	$51,776	88.49	8.03	11.86
INDIANA	11.19	5.51	16.88	112.95	$43,399	72.44	7.46	16.87
IOWA	8.87	3.11	14.62	96.42	$47,425	64.02	4.88	32.26
KANSAS	12.76	5.78	19.75	72.51	$45,414	74.20	5.51	42.70
KENTUCKY	13.44	7.34	19.56	128.41	$37,883	58.38	7.79	35.09
LOUISIANA	19.47	13.62	25.29	142.49	$45,830	73.19	6.52	11.10
MAINE	5.61	0.05	11.18	123.63	$38,127	38.66	6.56	46.13
MARYLAND	13.04	7.48	18.60	113.52	$53,622	87.20	6.03	23.09
MASSACHUSETTS	9.46	3.88	15.01	126.15	$61,643	91.97	6.50	4.43
MICHIGAN	7.29	1.78	12.81	86.66	$40,287	74.57	9.04	23.04
MINNESOTA	5.28	−0.47	11.04	71.82	$51,350	73.27	5.58	34.91
MISSISSIPPI	17.80	11.51	24.07	143.16	$31,838	49.35	8.34	33.54
MISSOURI	12.81	6.84	18.77	115.50	$42,366	70.44	7.03	12.53
MONTANA	5.90	−0.88	12.67	49.40	$38,284	55.89	5.69	32.96
NEBRASKA	9.59	2.57	16.62	63.55	$50,261	73.13	3.86	14.50
NEVADA	10.67	3.01	18.33	23.64	$45,451	94.20	9.43	11.41
NEW HAMPSHIRE	6.81	0.89	12.73	127.81	$48,675	60.30	4.83	36.69
NEW JERSEY	12.12	6.60	17.64	123.36	$55,895	94.68	7.51	38.74
NEW MEXICO	12.49	4.06	20.91	33.77	$40,579	77.43	6.63	38.25
NEW YORK	7.88	2.38	13.39	113.34	$61,476	87.87	7.00	35.72
NORTH CAROLINA	15.33	9.19	21.45	123.45	$43,734	66.09	7.94	24.04
NORTH DAKOTA	4.85	−1.40	11.10	50.05	$58,332	59.90	3.29	25.06
OHIO	10.81	5.19	16.44	105.84	$44,418	77.92	7.39	31.30
OKLAHOMA	15.72	9.02	22.44	91.21	$41,410	66.24	5.24	16.91
OREGON	8.83	2.35	15.28	79.61	$48,781	81.03	8.12	30.00
PENNSYLVANIA	9.70	4.00	15.39	114.82	$47,462	78.66	6.68	41.20
RHODE ISLAND	10.51	5.30	15.70	123.79	$46,315	90.73	8.86	28.97
SOUTH CAROLINA	17.42	11.07	23.77	118.10	$36,043	66.33	8.32	18.27
SOUTH DAKOTA	7.46	0.80	14.10	56.02	$46,320	56.65	4.01	17.08
TENNESSEE	14.63	8.51	20.78	136.27	$40,887	66.39	7.63	32.97
TEXAS	18.77	11.81	25.73	69.54	$49,971	84.70	6.09	11.82
UTAH	9.52	2.34	16.72	33.67	$42,799	90.58	5.14	15.88
VERMONT	6.33	0.60	12.04	122.98	$42,431	38.90	4.96	37.50
VIRGINIA	13.35	7.30	19.40	113.47	$51,656	75.45	5.44	14.11
WASHINGTON	8.41	3.04	13.77	109.87	$54,012	84.05	7.30	20.71
WEST VIRGINIA	11.39	5.33	17.44	117.64	$35,385	48.72	6.84	31.55
WISCONSIN	6.47	0.74	12.19	85.88	$45,195	70.15	6.51	15.95
WYOMING	5.73	−1.48	12.94	41.20	$63,715	64.76	4.82	32.55
DISTRICT OF COLUMBIA	13.31	7.63	19.00	104.88	$164,536	100.00	8.17	33.78

Since the focus of this article is on the impact of climate on mental health, a graphical representation of the average temperatures for each state and DC is provided in Figure 1. The error bars in this figure represent the range of maximum and minimum temperatures, averaged over the 2007 to 2015 time period.

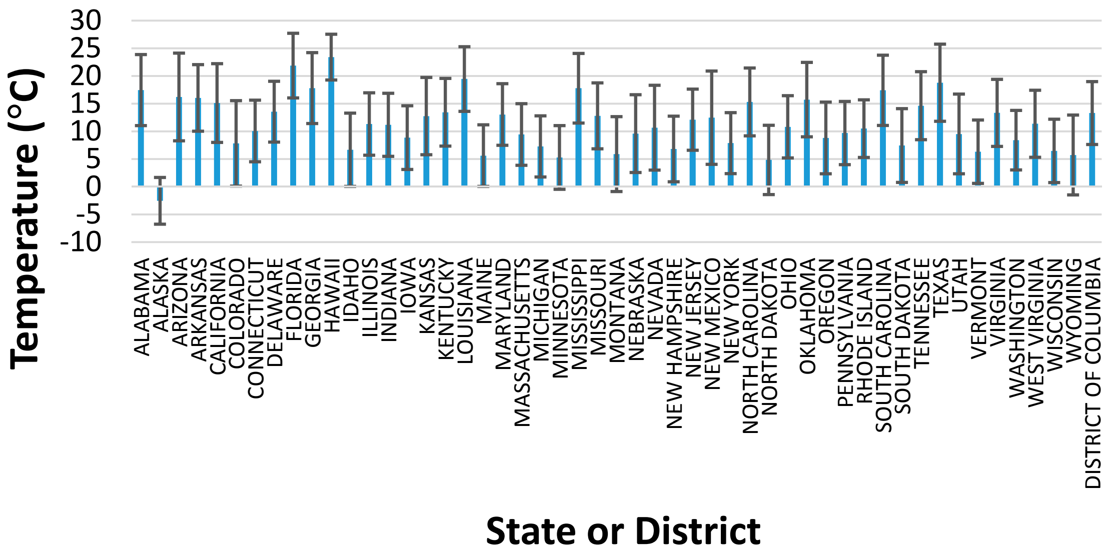

Figure 1. Average statewide temperatures, averaged over the years 2007 to 2015, with error bars showing the average maximum and minimum temperatures during the same period.

Our attempt at multivariate regression analysis will be discussed in the next section. Before that, we single out the effects of two independent variables that may have an impact on the utilization of mental health services: average temperature and the fraction of a state's population that lives in urban areas. Beginning with average temperature, Figure 2 presents the penetration rate as a function of only the average temperature, for the time period 2007–2015.

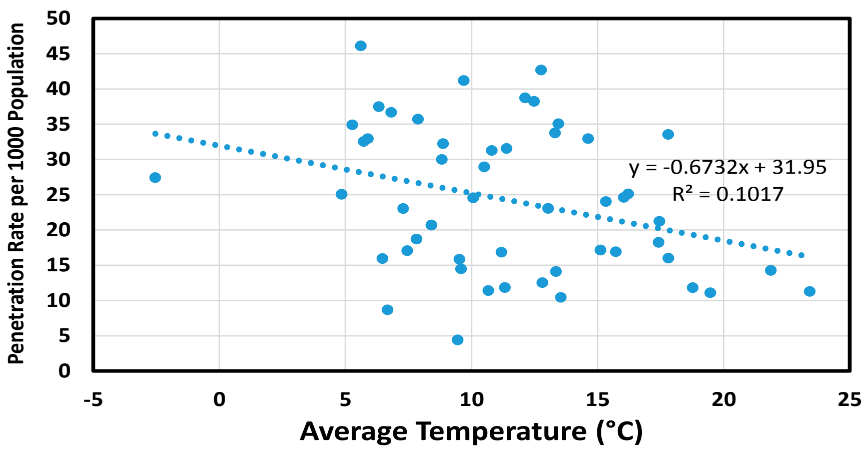

Figure 2. Penetration rate as a function of the statewide average temperature, averaged over the years 2007 to 2015.

The assumed linear correlation suggests that as temperature increases, the penetration rate decreases. However, there are other potentially confounding factors, including the other variables given in Table 2. We therefore divided the 50 states and the District of Columbia into six groups, ranging from the lowest average temperatures (−3 to 6 °C) to the highest average temperatures (17 to 23 °C). These grouped temperature results are presented in Figure 3 as a function of the year. Interestingly, the states with the lowest average temperatures show the highest penetration rates, while those with the highest temperature show the lowest. States with intermediate average temperatures fall between these two groups.

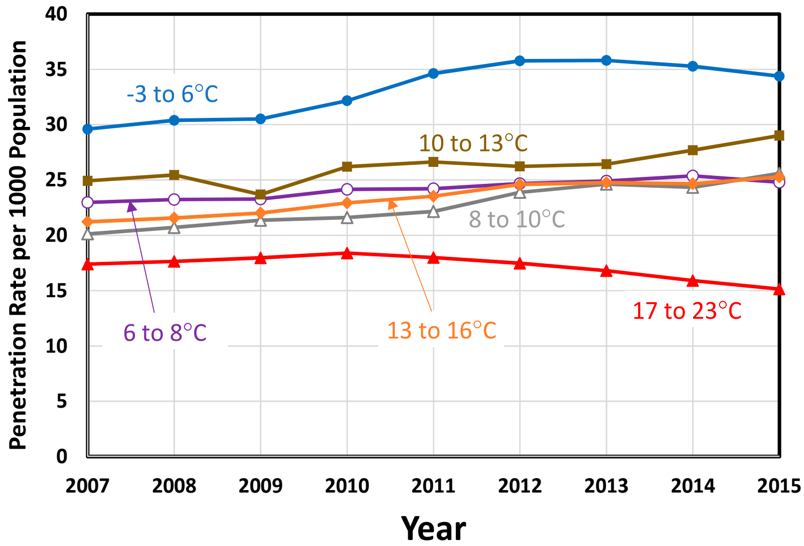

Figure 3. Penetration rate as a function of the average temperature, over the period 2007 to 2015.

Another variable which appears to be important for mental health service utilization is the fraction, or percentage, of the population that lives in urban areas. Similar to the results in Figure 3, the 50 states plus the District of Columbia were divided into six groups, ranging from the least urbanized (less than 50%) to the most urbanized (91 to 100%). These results are plotted in Figure 4, again as a function of the year. Perhaps contrary to expectations, the more rural states exhibit the highest penetration rates, while the most urbanized exhibit the lowest.

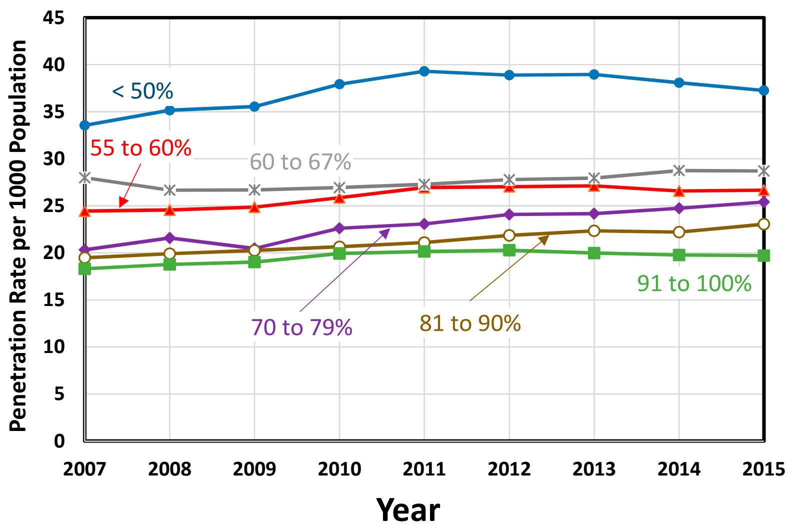

Figure 4. Penetration rate as a function of the percentage of the population that lives in urban areas, over the period 2007 to 2015.

A similar attempt was made to group the data by precipitation amount, but no clear dependence on precipitation was seen. This is in contrast to a previous study linking the amount of sunshine to suicide attempts [15], but it should be noted that the annualized data that we are considering makes it impossible to distinguish the amount of sunshine on any given day.

4. Multiple Linear Regression Attempt

Results of the multiple regression did not show any significant relationships between climate indicators and the rate of mental health service utilization (Table 3) as some of the studies earlier cited in this paper [3–7] suggested, but in agreement with [8]. The results derived from this study suggest that high temperatures do not necessarily correlate with an increased utilization of mental health services. The traditional factors that account for low mental health service utilization—such as one's low perception of the need for services, lack of insurance, prohibitive cost of treatment, stigma, or even the perception that treatment would not help—may partially explain why a linear and strong correlation was not shown [16]. In addition, the regression analysis did not account for the lag time effect of high temperatures in service utilization rates, which was observed in [5]. This may have provided important insights on the gestation period when the interaction between high temperature and one's emotional and behavioral well-being leads an individual to seek treatment. The analysis was also limited by the aggregate nature of the data, which did not allow for determining the duration of extreme temperatures (very low or very high).

Table 3. Regression statistics when considering all dependent variables.

SUMMARY OUTPUT (All Variables)					
Regression Statistics					
Multiple R	0.54				
R Square	0.29				
Adjusted R Square	0.17				
Standard Error	9.48				
Observations	51				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	1551.28	221.61	2.46	0.03
Residual	43	3867.19	89.93		
Total	50	5418.47			
	Coefficients	*Standard Error*	*t Stat*	*p-Value*	
Intercept	11.55	25.24	0.46	0.65	
Average Temperature (°C)	−116.43	212.08	−0.55	0.59	
Minimum Temperature (°C)	56.32	106.29	0.53	0.60	
Maximum Temperature (°C)	59.37	105.85	0.56	0.58	
Precipitation (cm)	0.08	0.08	1.07	0.29	
Per Capita Real GDP ($)	0.00	0.00	1.51	0.14	
% Urban Population	−0.26	0.13	−1.94	0.06	
Unemployment Rate	1.03	1.13	0.91	0.37	

An interesting observation from the regression is the suggested inverse relationship between average temperature and mental health penetration (utilization rate). As supported by the state data in Table 2, the states with lower average temperature have higher rates. That is, colder states report higher rates of mental health service utilization. Although this may not be totally surprising as explained by the condition of *seasonal affective disorder*, the limitation of the data as earlier cited was not able to confirm this explanation. Seasonal affective disorder (SAD) means that "some people experience a serious mood change during the winter months, when there is less natural sunlight. SAD is a type of depression. It usually lifts during spring and summer [17]."

5. Discussion

An analysis of USA state-wide annualized mental health data for the years 2007 through 2015 reveals that the states with the lowest average temperatures exhibit the highest utilization of mental health services, while the states with the highest average temperatures exhibit the lowest. Similarly, the most rural states have a higher utilization of mental health services than more urban states.

An attempt at multivariate regression analysis did not yield statistically significant results, perhaps because the available mental health data are only available at the state-wide level and are given as annual averages, and therefore do not allow the effects of localized transient climatic conditions to be considered.

This study suggests that relationships are harder to determine when using aggregate data. This raises the concern on the usefulness of available secondary treatment data across all 50 US states when examining the impact of climate on mental health. Using primary data to examine the impact of climate on mental health is too costly, in effect becoming an obstacle for further inquiry on this subject matter. Lower units of analysis or disaggregated data such as person-level data on treatment, and episodes of treatment with time factor may all be helpful. Modification in data collection protocols may bring greater research capacity and more meaningful, conclusive findings.

6. Conclusions

An examination of statewide-aggregated mental health service utilization data in the USA revealed no statistically significant relationship between ambient temperature and penetration rate per 1000 population. Potentially confounding variables that were analyzed included precipitation, per capita gross domestic product, unemployment rate, and the percentage of the state's population that lives in rural vs. urban areas. Although no statistically significant correlations were found with any of these variables, the results suggest that states with lower average temperatures and percent urbanization have populations with greater mental health service utilization. Analyzing disaggregated data, especially with finer time resolution, may allow quantitative relationships between mental health service utilization and these variables to be determined.

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Conflicts of Interest: The authors declare no conflict of interest.

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