

Correlations Between Temperature Exposure and Mental Disorders: A Global Ecological Study

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Abstract

Background: Previous studies have presented inconsistent findings regarding the association between ambient temperature and mental disorders. This study was conducted to systematically investigate the correlation between temperature variations and the prevalence of mental disorders on a global scale.

Methods: This ecological study extracted data on temperature and mental disorders for 204 countries from the Global Burden of Disease website. Correlation analyses between these variables were performed using SPSS version 22.

Results: Our findings revealed that anxiety disorders were least prevalent in Japan and most prevalent in Mexico City. A significant positive correlation was observed between average annual temperature ($r=0.226$, $p \leq 0.001$) and low-temperature exposure ($r=0.126$, $p \leq 0.001$) with anxiety disorders. Furthermore, average annual temperature ($r=0.137$, $p=0.018$) and low-temperature exposure ($r=0.057$, $p=0.024$) were positively and significantly correlated with major depressive disorder. Singapore reported the lowest prevalence of mental disorders, while the United States reported the highest. A positive significant correlation was found between suicide rates and average annual temperature ($r=0.226$, $p=0.030$).

Conclusion: Elevated average annual temperatures were significantly correlated with an increase in major depressive disorders, while exposure to low temperatures was associated with a reduction in these disorders. These findings highlight the potential impact of climate on mental health and emphasize the need to implement effective public health strategies and provide accessible mental health services, especially in regions experiencing significant temperature fluctuations.

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Introduction

Mental health is an essential component of overall health and well-being, extending beyond the mere absence of mental disorders. It is influenced by a complex interplay of social, biological, and environmental factors, and maintaining it depends on effective multisectoral and population-based strategies. Promoting mental health

enables individuals to manage everyday stress, work productively, and contribute meaningfully to their communities.¹

Mental disorders vary in prevalence. Some, such as schizophrenia and bipolar disorder, are relatively less common, while others—such as depression, anxiety, and substance use disorders—are far more

widespread. Environmental stressors, particularly extreme weather events, can significantly affect mental well-being. For instance, floods—among the most frequent natural disasters—have been associated with increased rates of anxiety, depression, and post-traumatic stress disorder (PTSD). In severe cases, these conditions may heighten the risk of suicide.²

According to the most recent assessment by the Intergovernmental Panel on Climate Change (IPCC), greenhouse gas emissions resulting from human activities are the primary drivers of current global climate change. It is projected that, depending on future mitigation efforts, global temperatures will rise between 1.8°C and 4.0°C by the year 2100 [3]. Such changes are expected to cause greater climate variability, including more frequent and intense extreme weather events such as heatwaves and severe storms. Notably, cities such as Cairo and Athens are already experiencing temperature increases exceeding the global average.^{3,4} The impact of climate disasters like droughts on mental health hasn't been well studied, but they are likely to lead to issues such as depression.⁵

A study examined the effects of temperature and humidity on mental health. It found that increases in temperature and humidity correspond to slight increases in psychological distress. However, when humidity is very high, the negative impact of heat on mental health is amplified. This suggests that humidity intensifies the adverse effects of heat on mental well-being and should be considered in healthcare planning for climate change.⁶ Most of the world's suicides occur in poor countries, but there is little information about the causes of these suicides in these countries. India alone accounts for a fifth of the world's suicides, and since 1980, the global suicide rate has doubled. Studies show that climate change, especially the increase in temperature, has a great impact on the suicide rate. When the temperature exceeds 20°C, an increase of 1°C can cause about 70 suicides on average. This occurs mostly during the crop-growing season in India, when heat also reduces crop yields. In the last 30 years, global warming has been estimated to have caused 59,300 suicides in India, which is 6.8% of the overall increase in suicides.⁷

Therefore, the present study aimed to determine the correlation between temperature changes (e.g., average temperature and temperature changes, exposure to high and low temperatures) with mental disorders (e.g., major depressive disorder, bipolar disorder, anxiety, self-harm, and suicide).

Methods

As defined by the World Health Organization (WHO),

mental disorders encompass a range of conditions, including bipolar disorder, depression, anxiety disorders, Post-Traumatic Stress Disorder (PTSD), eating disorders, schizophrenia, disruptive behavior and dissociative disorders, and neurodevelopmental disorders. For this study, we collected global data about anxiety disorder, bipolar disorder, self-harm, suicide, major depressive disorder, and broader mental disorders from <https://www.healthdata.org/> for 204 countries.

Concurrently, data on annual average temperature, exposure to high and low temperatures, and temperature changes were sourced from <https://tradingeconomics.com/country-list/temperature>. The Socio-Demographic Index (SDI), a composite measure of country or regional development, was also included. This index, ranging from 0 to 1, integrates factors such as per capita income, education level, and fertility rate. Data for the SDI from 1990 to 2019 were extracted from <https://ghdx.healthdata.org/record/ihme-data/gbd-2019-socio-demographic-index-sdi-1950-2019>.⁸

Exposure to high and low temperatures was defined according to the methodology by Katrin G. Burkart et al.,⁹ based on the 1st and 99th percentiles of daily average temperatures. Pearson's correlation coefficient was used to assess associations among the study variables, with results visualized as a heatmap. Additionally, the spatial distribution of changes in mental disorders, major depressive disorder, anxiety disorder, self-harm, and suicide between 1990 and 2019 was illustrated using global maps created with Datawrapper (<https://www.datawrapper.de/>).

All downloaded data, initially in Excel format, were cleaned and prepared for analysis. Subsequent data entry and analysis were conducted using Microsoft Excel and Stata version 12, respectively. A p-value of 0.05 was set as the threshold for statistical significance.

Ethical Consideration

This study was approved by the Ethics Committee of Shiraz University of Medical Sciences (IR.SUMS.SCHEANUT.REC.1402.096).

Results

The difference in the incidence of anxiety disorders between 1990 and 2019 was lowest in Japan (-0.113) and highest in Mexico City (0.185). Regarding depressive disorders, Singapore showed the lowest change at -0.346, while the United States experienced the highest increase at 0.311. Similarly, for overall mental disorders, Singapore recorded the lowest change (-0.257), and the United States showed the highest (0.250).

In terms of self-harm, China exhibited the least change, with a decrease of -0.553, whereas Saudi Arabia had the greatest increase at 0.832. Regarding suicide rates, Turkey had the lowest (2.29), and Guam had the highest (53.34).

The spatial distribution of mental disorders worldwide from 1990 to 2019 is illustrated in Supplementary Figures 1-5. Additional details on changes in the incidence of mental disorders, as well as data on average, minimum, and maximum temperatures, are presented in Table 1.

Table 1: Incidence rate Change 2019-1990 of some of mental disorders in world

Country	Mental disorders	Major depressive disorder	Bipolar disorder	Anxiety disorder	Self-harm incidence	Suicide	Average temperature (C°)	Low temperature (Summary exposure)	High temperature (Summary exposure)
Afghanistan	NR	-0.01	NR	.04	-0.13	-2.15	14.3	-0.24 (-0.39,-0.11)	-0.34 (-0.51,-0.16)
Albania	0.05	0.05	NR	0.03	0.56	0.83	12.92	-0.41 (-0.55,-0.27)	0.95 (-0.88,5.04)
Algeria	0.02	0.04	NR	.04	-0.20	-2.99	23.93	-0.34 (-0.45,-0.18)	-0.37 (-0.50,0.09)
American Samoa	-0.01	-0.02	NR	0.03	0.14	0.08	27.34	NR	1.11 (-2.11,2.80)
Andorra	-0.01	-0.02	0.02	0.01	-0.15	-2.57	8.43	-0.34 (-0.51,-0.13)	NR
Angola	-0.04	-0.05	NR	-0.01	-0.02	-5.3	21.74	-0.39 (-0.54,-0.18)	-0.08 (-0.59,0.77)
Antigua and Barbuda	0.01	NR	NR	0.01	0.23	0.43	27.33	NR	-0.52 (-1.15,-0.20)
Argentina	-0.03	-0.05	0.06	NR	0.49	1.84	15.4	-0.17 (-0.27,-0.06)	0.32 (-0.14,1.71)
Armenia	0.08	0.07	NR	0.01	0.82	4.56	8.84	-0.31 (-0.42,-0.20)	4.54 (1.67,60.77)
Australia	0.01	NR	0.02	0.04	NR	-2.41	22.06	-0.57 (-0.61,-0.54)	-0.37 (-0.51,0.24)
Austria	-0.13	-0.19	0.01	0.03	-0.34	-8.16	7.35	-0.49 (-0.56,-0.41)	6.57 (-61.16,317.42)
Azerbaijan	NR	-0.01	NR	-0.02	0.24	0.13	14.29	0.06 (-0.05,0.19)	2.57 (1.63,4.40)
Bahamas	-0.01	-0.02	NR	0.01	0.06	-0.18	25.5	-0.60 (-0.81,-0.43)	-0.26 (-0.64,0.09)
Bahrain	-0.10	-0.12	NR	0.02	0.33	-1.12	29.15	NR	-0.09 (-1.31,0.66)
Bangladesh	-0.03	-0.04	NR	0.03	-0.37	-7.08	25.68	-0.15 (-0.37,0.48)	0.06 (-0.31,0.59)
Barbados	0.01	0.01	NR	0.01	-0.07	-0.63	26.64	NR	-0.01 (-1.13,0.69)
Belarus	-0.02	-0.03	NR	-0.01	-0.02	-1.28	7.33	-0.22 (-0.40,-0.02)	NR
Belgium	0.08	0.10	0.01		-0.10	-3.03	10.47	-0.45 (-0.51,-0.35)	1.29 (-0.38,45.94)
Belize	0.04	0.04	NR	0.02	0.11	1.72	26.15	-0.67 (-0.85,-0.48)	2.07 (-1.53,5.64)
Benin	0.03	0.03	NR	0.02	0.12	-0.18	28.7	NR	-0.08 (-0.62,0.41)
Bhutan	-0.05	-0.07	NR	0.04	-0.01	-2.82	10.8	-0.13 (-0.31,0.11)	-0.06 (-20.70,22.70)
Bolivia	-0.07	-0.10	NR	0.01	0.09	-0.95	20.82	-0.41 (-0.52,-0.29)	-0.05 (-0.37,0.29)
Bosnia and Herzegovina	-0.17	-0.22	NR	NR	0.01	-1.6	10.66	-0.20 (-0.34,-0.03)	3.03 (-7.98,33.63)
Botswana	0.03	0.03	NR	NR	0.21	0.33	21.74	-0.20 (-0.41,0.05)	0.67 (-0.11,1.65)
Brazil	-0.03	-0.07	NR	0.15	-0.18	-1.57	25.58	-0.62 (-0.65,-0.57)	0.30 (-3.63,3.79)
Bulgaria	-0.11	-0.15	NR	-0.01	-0.37	-6.57	11.98	-0.29 (-0.41,-0.15)	-0.17 (-1.16,0.63)
Burkina Faso	-0.02	-0.02	NR	0.01	0.12	-1.01	30.01	NR	-0.07 (-0.71,0.42)

Country	Mental disorders	Major depressive disorder	Bipolar disorder	Anxiety disorder	Self-harm incidence	Suicide	Average temperature (C°)	Low temperature (Summary exposure)	High temperature (Summary exposure)
Burundi	-0.17	-0.19	NR	0.02	-0.24	-7.7	20.53	-0.39 (-0.52,-0.21)	-0.61 (-7.80,10.88)
Cambodia	-0.10	-0.14	NR	0.03	-0.14	-2.61	27.44	-0.82 (-0.94,-0.14)	0.04 (-0.69,0.96)
Cameroon	0.03	0.04	NR	0.01	0.25	1.49	25.21	-0.39 (-0.62,-0.20)	0.09 (-0.39,0.60)
Canada	NR	NR	0.03	-0.01	0.04	-2.53	-3.71	-0.48 (-0.56,-0.27)	-0.40 (-4.59,10.23)
Cape Verde	NR	NR	NR	NR	NR	3.15	NR	NR	NR
Central African Republic	-0.01	-0.02	NR	0.03	-0.11	-4.31	25.78	-0.41 (-0.68,-0.21)	0.21 (-0.22,0.65)
Chad	0.03	0.03	NR	0.04	0.20	2.49	27.72	-0.16 (-0.68,68,0.49)	-8 (-0.48,0.32)
Chile	-0.14	-0.15	0.06	0.05	-0.15	-10.41	9.88	-0.53 (-0.59,-0.47)	-0.66 (-8.43,186.33)
China	-0.08	-0.13	NR	-0.06	-0.55	-13.82	8.19	-0.52 (-0.59,-0.43)	-0.35 (-0.54,-0.10)
Colombia	-0.07	-0.11	NR	0.02	0.34	0.63	24.97	-0.61 (-0.69,-0.52)	0.28 (-1.51,1.14)
Comoros	-0.04	-0.05	NR	0.02	0.09	-1.83	23.51	-0.64 (-1.01,2.88)	1.03 (-34.49,51.61)
Congo	-0.08	-0.09	NR	NR	-0.22	-8.88	25.23	-0.61 (-0.77,-0.50)	0.74 (-1.70,2.46)
Costa Rica	0.05	0.05	NR	0.03	0.16	1.32	24.94	-0.37 (-0.50,-0.21)	0.93 (-4.09,4.00)
Croatia	-0.14	-0.18	NR	0.01	-0.38	-9.96	11.95	-0.44 (-0.54,-0.32)	1.94 (-8.78,13.33)
Cuba	-0.22	-0.26	NR	0.01	-0.54	-9.17	26.05	-0.56 (-0.67,-0.38)	-0.31 (-0.98,0.32)
Cyprus	0.01	NR	0.01	0.01	-0.01	-1.04	19.84	-0.58 (-0.63,-0.52)	0.96 (-5.65,6.64)
Czech Republic	-0.13	-0.17	NR	-0.01	-0.22	-8.77	8.5	-0.56 (-0.64,-0.47)	9.48 (-151.82,606.09)
Denmark	-0.21	-0.27	NR	NR	-0.54	-15.45	8.92	-0.40 (-0.52,-0.03)	NR
Djibouti	0.01	0.01	NR	0.02	0.14	0.05	28.46	NR	-0.21 (-0.50,0.10)
Dominica	0.01	0.01	NR	0.02	0.01	0.33	26.91	-0.39 (-0.94,0.25)	0.40 (-6.04,3.40)
Dominican Republic	0.02	0.02	NR		0.46	1.47	24.7	-0.03 (-0.25,0.23)	1.43 (-4.84,6.75)
Ecuador	0.02	0.02	NR	0.02	0.73	4.05	21.38	-0.28 (-0.41,-0.14)	-0.27 (-0.94,0.32)
Egypt	0.05	0.06	NR	0.05	0.06	-0.69	23.88	-0.09 (-0.29,0.18)	0.15 (-0.37,1.40)
El Salvador	-0.07	-0.1	NR	0.03	-0.21	-3.54	25.56	-0.62 (-1.52,0.19)	0.40 (-0.48,1.34)
Equatorial Guinea	-0.05	-0.07	NR	-0.01	-0.03	-9.46	25.08	-0.71 (-1.01,-0.51)	-0.19 (-1.63,4.77)
Eritrea	-0.04	-0.05	NR	0.01	0.21	-0.5	26.87	-0.39 (-0.64,0.48)	-0.11 (-0.58,0.31)
Estonia	-0.22	-0.26	NR	-0.01	-0.46	-14.76	6.28	-0.53 (-0.75,-0.20)	NR
Ethiopia	-0.09	-0.11	NR	-0.03	-0.41	-11.54	23.35	-0.53 (-0.62,-0.42)	-0.12 (-5.24,4.74)
Fiji	0.01	0.01	NR	0.03	-0.10	-1.96	25.01	-0.46 (-0.85,-0.14)	1.53 (-3.66,3.33)
Finland	-0.17	-0.20	NR	-0.07	-0.39	-15.38	2.3	-0.57 (-0.65,-0.49)	NR
France	-0.13	-0.17	0.01	NR	-0.31	-9.37	11.57	-0.50 (-0.54,-0.46)	-0.11 (-0.33,0.21)

Country	Mental disorders	Major depressive disorder	Bipolar disorder	Anxiety disorder	Self-harm incidence	Suicide	Average temperature (C°)	Low temperature (Summary exposure)	High temperature (Summary exposure)
Gabon	-0.04	-0.04	NR	0.01	-0.11	-5.19	25.65	-0.70 (-0.89,-0.14)	-0.11 (-0.95,0.32)
Gambia	-0.01	-0.01	NR	0.01	0.16	1.33	29	-0.06 (-0.42,3.29)	0.06 (-0.57,0.68)
Georgia	0.01	0.01	NR	-0.01	0.22	1.66	10.06	-0.38 (-0.48,-0.25)	1.43 (0.49,5.01)
Germany	0.07	0.09	NR	0.03	-0.23	-5.01	9.49	-0.50 (-0.55,-0.39)	5.96 (-12,18,91.90)
Ghana	NR	NR	NR	0.01	0.25	0.56	28.3	-0.61 (-0.80,0.35)	0.29 (-0.42,0.96)
Greece	0.01	0.01	0.01	0.02	0.04	-0.04	14.89	-0.35 (-0.38,-0.31)	0.08 (-0.28,0.96)
Greenland	-0.09	-0.10	0.05	0.03	-0.28	-34.01	-17.56	-0.48 (-0.61,-0.32)	NR
Grenada	0.01	NR	NR	0.01	-0.09	-1.87	26.49	NR	0.04 (-1.08,0.48)
Guam	0.01	0.01	NR	0.03	0.19	2.24	27.88	NR	0.51 (-1.65,1.52)
Guatemala	-0.03	-0.04	NR	0.03	0.20	-2.12	24.09	-0.49 (-0.60,-0.36)	0.99 (-0.64,6.20)
Guinea	0.04	0.04	NR	0.01	0.27	1.99	26.59	-0.37 (-0.64,-0.04)	-0.09 (-0.61,0.33)
Guinea Bissau	0.04	0.04	NR	0.01	0.07	-1.45	28.76	NR	-0.29 (-0.73,0.01)
Guyana	0.07	0.09	NR	NR	0.14	1.94	26.15	-0.57 (-0.71,-0.42)	1.10 (-5.36,6.79)
Haiti	-0.02	-0.03	NR	0.03	-0.05	-2.98	25.06	-0.34 (-0.58,-0.01)	-0.29 (-0.63,0.08)
Honduras	0.05	0.05	NR	0.04	-0.13	-1.79	25.05	0.21 (-0.01,0.59)	0.55 (-1.04,3.13)
Hungary	-0.19	-0.24	NR	-0.01	-0.42	-20.37	11.57	-0.42 (-0.52,-0.30)	1.49 (-2.17,16.16)
Iceland	-0.08	-0.12	0.03	NR	-0.31	-5.71	2.4	-0.53 (-0.59,-0.44)	NR
India	-0.09	-0.12	NR	NR	-0.27	-6.36	24.99	-0.21 (-0.37,0.19)	0.09 (-0.31,1.36)
Indonesia	0.01	-0.01	NR	0.04	-0.20	-1.04	25.99	-0.26 (-0.48,-0.03)	1.46 (-8.27,11.84)
Iran	0.05	0.05	0.01	0.04	-0.22	-2.75	19.54	-0.33 (-0.39,-0.28)	-0.16 (-0.29,0.16)
Iraq	0.01	NR	NR	0.06	0.14	-0.42	24.22	-0.09 (-0.26,0.08)	-0.04 (-0.24,0.32)
Ireland	0.06	0.06	0.01	0.04	-0.09	-2.22	9.95	-0.57 (-0.62,-0.50)	NR
Italy	-0.05	-0.06	0.03	-0.05	-0.34	-2.08	13.5	-0.48 (-0.52,-0.44)	2.15 (1.16,4.40)
Jamaica	0.02	0.01	NR	0.03	0.12	1.24	25.8	-0.77 (-1.43,-0.39)	4.72 (-14.39,14.73)
Japan	0.03	0.06	NR	-0.11	0.13	-1.63	12.36	-0.59 (-0.64,-0.55)	-0.34 (-0.44,-0.24)
Jordan	-0.08	-0.11	NR	0.04	-0.13	-2.27	20.36	-0.42 (-0.51,-0.30)	1.14 (-2.30,6.29)
Kazakhstan	-0.02	-0.02	NR	NR	0.13	0.64	7.88	-0.03 (-0.13,0.09)	0.41 (0.12,0.80)
Kenya	-0.06	-0.08	NR	0.01	-0.02	0.02	25.23	-0.24 (-0.33,-0.12)	2.96 (-25.11,23.57)
Kiribati	-0.06	-0.09	NR	0.03	-0.14	-8.1	27.49	NR	-0.07 (-1.34,0.34)
Kuwait	0.04	0.04	NR	0.07	0.13	0.12	27.89	-0.29 (-0.48,0.40)	-0.12 (-0.31,0.35)
Kyrgyzstan	-0.08	-0.1	NR	NR	-0.18	-6.44	3.35	-0.21 (-0.45,4)	2.19 (0.79,7.71)

Country	Mental disorders	Major depressive disorder	Bipolar disorder	Anxiety disorder	Self-harm incidence	Suicide	Average temperature (C°)	Low temperature (Summary exposure)	High temperature (Summary exposure)
Latvia	-0.15	-0.18	NR	NR	-0.37	-10.76	6.81	-0.34 (-0.45,-0.19)	NR
Lebanon	0.05	0.06	NR	0.02	0.12	-1.23	16.23	-0.32 (-0.44,-0.23)	-6.35 (-71.24,100.97)
Lesotho	0.02	0.02	NR	0.01	0.77	18.59	12.26	0.11 (-0.13,0.37)	NR
Liberia	NR	NR	NR	0.02	0.1	-0.99	25.87	-0.54 (-0.79,0.27)	-0.07 (-0.92,2.50)
Libya	0.04	0.05	NR	0.05	0.13	-0.35	23.05	-0.02 (-0.22,0.27)	0.26 (-0.14,1.42)
Lithuania	-0.06	-0.08	NR	NR	-0.13	-4.67	7.28	-0.28 (-0.41,0.11)	NR
Luxembourg	-0.16	-0.21	0.01	-0.01	-0.34	-7.8	9.81	-0.60 (-0.65,-0.50)	NR
Madagascar	-0.03	-0.04	NR	0.02	-0.13	-3.04	22.87	-0.21 (-0.37,-0.01)	-0.07 (-0.56,0.63)
Malawi	-0.04	-0.06	NR	0.03	-0.11	-2.17	22.79	-0.23 (-0.35,-0.05)	-0.53 (-0.86,-0.13)
Malaysia	0.15	0.19	NR	0.04	-0.03	-1.6	26.46	-0.60 (-0.82,-0.41)	1.20 (-4.91,4.72)
Maldives	-0.19	-0.26	-0.01	NR	-0.21	-5.14	27.74	NR	-0.49 (-1.16,-0.14)
Mali	-0.02	-0.03	NR	0.03	-0.03	-1.15	29.78	NR	-0.13 (-0.33,0.10)
Malta	-0.01	-0.02	NR	NR	0.05	-0.77	20.28	-0.55 (-0.60,-0.49)	0.87 (-16.07,6.64)
Marshall Islands	-0.03	-0.05	NR	0.03	-0.02	-4.46	28.07	NR	-0.14 (-1.25,0.43)
Mauritania	-0.03	-0.04	NR	0.01	-0.05	-3.41	29.3	-0.14 (-0.53,0.52)	-0.40 (-0.55,-0.26)
Mauritius	-0.10	-0.13	NR	0.02	-0.25	-4.68	23.67	NR	NR
Mexico	0.19	0.22	NR	0.19	0.68	2.22	21.86	-0.23 (-0.32,-0.13)	0.78 (-0.04,4.31)
Micronesia	-0.04	-0.06	NR	0.02	-0.01	-4.8	27.01	NR	-0.03 (-1.38,0.65)
Moldova	NR	NR	NR	NR	NR	-5.44	NR	NR	NR
Monaco	NR	NR	0.01	NR	-0.07	-1.21	13.62	-0.43 (-0.53,-0.30)	NR
Mongolia	NR	NR	NR	0.02	0.06	0.12	2.07	-0.31 (-0.53,-0.10)	0.13 (-2.01,4.96)
Montenegro	-0.02	-0.02	NR	NR	-0.01	-1.45	10.2	-1 (-0.13,0.14)	14.28 (-78.20,83.07)
Morocco	-0.01	-0.02	NR	0.04	0.04	-1.79	18.48	-0.08 (-0.23,0.04)	-0.13 (-0.33,0.26)
Mozambique	0.04	0.04	NR	0.02	0.48	3.62	24.53	-0.21 (-0.40,0.04)	-0.26 (-0.49,0.02)
Myanmar	0.01	-0.02	NR	0.04	-0.28	-4	24.08	-0.36 (-0.47,-0.22)	-9 (-0.37,0.42)
Namibia	-0.01	-0.02	NR	0.01	0.29	-0.97	20.12	-0.33 (-0.45,-0.18)	0.65 (-0.15,1.84)
Nepal	0.07	0.07	NR	0.09	0.05	-5.21	14.32	-0.07 (-0.26,0.14)	-0.12 (-0.55,0.40)
Netherlands	-0.02	-0.04	0.01	0.04	-0.09	-1.67	10.39	-0.44 (-0.52,-0.27)	3.62 (-43.00,238,52)
New Zealand	0.05	0.06	0.03	0.03	-0.24	-2.32	11.23	-0.51 (-0.55,-0.47)	-0.91 (-1,-0.79)
Nicaragua	0.02	0.01	NR	0.03	0.03	-0.87	26.19	-0.07 (-0.37,0.26)	0.06 (-2.39,1.04)
Niger	0.03	0.03	NR	0.04	0.09	-0.33	28.09	-0.20 (-2.64,2.65)	-0.24 (-0.63,0.10)

Country	Mental disorders	Major depressive disorder	Bipolar disorder	Anxiety disorder	Self-harm incidence	Suicide	Average temperature (C°)	Low temperature (Summary exposure)	High temperature (Summary exposure)
Nigeria	-0.12	-0.15	NR	0.01	-0.01	-1.06	27.67	-0.31 (-0.52,-0.27)	-0.19 (-0.99,0.74)
Northern Mariana Islands	-0.06	-0.08	NR	NR	-0.10	0.84	27.65	NR	NR
Norway	0.09	0.14	NR	-0.04	-0.28	-6.49	2.06	-0.51 (-0.59,-0.38)	NR
Oman	0.01	0.01	NR	0.03	0.07	-1.77	28.1	-0.20 (-0.49,4.1)	-0.25 (-1.83,0.42)
Pakistan	-0.03	-0.04	NR	0.04	0.22	0.63	21.68	0.19 (-0.06,0.88)	0.16 (-0.23,1.45)
Palau	NR	-0.01	NR	0.01	-0.02	-2.09	27.56	NR	-0.29 (-0.90,0.31)
Palestine	-0.01	-0.02	NR	0.04	0.07	-1.05	20.36	-0.27 (-0.41,-0.07)	3.58 (-26.84,16.56)
Panama	NR	-0.02	NR	0.04	0.03	-0.11	25.62	-0.54 (-0.68,-0.37)	1.53 (-3.58,5.07)
Papua New Guinea	-0.04	-0.05	NR	0.02	0.04	-0.36	24.73	-0.21 (-0.35,-0.04)	1.30 (-7.33,10.58)
Paraguay	0.06	0.08	NR	0.02	0.56	2.65	24.01	-0.26 (-0.45,0.01)	0.20 (-0.13,0.81)
Peru	-0.07	-0.13	NR	0.01	0.03	-0.65	19.79	-0.55 (-0.66,-0.42)	-0.25 (-0.94,0.77)
Philippines	-0.11	-0.17	NR	0.02	-0.11	-1.51	26.6	0.09 (-0.30,1.54)	1.24 (-8.79,14.66)
Poland	0.01	NR	NR	-0.01	-0.04	-3.35	8.75	-0.52 (-0.59,-0.42)	6.91 (2.36,152.32)
Portugal	-0.10	-0.13	NR	0.01	-0.31	-6.05	16.09	-0.53 (-0.57,-0.49)	-0.46 (-0.62,-0.01)
Puerto Rico	-0.02	-0.04	NR	0.02	-0.21	-4.56	25.11	-0.76 (-1.33,-0.45)	-0.05 (-2.54,1.27)
Qatar	-0.05	-0.07	NR	0.02	-0.01	-1.68	29.42	NR	-0.13 (-0.68,0.50)
Romania	-0.02	-0.04	NR	NR	0.08	-0.84	10.35	-0.44 (-0.52,-0.35)	-0.31 (-0.98,0.10)
Russia	-0.06	-0.07	NR	-0.01	-0.21	-5.04	-3.64	-0.31 (-0.40,-0.22)	2.01 (0.92,5.53)
Rwanda	-0.13	-0.15	NR	0.03	-0.33	-9.04	19.21	-0.49 (-0.58,-0.38)	NR
Samoa	-0.06	-0.10	NR	0.03	-0.04	-3.48	27.56	-0.66 (-0.95,-0.37)	-0.18 (-1.19,0.46)
San Marino	0.01	0.01	0.01	0.01	-0.01	-1.59	12.95	-0.35 (-0.54,-0.12)	1.19 (-0.44,23.80)
Sao Tome and Principe	0.01	0.01	NR	0.01	0.35	0.36	24.7	-0.33 (-0.86,7.77)	0.08 (-1.89,4.68)
Saudi Arabia	0.06	0.06	NR	0.05	0.83	0.96	26.8	-0.23 (-0.40,-7)	-2 (-0.23,0.63)
Senegal	0.01	0.01	NR	NR	0.08	-1.45	29.63	-0.42 (-0.64,3.95)	-0.24 (-0.49,0.01)
Serbia	-0.10	-0.13	NR	0.01	-0.32	-8.52	11.67	-0.22 (-0.33,-0.08)	0.55 (-1.87,2.75)
Seychelles	-0.06	-0.10	NR	0.02	0.03	-1.5	27.07	NR	-0.25 (-0.76,0.07)
Sierra Leone	0.06	0.07	NR	0.02	0.34	0.96	27.19	-0.63 (-0.86,-0.40)	-0.22 (-0.66,0.19)
Singapore	-0.26	-0.35	0.01	-0.02	-0.34	-8.53	27.74	NR	-0.25 (-1.88,1.56)
Slovakia	-0.08	-0.12	NR	-0.01	-0.13	-7.14	8.78	-0.50 (-0.59,-0.40)	4.80 (-20.17,436.51)
Slovenia	-0.19	-0.24	NR	NR	-0.36	-14.91	9.9	-0.59 (-0.69,-0.45)	NR

Country	Mental disorders	Major depressive disorder	Bipolar disorder	Anxiety disorder	Self-harm incidence	Suicide	Average temperature (C°)	Low temperature (Summary exposure)	High temperature (Summary exposure)
Solomon Islands	-0.03	-0.05	NR	0.03	0.12	-2.02	25.6	-0.75 (-0.92,-0.50)	-0.30 (-0.76,0.26)
Somalia	-0.01	-0.01	NR	-0.01	0.02	-1.36	26.88	-0.35 (-0.51,-0.08)	-0.14 (-0.65,0.29)
South Africa	NR	NR	NR	NR	NR	-7.19	NR	NR	NR
South Korea	NR	NR	NR	NR	NR	7.77	NR	NR	NR
Spain	0.18	0.21	0.01	0.03	-0.09	NR	14.25	-0.50 (-0.54,-0.47)	-0.49 (-0.58,-0.35)
Sri Lanka	-0.17	-0.24	NR	0.05	-0.46	NR	27.41	-0.47 (-0.67,0.09)	-0.01 (-1.47,0.77)
St Kitts and Nevis	NR	-0.01	NR	0.01	0.06	NR	NR	NR	NR
St Lucia	0.02	0.01	NR	0.01	-0.03	NR	NR	NR	NR
Sudan	-0.01	-0.02	NR	0.03	NR	-2.2	28.17	-0.19 (-0.37,0.08)	-0.18 (-0.41,1.21)
Suriname	0.05	0.06	NR	NR	NR	-0.98	26.56	-0.51 (-1.06,0.06)	0.22 (-1.47,0.77)
Sweden	-0.01	-0.03	0.01	0.01	-0.26	-7.55	3.02	-0.47 (-0.54,-0.37)	NR
Switzerland	-0.16	-0.21	0.02	0.02	-0.49	-12.08	6.42	-0.53 (-0.58,-0.47)	NR
Syria	0.01	NR	NR	0.07	0.21	-0.89	19.72	-0.14 (-0.33,0.11)	0.71 (-1.50,2.76)
Taiwan	0.04	0.07	NR	-0.06	0.35	3.21	21.03	-0.53 (-0.63,-0.40)	-0.23 (-0.96,1.31)
Tajikistan	-0.07	-0.09	NR	0.01	-0.05	-1.08	4.52	0.33 (0.02,0.66)	0.55 (0.17,1.07)
Tanzania	-0.04	-0.05	NR	0.02	-0.06	-2.47	NR	NR	NR
Thailand	0.01	NR	NR	0.04	-0.33	-4.02	26.91	-0.74 (-0.88,-0.56)	-0.17 (-0.45,0.30)
Togo	0.03	0.04	NR	0.01	0.13	0.81	28.05	-0.55 (-0.72,0.15)	0.15 (-0.47,0.72)
Tonga		-0.01	NR	0.03	0.16	0.13	24.74	-0.19 (-0.53,0.19)	0.70 (-1.59,1.55)
Trinidad and Tobago	-0.04	-0.06	NR	0.02	-0.27	-4.73	26.54	NR	-0.35 (-1.15,-0.01)
Tunisia	0.01	NR	NR	0.05	0.12	-0.52	21.33	-0.13 (-0.34,0.10)	0.12 (-1.43,2.22)
Turkey	-0.01	-0.04	NR	0.10	-0.01	-3.05	12.63	-0.44 (-0.54,-0.34)	-0.16 (-0.34,0.04)
Turkmenistan	-0.06	-0.08	NR	0.02	0.29	-0.19	17.65	-0.18 (-0.31,-0.02)	-0.11 (-0.31,0.11)
Uganda	-0.03	-0.04	NR	0.04	0.07	-0.77	23.22	-0.44 (-0.59,-0.32)	1.99 (-1.99,8.83)
Ukraine	-0.10	-0.11	NR	0.01	0.37	6.88	9.38	-0.14 (-0.27,5)	9.11 (5.24,26.02)
United Arab Emirates	-0.06	-0.08	NR	0.05	0.03	-1.54	29.08	NR	-0.25 (-0.47,0.50)
United Kingdom	-0.10	-0.13	0.01	0.03	-0.22	-2.4	9.38	-0.46 (-0.52,-0.37)	-0.87 (-0.99,-0.70)
United States	0.25	0.31	0.01	0.09	0.12	-0.43	10	-0.28 (-0.33,-0.22)	-0.16 (-0.34,0.02)
Uruguay	0.11	0.14	0.06	0.03	0.66	5.86	18.06	-0.38 (-0.42,-0.33)	-0.64 (-0.75,-0.48)
Uzbekistan	-0.05	-0.07	NR	NR	0.77	2.63	14.78	0.65 (0.42,0.86)	1.23 (0.76,1.86)
Vanuatu	-0.04	-0.06	NR	0.03	0.02	-0.26	24.72	-0.14 (-0.49,0.38)	-8.33 (-121.31,163.43)
Venezuela	0.02	0.02	NR	0.05	0.33	1.24	25.61	-0.44 (-0.56,-0.29)	0.92 (-2.52,2.48)
Vietnam	-0.06	-0.10	NR	0.01	0.08	-2.43	25.03	-0.34 (-0.47,-0.18)	0.42 (-0.35,1.59)

Country	Mental disorders	Major depressive disorder	Bipolar disorder	Anxiety disorder	Self-harm incidence	Suicide	Average temperature (C°)	Low temperature (Summary exposure)	High temperature (Summary exposure)
Yemen	0.01	0.01	NR	0.03	0.09	-0.65	25.62	-0.24 (-0.40,0.08)	-0.17 (-0.40,0.83)
Zambia	0.01		NR	0.04	0.07	-0.79	22.12	-0.18 (-0.41,0.19)	-0.27 (-0.81,0.20)
Zimbabwe	0.03	0.4	NR	-0.01	0.29	5.74	21.87	-0.04 (-0.27,0.16)	0.43 (-0.35,1.03)

NR: Not Reported. All variables are reported as change 1990-2019.

The correlation analysis revealed a positive association between annual temperature and anxiety disorders ($r=0.226$, $p\leq 0.001$). Conversely, significant inverse correlations were observed between annual temperature and several other mental health outcomes, including bipolar disorder ($r=-0.386$, $p\leq 0.001$), depressive disorders ($r=0.137$, $p=0.018$), overall mental disorders ($r=0.138$, $p=0.010$), self-harm ($r=0.122$, $p=0.003$), and suicide ($r=0.226$, $p=0.030$). The correlations for each mental disorder with temperature are depicted in Figure 1.

Overall, the results indicate an inverse relationship between the Socio-Demographic Index (SDI) and mental disorders; however, these correlations were not statistically significant. Notably, significant negative correlations were found between SDI and both self-harm ($r=-0.230$, $p=0.002$) and suicide ($r=-0.229$, $p=0.002$). Scatterplots illustrating the relationships between changes in major depressive disorder, psychotic disorders, bipolar disorder, anxiety, self-harm, suicide, and average temperature relative to SDI across countries are shown in Supplementary Figures 6 through 11.

Discussion

The findings of this study showed that anxiety disorders

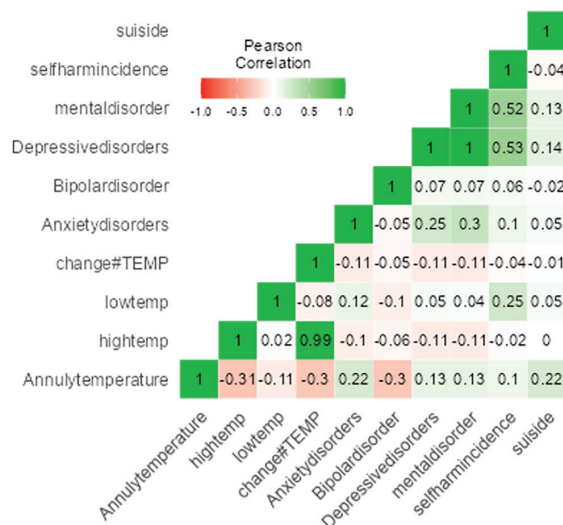


Figure 1: Correlation heatmap temperature exposure and mental disorders (Source: Prepared by the authors using Jamovi.)

were lowest in Japan and highest in Mexico. Moreover, the average annual temperature and low-temperature exposure were positively and significantly associated with anxiety disorders. In contrast, the relationship between high-temperature exposure (and temperature changes) and anxiety disorders was not statistically significant.

With respect to major depressive disorders, the lowest and highest changes were observed in Singapore and the United States, respectively. Major depressive disorders also demonstrated a positive, statistically significant correlation with both average annual temperature and low-temperature exposure. Collectively, these results suggest that higher average annual temperatures are associated with higher rates of major depressive disorders. Interestingly, greater low-temperature exposure (i.e., lower-temperature exposure) was also associated with lower rates of major depressive disorders, indicating that the direction and magnitude of temperature effects may vary by temperature metric.

For self-harm, China and Saudi Arabia showed the lowest and highest rates, respectively. Self-harm was positively and significantly correlated with both average annual temperature and low-temperature exposure.

Overall, mental disorders were lowest in Singapore and highest in the United States. This outcome was positively and significantly correlated with average annual temperature, indicating that increased average annual temperature may be linked to higher rates of mental disorders.

Regarding suicide, Turkey had a lower rate than other countries in the analysis. Suicide was positively and significantly correlated with average annual temperature, suggesting that higher average annual temperatures may contribute to increased suicide rates.

In line with these results, Javaid and colleagues (2023) reported that countries with high rates of anxiety disorders, particularly in the United States, showed a positive and statistically significant correlation

with the Socio-Demographic Index (SDI),¹⁰ which is consistent with the direction of associations observed here. Additionally, a previous study indicated a lower prevalence of mental disorders in Japan compared with Western countries,¹¹ which aligns with the lower anxiety and overall mental disorder rates observed in Japan in our study. These differences may reflect cultural, economic, genetic, social, and environmental variations between Japan and Western countries.

Finally, a systematic review conducted in 2023 reported that higher temperatures are associated with increased anxiety disorder rates, supporting the implementation of preventive strategies as a key step in improving mental health in hotter climates.¹²

The evaluation of the short-term association between heat and mental health outcomes indicates that for every 1°C increase in temperature, mental health-related deaths increase by 2.2%. In contrast, mental health-related complications rise by 0.9%. Furthermore, heat waves have been identified as significant contributors to the risk of adverse mental health outcomes, particularly among older people and individuals residing in tropical and subtropical climates.¹³

A study conducted in New York City examined the relationship between high ambient temperatures and acute mental health encounters among children, adolescents, and young adults. The findings revealed that elevated ambient temperatures were associated with increased rates of mental health-related hospital visits across all age groups.¹⁴ Additionally, a case-crossover study with a substantial sample size demonstrated that higher temperatures during hot seasons significantly correlated with an increased risk of emergency department visits for specific mental health issues. This information is vital for healthcare providers, as it underscores the need for heightened awareness and proactive measures during periods of extreme heat, which may increase demand for mental health services. This study reinforces the necessity of preventive strategies and adequate resources to address the potential mental health impacts of elevated temperatures.¹⁵ These findings are consistent with the present study's results, highlighting the urgent need for mental health support during heat spikes.

Moreover, exposure to high temperatures has been linked to increased anxiety levels, as evidenced in a randomized controlled trial. This form of anxiety, often elicited by heat stress, is attributed to the activation of the hypothalamus-pituitary-adrenal (HPA) axis. Heat stress can also instigate inflammation and oxidative stress, which may contribute to alterations in neurotransmitter activity. Additionally, metabolites released by the adrenal glands have been identified as

potential biomarkers for heat stress-induced anxiety.¹⁶

The findings by Greenberg and colleagues (2021) indicated an increasing trend in major depressive disorders among U.S. adults between 2010 and 2018.¹⁷ Similarly, a systematic review revealed that major depressive disorders were least prevalent in Asian countries.¹⁸ These observations align with the current study's findings.

It is imperative to integrate the effects of temperature on mental health into public health planning, particularly for managing extreme heat events.¹⁹ Research indicates that the strongest association between mental illness and high temperatures occurs within 0–4 days of exposure. Notably, 14.6% of emergency admissions (EA) for mental illness were attributed to extreme hot temperatures, with the elderly being more susceptible (19.1%). The risk of specific mental illnesses, including anxiety, dementia, schizophrenia, and depression, showed a significant association with hot temperatures; 31.6% of anxiety-related EAs were linked to extreme heat. Therefore, the relationship between high temperatures and mental disorders, especially among the elderly, warrants significant consideration.²⁰

Climate change, particularly global warming, poses a substantial threat to mental health. A study analyzing data from 60 countries between 1979 and 2016 concluded that relative humidity had a more significant association with suicide (intentional self-harm leading to death) than heatwaves. Both younger age groups and women were more remarkably affected by changes in humidity and heatwave frequency compared to the general population.²¹ These findings are consistent with our study. Rising temperatures are associated with increased suicides and suicidal behaviors, hospital admissions for mental illness, and a general decline in community health and well-being. Climate change is likely to exacerbate temperature anomalies, variability, and the occurrence of heatwaves.²²

Literature indicates a positive relationship between short-term exposure to extreme heat and an increase in emergency admissions for general mental disorders, a strong effect that was also observed across all subcategories of mental illnesses.²³ These findings support the results of the present study. Another study examining the impact of weather variables on suicide cases (both attempted and completed) revealed that after accounting for the day of the week and season, a 1°C increase in temperature was associated with a 0.01-point increase in the number of suicides.²⁴ Furthermore, Erhan Kartal and colleagues found that suicide rates in Turkey, particularly among males, were lower compared to other countries.²⁵

Strengths and Weaknesses

A key strength of this study lies in its universality, enabling a comprehensive analysis of the correlation between temperature and mental health across diverse climates and cultures. The utilization of a wide array of data sources further enriches the analysis. Given the ongoing climate crisis, the study's focus on the impact of temperature exposure on mental health is both appropriate and timely.

A primary weakness of this study is the potential for ecological fallacy. Consequently, the interpretation of the findings should be at the group level rather than the individual level. Factors such as population genetics, social and cultural influences, economic challenges, and access to methods for suicide (e.g., firearms, pesticides) can influence vulnerability to depression. As this is an ecological study, access to such individual-level data was not feasible. To mitigate the impact of potential confounders, the socio-demographic index variable was employed. However, ecological studies are susceptible to numerous confounders, rendering a causal interpretation of the results infeasible. In general, study designs of this nature are effective in generating research hypotheses that warrant rigorous examination at the individual level in future studies.

Conclusion

An increase in the average annual temperature was correlated with a rise in major depressive disorders, while greater exposure to lower temperatures appeared to reduce these disorders. Furthermore, elevated average temperatures may potentially contribute to higher global suicide rates. These findings underscore the significant impact of both high and low temperatures on various mental health disorders and suicide rates, highlighting the need for targeted public health strategies and mental health services that account for these environmental factors. Addressing this issue is crucial to developing public health policies that mitigate the adverse effects of high temperatures on mental health.

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Author Contributions

H.G. is the lead author and guarantor, contributing

to data interpretation and manuscript revision. Z.M., M.V., H.A.N., A.K., F.R., and M.R.N. were responsible for study planning and led the drafting and revision of the manuscript. Z.M., M.V., H.A.N., A.K., F.R., M.M., and M.R.N. contributed to data interpretation and the drafting and revision of the manuscript.

Conflict of Interest

The authors declare no competing interests.

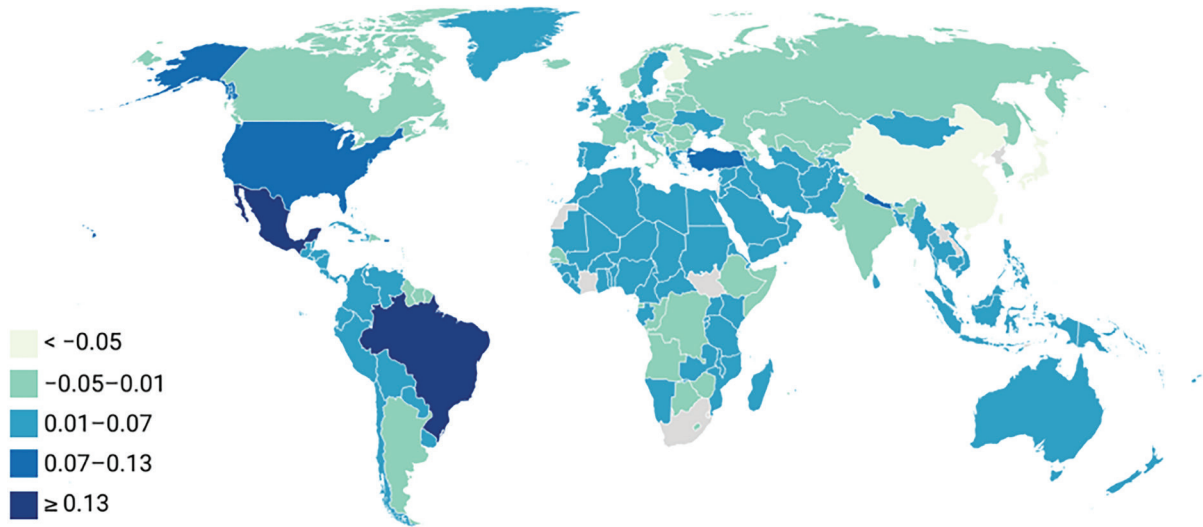
AI Assistance Declaration

In this study, we used OpenAI's ChatGPT-4.0, an advanced language model, to assist with editing and paraphrasing content. While ChatGPT-4.0 significantly enhanced the clarity and coherence of the text, all outputs were thoroughly reviewed and manually adjusted by the authors to ensure accuracy, integrity, and alignment with the study's objectives.

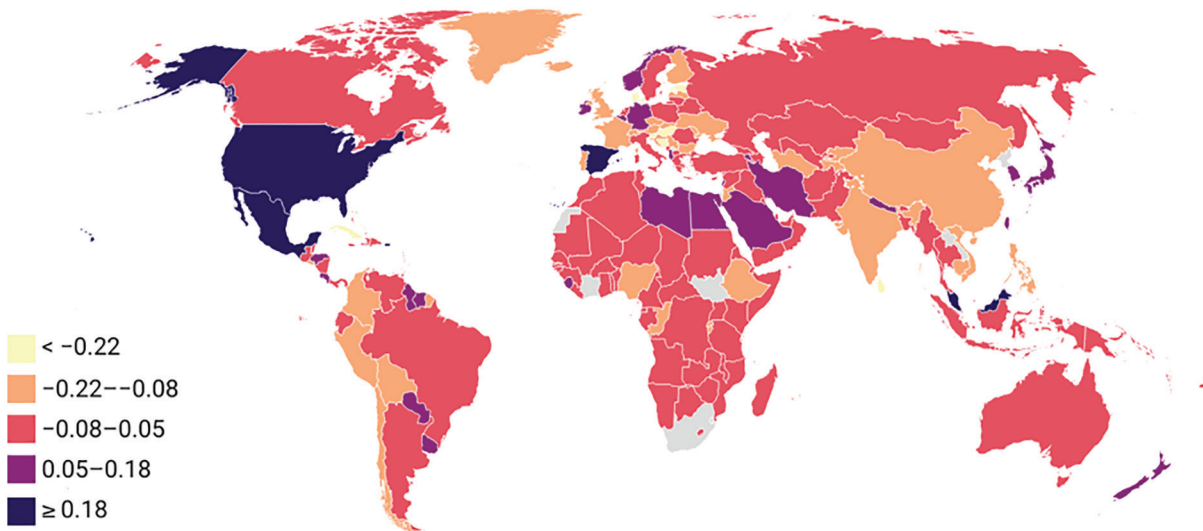
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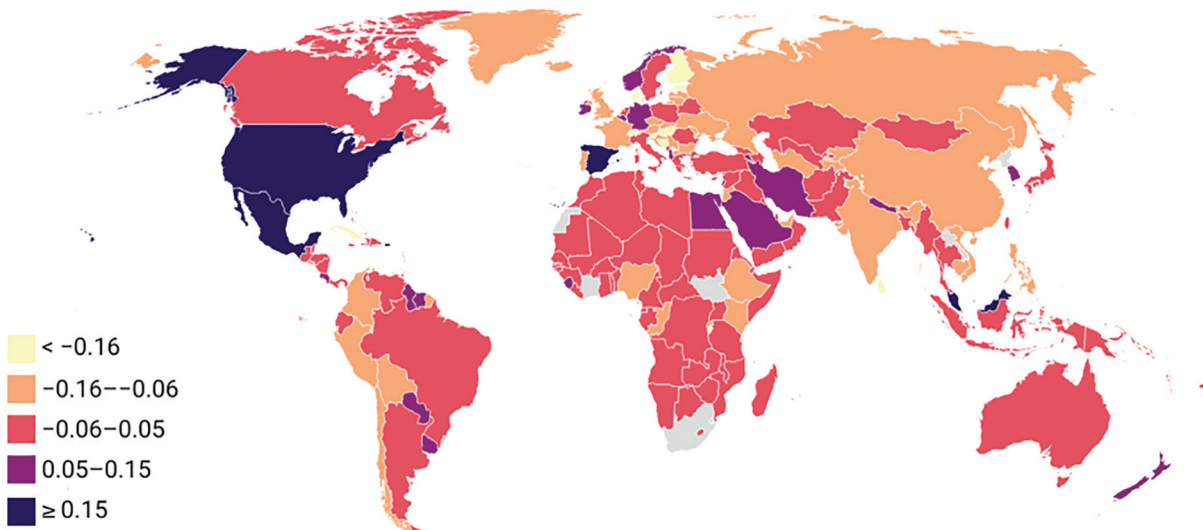
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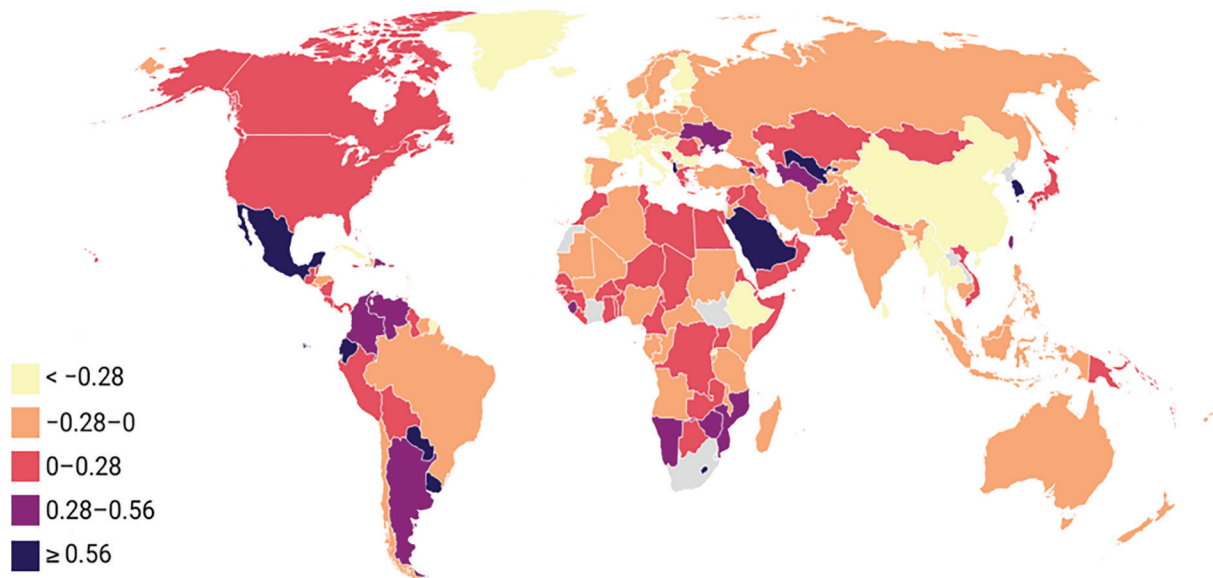
Supplementary 1: Spatial distribution of anxiety disorders in the countries of the world (change 2019-1990) Source: Authors' own data, visualized using Datawrapper.



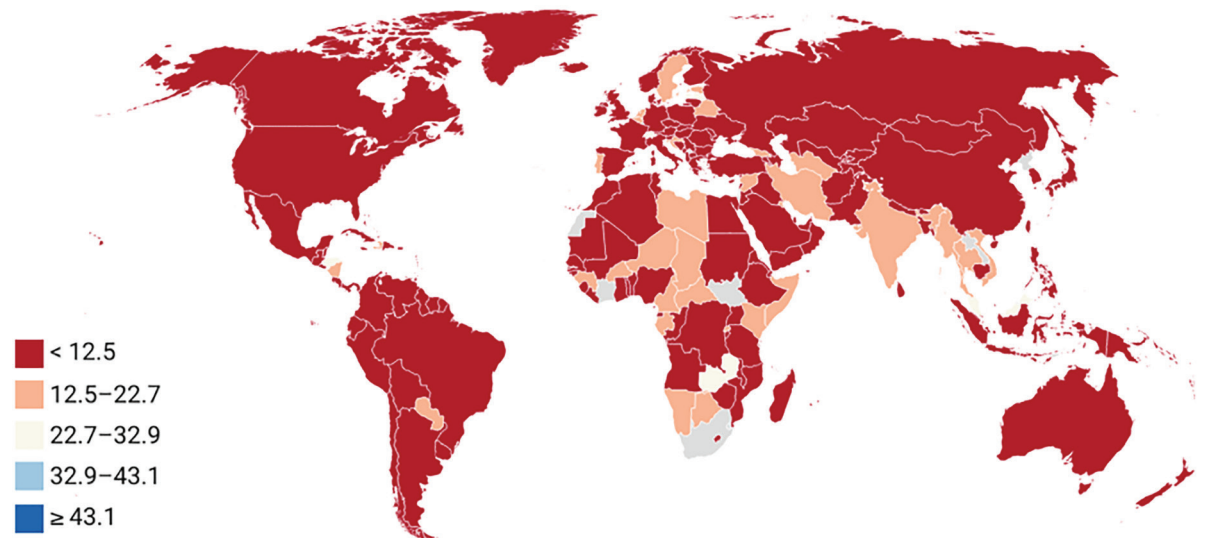
Supplementary 2: Spatial distribution of major depressive disorders in the countries of the world (change 2019-1990) Source: Authors' own data, visualized using Datawrapper.



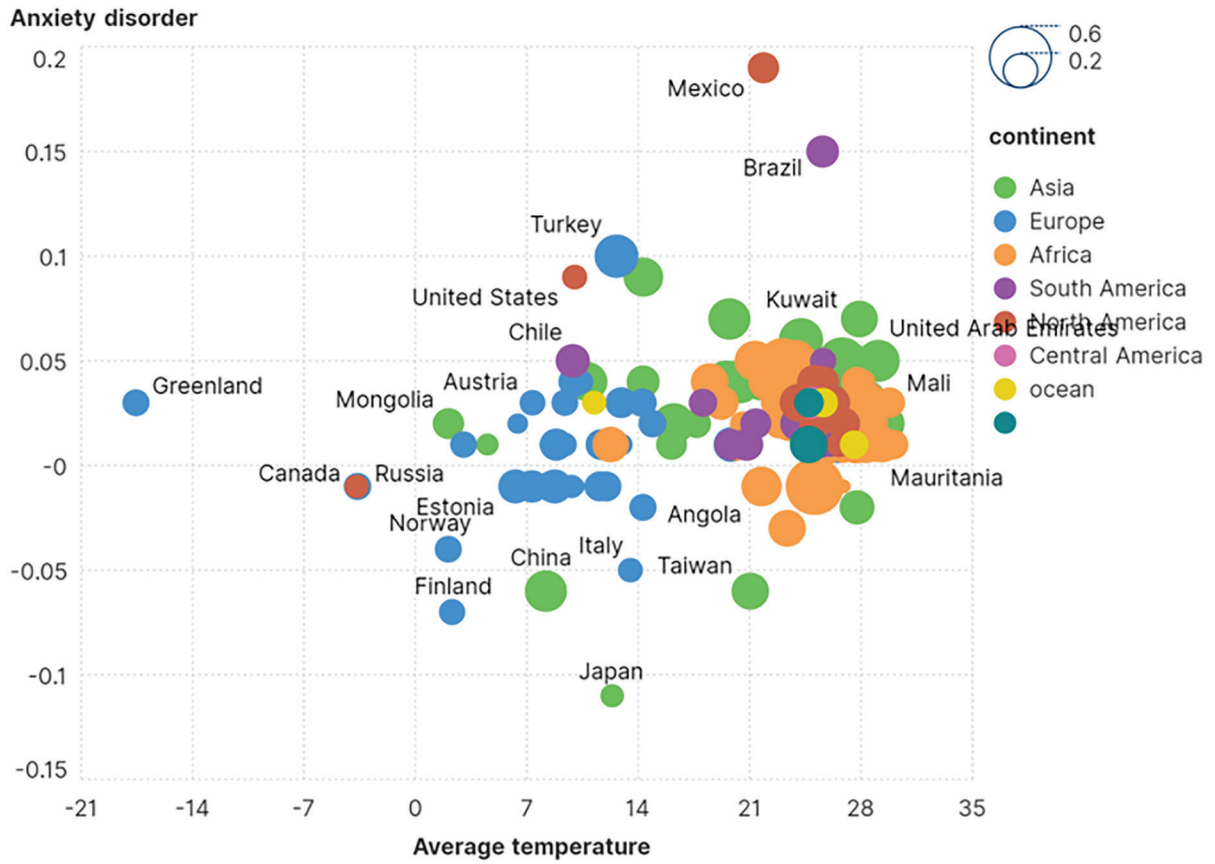
Supplementary 3: Spatial distribution of mental disorders in the countries of the world (change 2019-1990) Source: Authors' own data, visualized using Datawrapper.



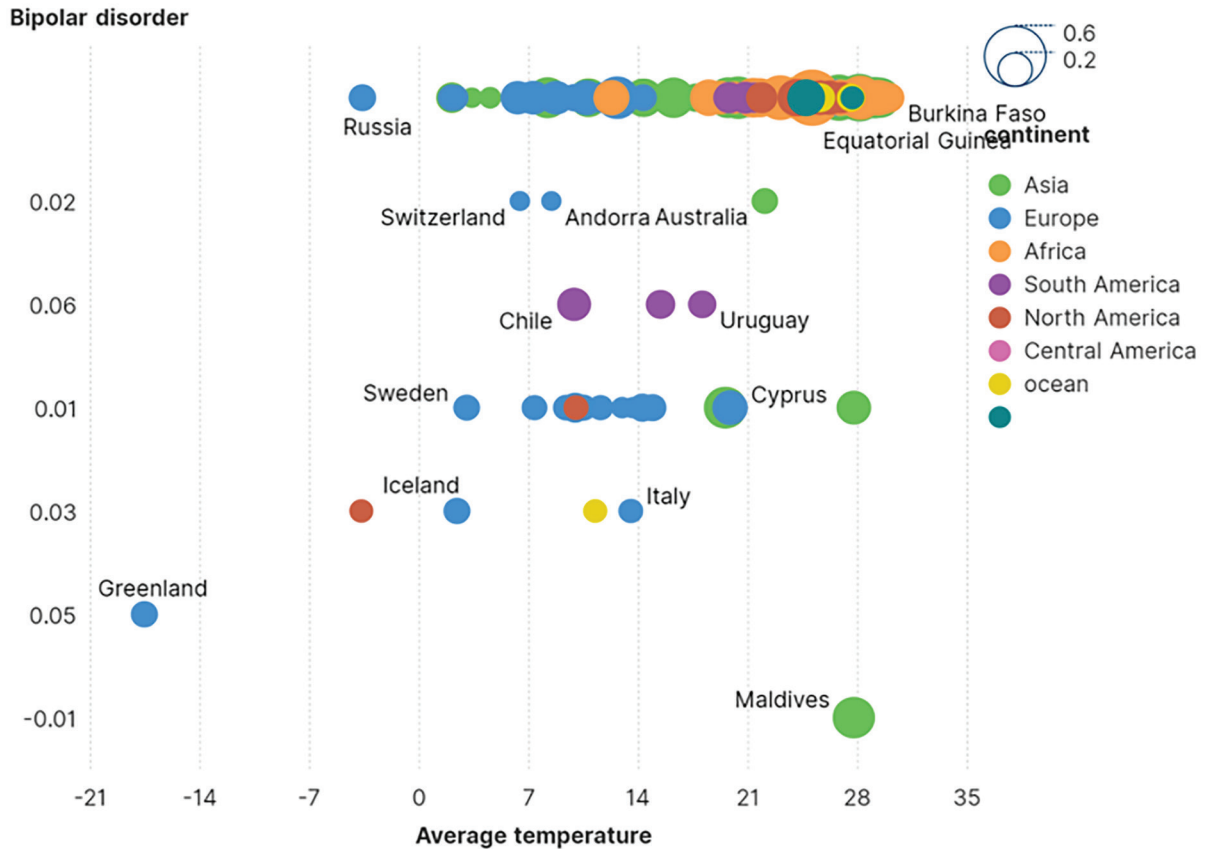
Supplementary 4: Spatial distribution of self harm in the countries of the world (change 2019-1990) Source: Authors' own data, visualized using Datawrapper.



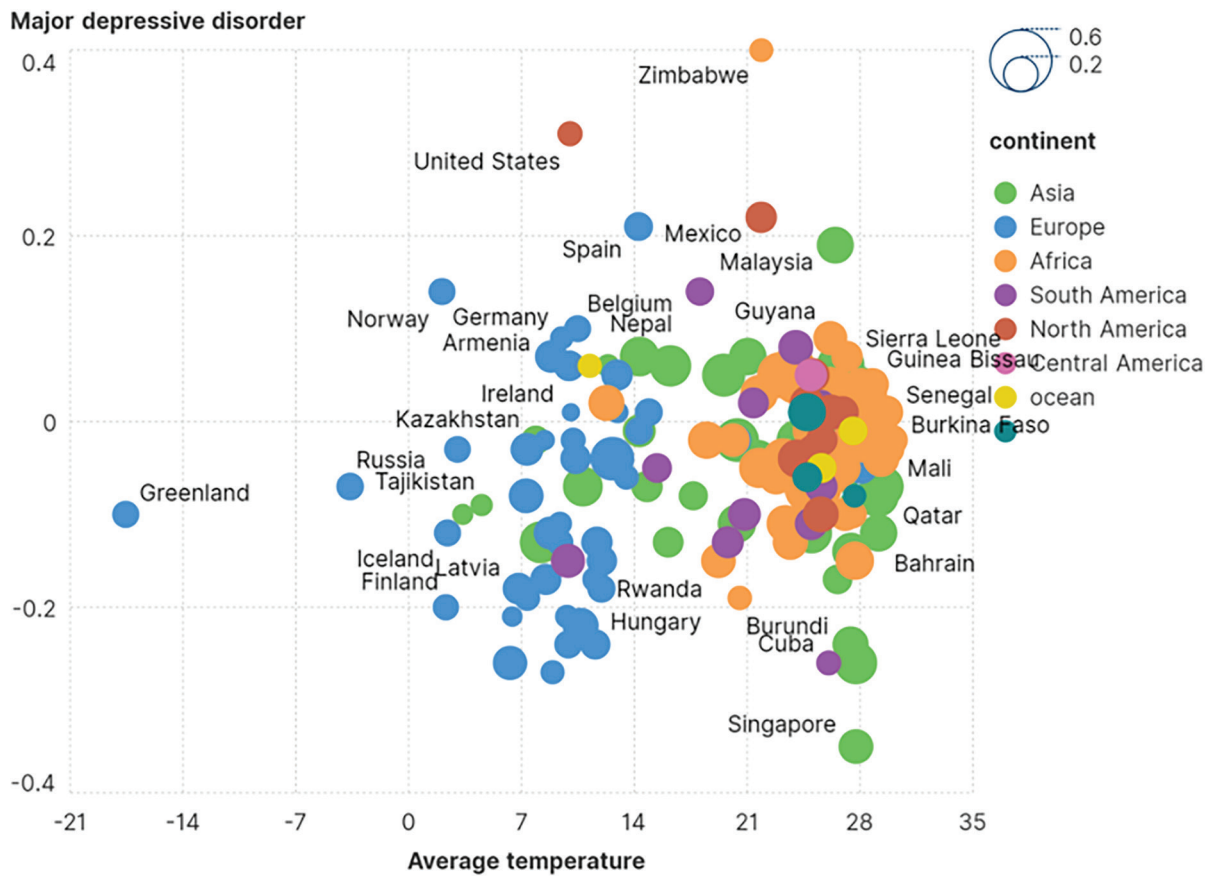
Supplementary 5: Spatial distribution of suicide in the countries of the world(change 2019-1990) Source: Authors' own data, visualized using Datawrapper.



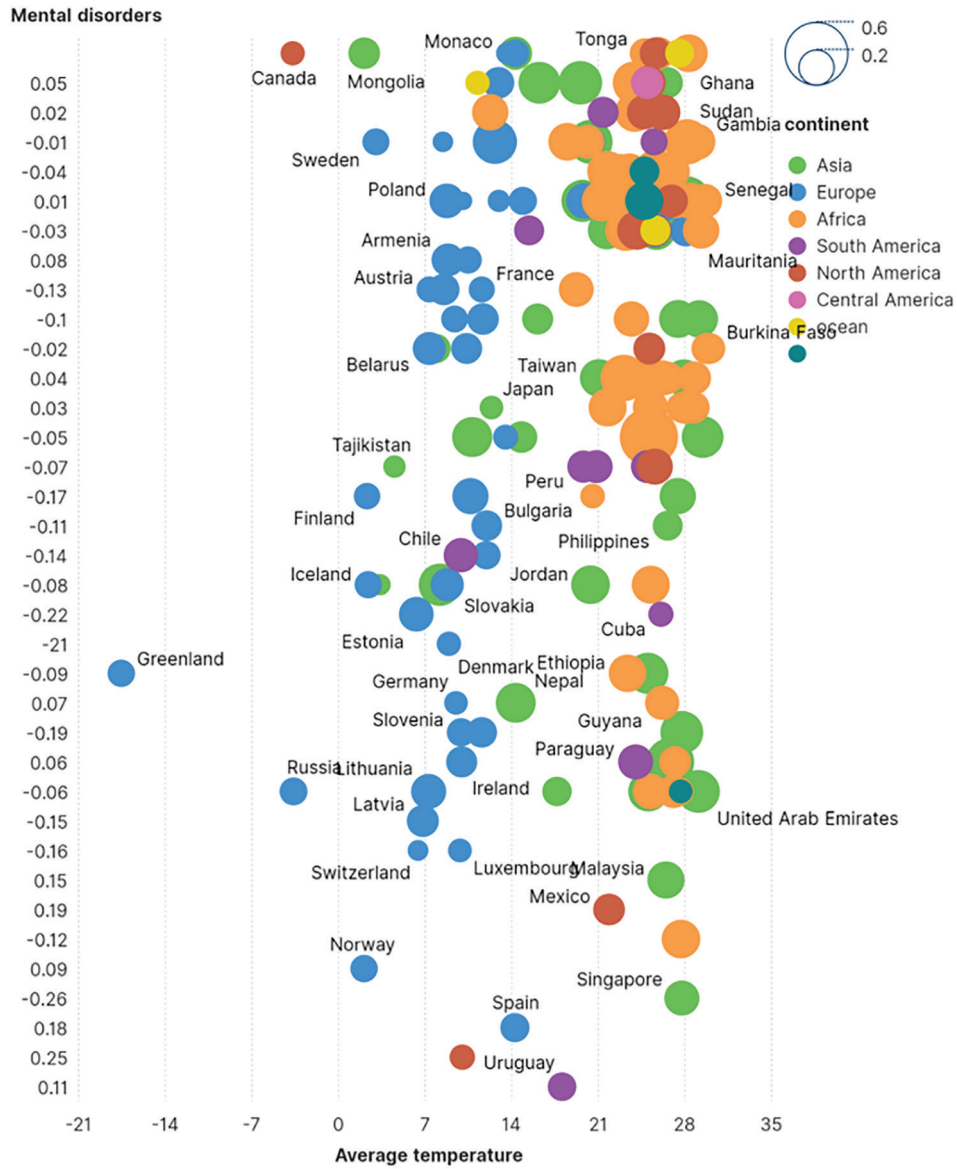
Supplementary 6: Correlations of changes of anxiety disorders and average temperature based on SDI in the countries of the world. Source: Prepared by the authors using SCImago software.



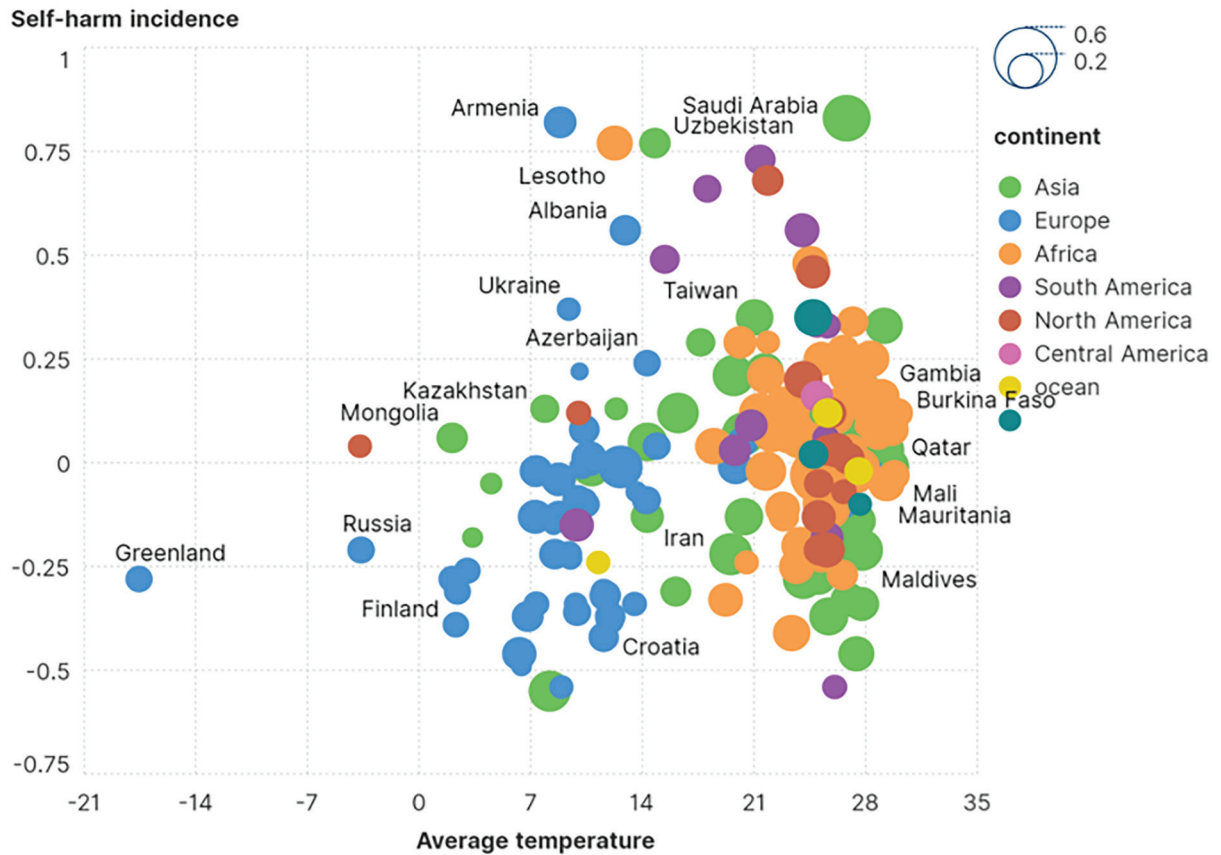
Supplementary 7: Correlations of changes of bipolar disorder and average temperature based on SDI in the countries of the world. Source: Prepared by the authors using SCImago software.



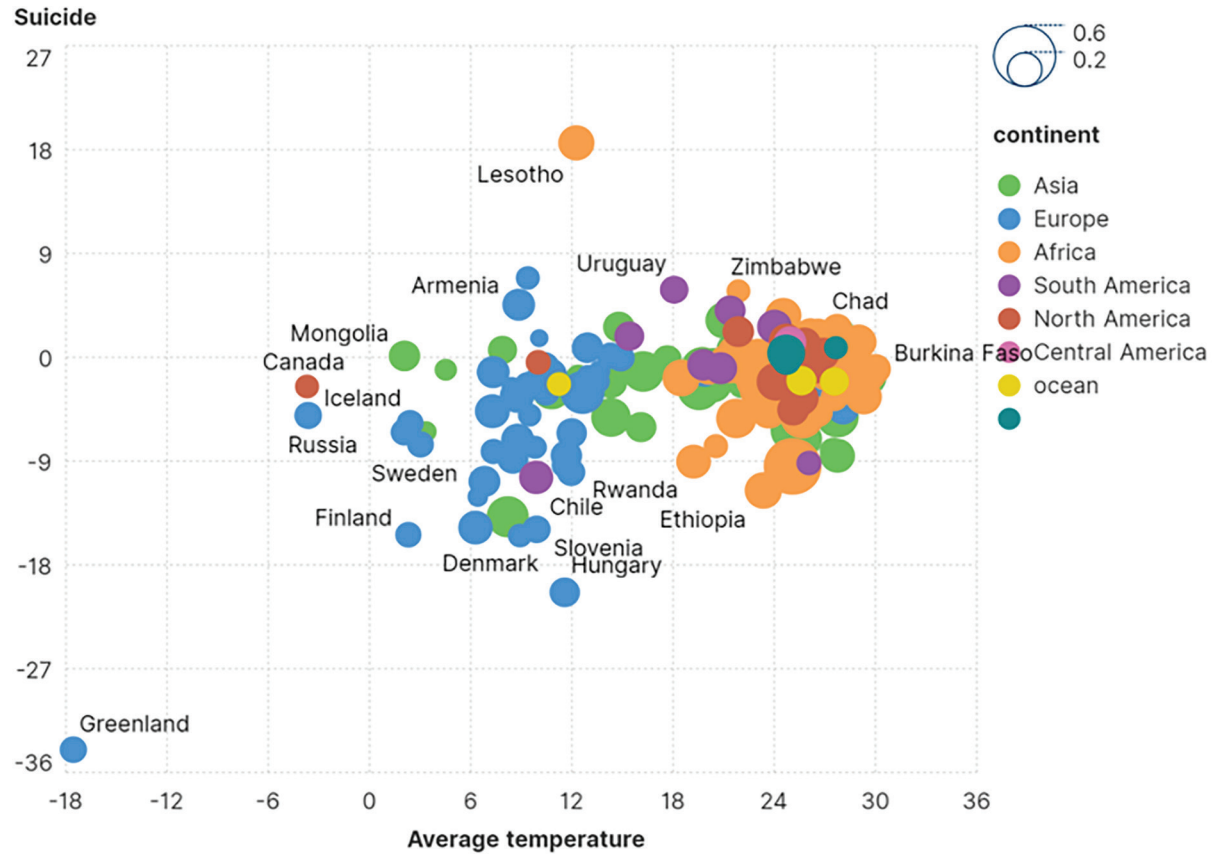
Supplementary 8: Correlations of changes of major depressive disorders and average temperature based on SDI in the countries of the world . Source: Prepared by the authors using SCImago software.



Supplementary 9: Correlations of changes of mental disorders and average temperature based on SDI in the countries of the world. Source: Prepared by the authors using SCImago software.



Supplementary 10: Correlations of changes of self-harm incidence and average temperature based on SDI in the countries of the world . Source: Prepared by the authors using SCImago software.



Supplementary 11: Correlations of changes of suicide and average temperature based on SDI in the countries of the world. Source: Prepared by the authors using SCImago software.