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The Effect of Temperature on the Suicide Rates in Turkey: A time Series Analysis

Erhan Kartal[1], Yasin Etli[1]

[1]*Van Yuzuncu Yil University, Faculty of Medicine, Department of Forensic Medicine, Van, Türkiye*

Abstract

Introduction: Rising ambient temperature is increasingly recognized as a potential risk factor for suicide, yet long-term, nationwide evidence from developing countries remains limited. This study investigates the association between temperature and suicide rates in Turkey over a 24-year period.

Methods: Monthly suicide data were obtained from the Turkish Statistical Institute (2000–2023), while average temperature was derived from the ERA5-Land reanalysis dataset. A Seasonal Autoregressive Integrated Moving Average with Exogenous Regressors (SARIMAX) model accounted for seasonality, autocorrelation, and temperature as a covariate.

Results: All three SARIMAX models showed a statistically significant positive relationship between temperature and suicide rates. For each 1°C increase, the suicide rate rose by 0.0038 per 100,000 population in the total group, 0.0043 per 100,000 among males, and 0.0025 per 100,000 among females. Model diagnostics (e.g., Ljung-Box, Jarque-Bera) suggested good overall fit. Despite limitations such as the lack of daily data and additional covariates, these findings underscore the robust link between ambient temperature and suicide.

Discussion and Conclusion: This nationwide analysis highlights temperature as an important environmental factor influencing suicide. In light of climate change, public health strategies should consider the implications of rising temperatures. Future work incorporating more covariates and higher-resolution data could further elucidate the complex relationship between temperature and suicidal behavior.

Key words: Suicide; temperature; seasons; climate change; models; statistical; Türkiye.

Introduction

Suicide is the 13th leading cause of death in the general population worldwide and ranks as the fourth leading cause of death among individuals aged 15 to 44 (1). Globally, over 700,000 suicide-related deaths occur each year, with an age-standardized suicide incidence of 9.0 per 100,000 population. Therefore, suicide remains a critical issue in global mental health (2). The triggering and risk factors of suicide have been extensively studied, and as a result, psychiatric disorders, somatic illnesses, inadequate social support, unemployment, divorce, familial conflicts, workplace-related problems, cultural factors such as honor, religion, and politics, economic difficulties, as well as individual characteristics such as age, gender, and place of residence, have been well established (3,4). In addition to these factors, research has also highlighted the role of genetic predisposition, specific personality traits such as impulsivity and aggression, restricted fetal growth and adverse perinatal conditions, early life trauma, neurobiological disturbances including serotonin dysfunction and hypothalamic-pituitary axis hyperactivity, psychosocial crises, access to means of suicide, and exposure to suicidal behavior in others as significant contributors to suicide risk (5). Meteorological factors have emerged as an important area of investigation among the diverse risk factors associated with suicide. Empirical studies have reported associations between suicidal behavior and various environmental parameters, including ambient temperature, duration of sunlight exposure, levels of air pollution, climatic conditions, atmospheric pressure, thunderstorms, and relative humidity. These findings suggest that meteorological conditions may play a modulatory role in influencing the onset or intensity of suicidal behavior, potentially through physiological, psychological, and social mechanisms (1,3,6–9). Among meteorological variables, temperature is the most extensively studied parameter and has shown the most consistent associations with suicide rates (6). However, the majority of these studies have been conducted in European and North American populations, limiting the generalizability of the findings to other regions (1). In Turkey, relatively few studies have directly or indirectly examined the relationship between suicide and temperature (3,8,10-12). Most existing studies have focused on regional datasets (8,10-

*Corresponding Author: Yasin Etli Department of Forensic Medicine, Faculty of Medicine, Van Yüzüncü Yıl University, Tuşba/Van, Turkey. **Email:** yasinetli@yyu.edu.tr **Orcid** Yasin Etli 0000-0002-7369-6083, Erhan Kartal 0000-0003-2459-7756

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12), and the only nationwide analysis to date evaluated suicide rates in relation to climate rather than temperature specifically (3). Furthermore, despite the known seasonal fluctuations in both suicide rates and temperature, time series analysis-which is essential for disentangling such temporal patterns-has been employed in only one study (8). Additionally, the majority of the available research has examined suicide attempts rather than completed suicides (8,10-12). Therefore, there is a clear need for a nationwide study in Turkey that investigates the relationship between completed suicides and temperature using national statistics and a time series analytical approach. The present study aims to address this gap by analyzing the association between suicide rates and temperature in Turkey through a SARIMAX time series model, using monthly average temperature data derived from satellite observations and monthly national suicide mortality statistics obtained from the Turkish Statistical Institute for the period between 2000 and 2023.

Materials and Methods

Suicide rates: In Turkey, suicide statistics have been officially reported by the Turkish Statistical Institute (TURKSTAT) annually since the year 2000. Although the initial aim of this study was to analyze daily suicide data in conjunction with daily temperature data, only annual and monthly suicide statistics are publicly available from TURKSTAT. Consequently, the analysis was conducted using monthly data. These statistics are openly accessible through TURKSTAT's official website (https://data.tuik.gov.tr/Bulten/Index?p=Olum-ve-Olum-Nedeni-Istatistikleri-2023-53709). The analysis incorporated all suicide statistics available on the TURKSTAT website covering the period from 2000 to 2023 (Supplementary Material).

Average temperature statistics: Although the initial plan was to use data from the Turkish State Meteorological Service (https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx), which are based on station measurements, it was found that these datasets primarily provide long-term climate averages dating back to 1927 and do not include detailed historical temperature records with sufficient temporal resolution. Therefore, alternative sources were explored, and monthly average temperature data were obtained from the ERA5-Land reanalysis dataset (13) developed by the European Centre for Medium-Range Weather Forecasts (ECMWF). ERA5-Land provides high-resolution hourly meteorological data with a spatial resolution of approximately 9 km, focusing specifically on land surface conditions. For our study, monthly average temperatures were calculated for all 81 provinces of Turkey for the period between 2000 and 2023. Using the Google Earth Engine platform, hourly temperature data were aggregated to monthly means within the administrative boundaries defined for each province. These values were then spatially averaged to generate monthly provincial temperature time series. The analysis utilized the "temperature_2m" band, summarized at a spatial scale of 9000 meters. Instead of aggregating monthly average temperature data at the national level, temperature values were recorded separately for each province to allow for population-weighted standardization. Population data for each province between 2000 and 2023 were obtained from TURKSTAT. Subsequently, the population-weighted national monthly average temperature-representing the average temperature experienced by the average individual in Turkey-was calculated using the weighted mean of each province's population and corresponding monthly average temperature (Supplementary Material).

Statistical analysis and time series modeling: In the study, descriptive statistics for monthly suicide data between 2000 and 2023 were first calculated separately for the female, male, and total populations. Normality tests were then performed. Since the temperature data did not follow a normal distribution, the linear component of the relationship between temperature and suicide was assessed using Spearman's rank correlation test to determine whether a statistically significant correlation existed between the two variables. The Seasonal Autoregressive Integrated Moving Average with Exogenous Regressors (SARIMAX) model extends the ARIMA framework by incorporating both seasonal components and external predictors. It is well-suited for time series data exhibiting periodic trends and autocorrelation, while allowing the inclusion of covariates such as meteorological or socioeconomic indicators. The model accounts for short- and long-term dependencies through AR, I, and MA terms, and captures seasonality via additional seasonal parameters. In this study, we used the SARIMAX model to examine the relationship between monthly suicide rates (per 100,000 population) and population-weighted average temperature across Turkey from January 2000 to December 2023. Suicide rates were calculated using monthly counts and corresponding population estimates, while temperature served as the exogenous predictor. A grid search procedure was used to identify the optimal (p, d, q) and (P, D, Q, s) parameters, with

Table 1: SARIMAX Results for the total population (2000–2023)

MODEL SUMMARY						
Statistic	**Value**		**Statistic**		**Value**	
Model	SARIMAX(1,0,1)(1,0,1)[12]		BIC		-1096.038	
Log-Likelihood	564.858		HQIC		-1109.015	
AIC	-1117.76		No. of Observations		288	
PARAMETER ESTIMATES						
Parameter	Coefficient	Std. Error	z-value	p-value	95% CI (Lower)	95% CI (Upper)
Monthly Average Temperature	0.0038	0.00076	5.027	0.001	0.002	0.005
ar.L1	0.9945	0.006	162.106	0.001	0.982	1.006
ma.L1	–0.6635	0.047	–14.030	0.001	–0.756	–0.571
ar.S.L12	0.9316	0.019	48.245	0.001	0.894	0.969
ma.S.L12	–0.8254	0.060	–13.823	0.001	–0.942	–0.708
sigma2	0.0009	0.000	10.833	0.001	0.001	0.001
DIAGNOSTIC TESTS						
Ljung-Box (L1) Q(1): p = 0.86						
Jarque-Bera (JB): p = 0.07						
Heteroskedasticity (H): p = 0.69						

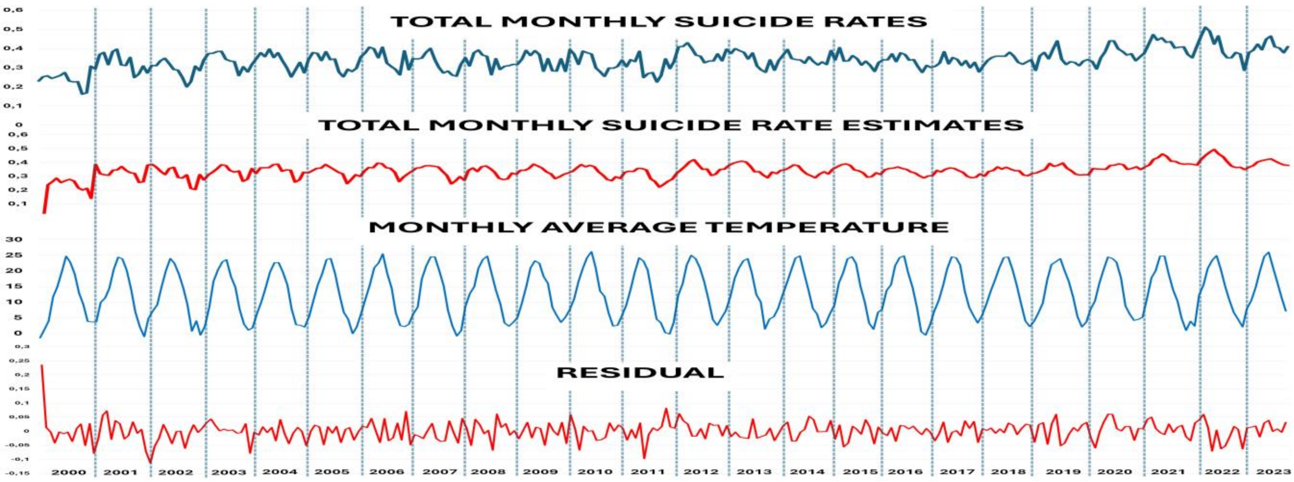

Figure 1: Graphical representation of monthly average temperature data between 2000-2023, monthly suicide rates, estimated and residual values obtained by time series analysis in the Total Population.

s set to 12 for annual seasonality, based on the minimum Akaike Information Criterion (AIC). Modeling was conducted in Python using the "statsmodels" package. Maximum likelihood estimation was applied, and model adequacy was evaluated through residual diagnostics, including the Ljung–Box test (autocorrelation), Jarque–Bera test (normality), and heteroskedasticity checks. The final model estimated the temperature–suicide relationship while controlling for autocorrelation and seasonality, providing a robust framework to assess the temporal influence of temperature on suicide incidence over the 24-year study period.

All descriptive and correlation analyses were carried out in SPSS v26.0, while SARIMAX time series modeling was implemented in Python via the Google Colab environment.

Results

Between 2000 and 2023, a total of 74,064 suicide-related deaths were recorded across Turkey (annual average: 3,086; annual minimum: 1,802 deaths in 2000; annual maximum: 4,218 deaths in 2022). Of these deaths, 52,648 (71.1%) were among males (annual average: 2,194; annual minimum: 1,114 in 2000; annual maximum: 3,263 in 2021), while 21,416 deaths (28.9%) occurred among females (annual average: 892.3; annual minimum: 688 in 2000; annual maximum: 1,131 in 2003). During this period, the average annual crude suicide rate in Turkey was 4.09 per 100,000 population (minimum: 2.80 per 100,000 in 2000; maximum: 4.98 per 100,000 in 2021). The analysis revealed a significant increase in total and male suicide rates over time (p=0.000), while a significant decrease was observed in the number of female suicides (p<0.001). During this 24-year period, the average monthly suicide incidence in the total population was found to be 0.339 per 100,000 (minimum: 0.162 per 100,000 in November 2000; maximum: 0.511 per 100,000 in May 2022). Among males, the rate was 0.477 per 100,000 (minimum: 0.189 in November 2000; maximum: 0.747 in May 2021), while among females, it was 0.200 per 100,000 (minimum: 0.106 in February 2023; maximum: 0.357 in May 2003).

Analysis of the correlation between monthly average temperature and suicide rates revealed a positive and statistically significant association for the total population (Spearman's Rho = 0.462; p < 0.001), as well as for males (Spearman's Rho = 0.292; p = 0.001) and females (Spearman's Rho = 0.366; p = 0.001). To assess the relationship between temperature and suicide rates, we applied SARIMAX models across total, male, and female populations. For the total population, SARIMAX(1,0,1)(1,0,1)[12] provided the best fit (AIC = –1117.72). Average temperature was positively and significantly associated with suicide rates (β = 0.0038, p = 0.001), and all temporal parameters were significant. Diagnostic tests confirmed model adequacy, with no issues in autocorrelation, normality, or variance stability (Table 1, Figure 1; Supplementary Material). Among males, the best-fitting model was SARIMAX(0,1,1)(1,0,1)[12] (AIC = –851.43). The temperature coefficient was again positive and significant (β = 0.0043, p = 0.001), with all key

Table 2: SARIMAX Results for the Male Population (2000–2023)

MODEL SUMMARY						
Statistic	**Value**			**Statistic**	**Value**	
Model	SARIMAX(0,1,1)(1,0,1)[12]			BIC	–833.383	
Log-Likelihood	430.715			HQIC	–844.185	
AIC	–851.430			No. of Observations	288	
PARAMETER ESTIMATES						
Parameter	Coefficient	Std. Error	z-value	p-value	95% CI (Lower)	95% CI (Upper)
Monthly Average Temperature	0.0043	0.00113	3.818	0.001	0.002	0.006
ma.L1	–0.6740	0.046	–14.538	0.001	–0.765	–0.583
ar.S.L12	0.9232	0.025	36.335	0.001	0.873	0.973
ma.S.L12	–0.8202	0.059	–14.013	0.001	–0.935	–0.705
sigma2	0.0024	0.00022	11.005	0.001	0.002	0.003
DIAGNOSTIC TESTS						
Ljung-Box (L1) Q(1): p = 0.63						
Jarque-Bera (JB): p = 0.67						
Heteroskedasticity (H): p = 0.99						

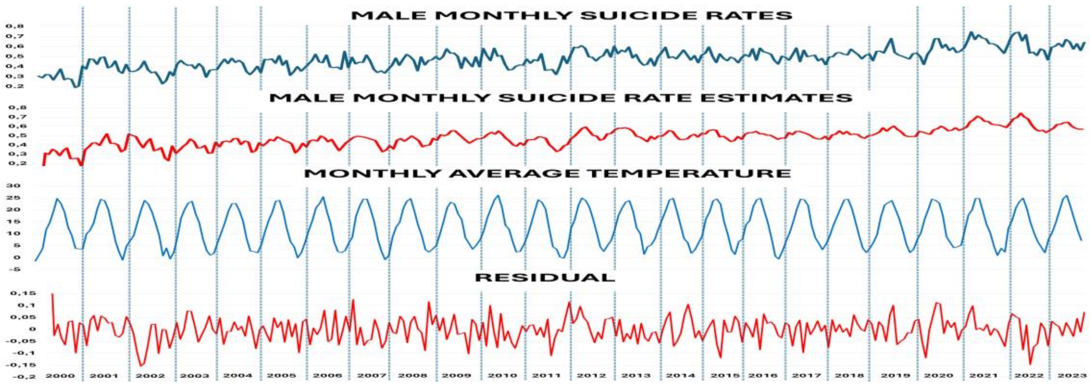

Figure 2: Graphical representation of monthly average temperature data between 2000-2023, monthly suicide rates, estimated and residual values obtained by time series analysis in the Male Population.

temporal terms contributing meaningfully. Residual diagnostics supported the model's robustness (Table 2, Figure 2). For females, SARIMAX(2,0,1) was optimal (AIC = –1153.62),

Table 3: SARIMAX Results for the female population (2000–2023)

MODEL SUMMARY			
Statistic	**Value**	**Statistic**	**Value**
Model	SARIMAX(2,0,1)	BIC	–1135.338
Log-Likelihood	581.809	HQIC	–1146.291
AIC	–1153.618	No. of Observations	288

PARAMETER ESTIMATES						
Parameter	Coefficient	Std. Error	z-value	p-value	95% CI (Lower)	95% CI (Upper)
Monthly Average Temperature	0.0025	0.00033	7.505	0.001	0.002	0.003
ar.L1	12.940	0.073	17.714	0.001	1.151	1.437
ar.L2	–0.2944	0.073	–4.024	0.001	–0.438	–0.151
ma.L1	–0.8892	0.036	–24.945	0.001	–0.959	–0.819
sigma2	0.0010	8.43e–05	11.806	0.001	0.001	0.001

DIAGNOSTIC TESTS
Ljung-Box (L1) Q(1): p = 0.58
Jarque-Bera (JB): p = 0.97
Heteroskedasticity (H): p < 0.05

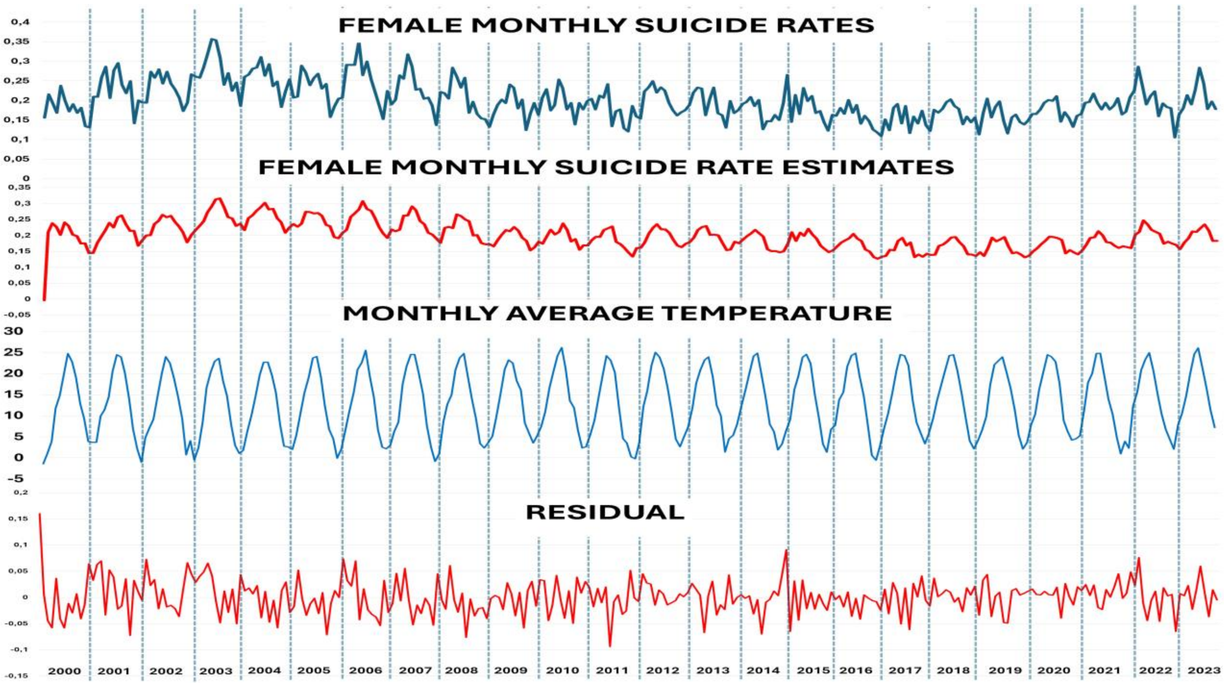

Figure 3: Graphical representation of monthly average temperature data between 2000-2023, monthly suicide rates, estimated and residual values obtained by time series analysis in the Female Population.

with a significant but smaller temperature effect (β = 0.0025, p = 0.001). Despite a heteroskedasticity finding ($p < 0.05$), other diagnostics confirmed model adequacy (Table 3, Figure 3). Across all subgroups, temperature was a consistent and significant predictor of suicide rates, with the strongest association in males, followed by the total and female populations. These findings highlight the relevance of ambient temperature as an environmental risk factor for suicide in Turkey.

During the 24-year study period, a 1 °C increase in population-weighted average temperature was associated with an estimated 1.12% increase in the monthly suicide incidence in the total population (based on SARIMAX coefficient: 0.0038; baseline rate: 0.339 per 100,000). Among males, the corresponding increase was approximately 0.90%, while for females it reached 1.25%, indicating a relatively greater temperature sensitivity in female suicide incidence rates.

Discussion

This study demonstrated a significant and consistent positive association between ambient temperature and suicide rates across the total, male, and female populations in Turkey. Using SARIMAX time series modeling over a 24-year period (2000-2023), the analysis revealed that increases in monthly average temperature were linked to elevated suicide rates, with the strongest effect observed among males. These findings align with a growing body of international literature suggesting that meteorological factors-particularly temperature-may influence suicidal behavior (14–27). However, to the best of our knowledge, this is the first nationwide study in Turkey to investigate this association using 24 years of monthly suicide statistics, high-resolution satellite-based temperature data, and a time series modeling approach that accounts for both seasonality and autocorrelation. Given ongoing climate change and global warming, these results serve as an important warning, emphasizing the need for proactive measures to address rising suicide risks associated with increasing temperatures. A review of prominent studies investigating the relationship between temperature and suicide in the literature reveals that all of them have reported a positive association between these two variables (6,14-27). While most of these studies have analyzed average temperature as the primary exposure variable (15-18,21,24-27), some have also focused on maximum temperature (16,20,22,23), minimum temperature (14,19,20,22,23), or combinations of these metrics. A meta-analysis examining the findings of such studies reported significant associations between both average and maximum temperatures and suicide rates, whereas the association between minimum temperature and suicide rates was not found to be statistically significant (6). In our study, average temperature was selected as the primary temperature parameter, consistent with the majority of previous research. This approach was adopted because the study aimed to capture nationwide suicide data and estimate the average temperature exposure experienced by the average population during each month. Given the hypothesis that temperature variability in late spring and early summer may lead to the overactivation of brown adipose tissue as a physiological adaptation to cold, resulting in heat intolerance, which in turn could trigger anxiety, psychomotor agitation, and ultimately negatively affect mental health and increase suicide risk (28), future studies may consider incorporating additional parameters such as temperature variability or temperature variance into their analyses. Previous studies, along with the findings of the present research, strongly support the assertion that rising temperatures represent a significant risk factor for suicide. Accordingly, it may be possible to prevent suicide cases by implementing timely interventions during periods of elevated ambient temperature, particularly among high-risk populations. Mental health services can be strengthened in anticipation of extreme heat events, based on forecasts from meteorological authorities. In urban planning, structural measures aimed at reducing the urban heat island effect should be prioritized. Broader climate change mitigation efforts may also contribute to reducing temperature-related suicide deaths. Furthermore, exploring the underlying mechanisms through which heat may trigger suicidal behavior could eventually lead to pharmacological strategies for prevention. In terms of the temporal resolution of temperature data, most studies in the literature have analyzed daily statistics (16–19,22–27), while fewer have utilized weekly (14) or monthly (15,20,21) data. Although higher temporal resolution undoubtedly provides more precise insights, this study relied on monthly temperature data due to the fact that only monthly and annual suicide statistics are available in Turkey. Nevertheless, the findings are considered noteworthy as they reflect the overall trend and demonstrate a positive correlation between temperature and suicide rates at the national level-consistent with results observed in Western countries. Furthermore, a review of the existing literature revealed no studies that examined temperature data corresponding to the exact hour of a suicide or suicide attempt. Future research could significantly enhance our understanding of this relationship by recording and analyzing the ambient temperature at the time of emergency department admissions for suicide attempts, thereby achieving the highest possible temporal resolution in this context. In analyses involving seasonally fluctuating variables such as suicide and temperature, selecting an appropriate analytical method or model is crucial for ensuring the accuracy and validity of the findings. Previous studies on this topic have employed a range of statistical models, including Generalized Linear Models (GLM) (22,26), Negative Binomial Regression (16,29), Poisson Regression (19), Multiple Regression (20), Hierarchical Multiple Logistic Regression (25), Conditional Poisson Models (27), Bayesian Conditional Autoregressive Models (CAR) (15), Generalized Additive Models (GAM) (14,17), Poisson Generalized Linear Mixed

Models (GLMM) (24), and SARIMA (21). In our study, we employed the SARIMAX method, which accounts for seasonal fluctuations and autocorrelation in monthly suicide data while simultaneously incorporating an exogenous covariate-average temperature-to assess its effect. In future studies, the inclusion of multiple covariates rather than a single predictor may yield more robust and comprehensive results. Furthermore, the application of advanced analytical tools such as Long Short-Term Memory (LSTM) networks-a deep learning-based time series modeling approach-could enhance predictive performance and offer deeper insights into the relationship between temperature and suicide. Previous studies have incorporated a wide range of control variables in their analyses, including meteorological and environmental factors such as rainfall (14,15,20,21,28), sunshine (17,21), solar radiation (26), insolation (14), wind velocity (16,20), barometric pressure (16), cloud cover (22), relative humidity (9,15–17,23), and deviation from mean temperature (27); temporal variables such as month (16,18,19), year (16,18), day of the week (18,27), public and national holidays (16,17,27), and length of daylight (18); demographic and socioeconomic indicators such as unemployment rates (15,21), labor force participation rates (21), Socio-Economic Indexes for Areas (SEIFA) (15), population density (25), log-transformed population (26), and the proportion of Aboriginal and Torres Strait Islander populations (ATSI) (15); as well as contextual controls such as seasonality (29). These control factors are important to reduce the risk of Type I and Type II errors and to better isolate the specific effect of temperature on suicide rates. In our study, we accounted for key confounders such as seasonality, autocorrelation, and sex. Although it was not feasible to include additional variables such as age, socioeconomic status, psychiatric illness, divorce rates, unemployment rates, or physical health indicators-due to the lack of comprehensive nationwide monthly retrospective data in Turkey-future research that incorporates such covariates may yield more reliable and nuanced findings regarding the complex relationship between temperature and suicide.

Limitations: This study has several strengths and limitations that should be considered when interpreting the findings. The first limitation is the unavailability of day-based suicide data. While this limitation is unlikely to be overcome at the national level in Turkey due to current data reporting practices, it could potentially be addressed in future research conducted in emergency departments or forensic medicine units. Another limitation is the limited availability of control variables. It was not feasible to obtain comprehensive monthly data on relevant covariates across all provinces over the 24-year period. Although our analyses revealed strong evidence of a significant association between rising temperatures and increased suicide rates, it should be acknowledged that this finding may, at least in part, be influenced by unmeasured covariates such as socioeconomic, psychiatric, or cultural factors. Until these results are confirmed through future analyses that incorporate such covariates, they should be interpreted with caution.

Ethical considerations: This study was conducted using publicly available, anonymized data sources, including official suicide statistics provided by the Turkish Statistical Institute and temperature data from the ERA5-Land reanalysis dataset, which is distributed under a Creative Commons Attribution 4.0 International (CC BY 4.0) license. As no individual-level or identifiable personal data were used, ethical approval was not required. All procedures were carried out in accordance with the principles of the Declaration of Helsinki and complied with national and international standards for research ethics. The study also adheres to the ethical guidelines of the Committee on Publication Ethics (COPE), the research integrity principles of the Scientific and Technological Research Council of Turkey (TÜBİTAK), and the broader framework of open science and responsible data use

Conclusion

This 24-year nationwide analysis identified a positive and statistically significant association between ambient temperature and suicide rates in Turkey. Using monthly official suicide data and satellite-based temperature estimates, a SARIMAX model was applied to account for seasonality and autocorrelation. Despite limitations-such as the lack of daily data and limited covariates-our findings highlight temperature as a potential environmental risk factor for suicide. In the context of global warming, these results offer a critical warning and underscore the need for preventive strategies. Future studies should consider additional covariates, higher-resolution data, and advanced modeling approaches to better understand and mitigate climate-related suicide risks.

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Author contributions: E.K. conceptualized the study, developed the study design, and drafted the initial version of the manuscript. Y.E. performed the data analysis and programming/coding, conducted the literature review, and created the visualizations. Both authors contributed to the interpretation of the results, revised the manuscript critically for important intellectual content, and approved the final version of the manuscript.

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