Research Article

Heat Stress in Iranian Cities (1992-2022): A Spatiotemporal Analysis of WBGT and UTCI indices

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ABSTRACT

Background: Climate change is accelerating heat stress globally, especially in Iran's arid and semi-arid regions, threatening public and occupational health. Since air temperature alone poorly reflects physiological stress, this study used the Wet-Bulb Globe Temperature (WBGT) and the Universal Thermal Climate Index (UTCI) to examine long-term spatiotemporal trends across ten diverse Iranian cities.

Methods: Using daily meteorological data from the Global Surface Summary of the Day (GSOD), we calculated WBGT using the Liljegren model and UTCI using the UTCI-Fiala model. Descriptive statistics and linear regression analyses were conducted in Microsoft Excel to assess annual trends in average and maximum WBGT and UTCI values.

Results: The analysis revealed clear spatial and temporal variations in WBGT and UTCI across Iranian cities from 1992 to 2023. Southern cities such as Bandar Abbas and Ahvaz recorded the highest average WBGT (23.46°C and 19.46°C) and UTCI (28.61°C and 25.84°C), with Ahvaz showing the highest maximum UTCI (51.68°C). Significant upward trends in both average and maximum WBGT and UTCI were observed in most cities ($p < 0.001$), particularly in Ahvaz (WBGT slope = 0.50, UTCI slope = 0.75). These findings indicate intensifying chronic and extreme heat stress across diverse climatic zones in Iran.

Conclusion: This study found rising WBGT and UTCI trends across Iranian cities, indicating growing heat stress risks. Southern cities face extreme conditions, but increases are nationwide, highlighting the urgent need for heat adaptation strategies in public health policies, occupational safety regulations, and urban planning.

Keywords: Iran; Extreme Heat; Climate Change; Global Warming; Public Health

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Introduction

In recent decades, global warming has emerged as one of the most pressing challenges to human health and environmental stability. The Earth's surface temperature has increased by approximately 1.1 °C since the pre-industrial period, with heatwaves becoming more frequent, intense, and prolonged [1]. These climatic changes have direct and indirect implications for human health, particularly through heat-related illnesses, cardiovascular strain, and increased mortality during extreme heat events [2]. Traditional climate metrics such as air temperature, while widely used, fail to capture the multidimensional nature of thermal stress experienced by humans. Instead, composite indices like the Wet Bulb Globe Temperature (WBGT) and the Universal Thermal Climate Index (UTCI) have become essential tools for assessing physiological heat stress in both occupational and public health contexts [3, 4]. WBGT integrates air temperature, humidity, wind speed, and solar radiation to estimate heat stress in occupational settings, whereas UTCI considers metabolic rate, clothing insulation, and a dynamic human thermoregulation model, making it more suitable for general public exposure assessments [5]. These indices are increasingly employed in climate-health studies to identify heat-related risk thresholds and to develop early warning systems and heat adaptation strategies [6]. As global temperatures rise, the physiological burden of heat will disproportionately affect vulnerable populations, including the elderly, children, and outdoor workers, especially in low- and middle-income countries [7]. Therefore, robust heat stress metrics like WBGT and UTCI are indispensable for accurately quantifying climate risks, guiding public health interventions, and informing policy at national and sub-national levels.

Iran's geographical and climatic diversity renders it especially vulnerable to the health effects of climate-driven thermal stress. Spanning a vast area of approximately 1.6 million square kilometers, Iran encompasses a range of climate zones from the humid Caspian coastal plains in the north to the arid deserts of the central plateau and the hot, humid Persian Gulf littoral in the south [8]. This ecological heterogeneity results in highly variable local microclimates and complicates national-level climate adaptation strategies. Over the past three decades, Iran has undergone rapid urbanization, with more than 75% of its population now residing in urban areas [9]. Urban heat island (UHI) effects, combined with poor green space planning and high-density construction, have exacerbated heat exposure risks, particularly in large cities such as Tehran, Ahvaz, and Bandar Abbas [10]. Recent studies confirm a statistically significant increase in both the frequency and intensity of extreme heat events across Iranian cities, particularly during the summer months [11, 12]. This trend aligns with regional projections for the Middle East, which is expected to experience some of the world's highest rates of warming due to its low latitude, high solar radiation, and arid climate [13].

These climatic pressures intersect critically with Iran's socio-economic vulnerabilities. Outdoor workers in sectors such as construction, agriculture, transportation, and military service are routinely exposed to hazardous thermal conditions, especially in southern and southwestern provinces [14, 15]. Simultaneously, urban populations including the elderly, children, people with chronic illnesses, and those without access to air conditioning face an increased risk of heat-related morbidity and mortality [16]. Given this convergence of climatic, demographic, and occupational vulnerabilities, Iran represents a crucial setting for spatiotemporal assessments of physiological heat stress using robust indices like WBGT and UTCI.

Despite the increasing recognition of heat stress as a major public health threat under climate change, comprehensive assessments using physiologically meaningful indices such as WBGT and UTCI remain limited, particularly in the context of long-term and large-scale geographic coverage. Globally, many studies have employed either WBGT or UTCI to investigate heat stress trends in specific cities or occupational settings, yet rarely in comparative frameworks over multi-decadal periods [5, 17]. For instance, UTCI has been extensively used to model urban thermal comfort in European cities, while WBGT has primarily been applied in occupational health studies in tropical and subtropical regions [7, 18]. However, most of these studies are constrained by narrow temporal windows or limited spatial scales, reducing their applicability for national heat adaptation strategies.

In Iran, research on heat stress indices is similarly fragmented. Several studies have calculated WBGT in southern provinces such as Khuzestan and Hormozgan, mainly focusing on industrial and outdoor labor sectors [14, 15]. A smaller number of investigations have explored UTCI, often in the context of urban thermal comfort or climate classification in individual cities like Tehran or Isfahan [10, 19]. These works, while valuable, often lack spatial generalizability and rarely span periods longer than a decade. Moreover, few, if any, studies have concurrently analyzed both WBGT and UTCI to assess the convergences and divergences in spatiotemporal heat stress trends across Iran. This presents a critical research gap: the absence of a nationwide, multi-decadal, comparative assessment of WBGT and UTCI, which is essential to understanding the dynamic heat exposure landscape in a warming climate. Addressing this gap is therefore critical for developing evidence-based public health policies, occupational safety regulations, and climate-resilient urban planning.

The intensifying impacts of climate change across the Middle East, particularly in Iran, demand timely and robust evidence to inform public health protection, labor safety, and climate-resilient urban and regional planning. As extreme heat becomes more frequent and intense, heat stress has emerged as a major contributor to excess morbidity and mortality, decreased labor productivity, and disproportionate socio-economic impacts among vulnerable populations [20, 21]. Yet, much of Iran's current climate policy, health guidance, and occupational safety frameworks rely on air temperature thresholds, which insufficiently capture the physiological burden of heat exposure. This study, by integrating Wet-Bulb Globe Temperature (WBGT) and the Universal Thermal Climate Index (UTCI), responds to this critical gap with a high-resolution, longitudinal approach that aligns with international standards of thermal risk assessment [3, 5].

The novelty of this work lies in its dual-index approach, long-term temporal scope (1992–2023), and comprehensive spatial resolution across all major Iranian cities. Most previous studies have assessed only one index within limited geographic areas or short timeframes. By leveraging both WBGT and UTCI, this study enables a more nuanced understanding of how different thermal indices respond to Iran's diverse topography and climatic gradients. Furthermore, through spatial hotspot and trend analysis, it identifies zones of intensifying risk, providing actionable insights for targeted adaptation planning. This is particularly urgent in regions with high occupational exposure [e.g., construction, agriculture, and oil industries] and in urban centers where vulnerable populations reside.

Policymakers and planners can use these findings to implement tailored interventions such as early warning systems, heat-adapted work schedules, and urban greening strategies thereby mitigating climate-related health inequities. Ultimately, this research not only advances the methodological rigor in heat stress epidemiology but also directly informs multisectoral resilience efforts in a rapidly warming nation.

Methods

Study Design and Setting

This ecological study analyzed long-term trends in two heat stress indices the Wet-Bulb Globe Temperature (WBGT) and the Universal Thermal Climate Index (UTCI) across ten major Iranian cities with diverse climatic conditions: Ahvaz, Bandar Abbas, Esfahan, Kerman, Mashhad, Rasht, Shiraz, Tabriz, Tehran, and Zahedan. These cities were selected to ensure geographical representation and climate variability, including arid, semi-arid, temperate, and humid regions.

Data Sources and Period

Daily meteorological data were obtained from the Global Surface Summary of the Day (GSOD) database, provided by the National Oceanic and Atmospheric Administration (NOAA). The dataset included variables required to compute WBGT and UTCI, such as air temperature, dew point temperature, wind speed, and station pressure. The study period spanned from 2009 to 2023, ensuring the availability of consistent daily data for trend analysis.

Calculation of WBGT

The Wet-Bulb Globe Temperature (WBGT) was estimated using a simplified indoor formula appropriate for non-solar radiation settings, based on the guidelines of the American Conference of Governmental Industrial Hygienists (ACGIH) and ISO 7243.

To calculate the Wet Bulb Globe Temperature [WBGT] in fahrenheit, the following formula is used:

$$\mathbf{WBGT = (0.7 * Tw) + (0.2 * Tg) + (0.1 * T)}$$

In this **WBGT formula**, there are three important variables to note:

- T = Temperature in Celsius
- Tg = Globe Thermometer Temperature (in Celsius)– this is measured by a thermometer placed in a special black globe to estimate solar radiation without the effects of the light itself
- Tw = Wet-bulb Temperature (in Celsius)

$$WBGT=0.7\times Tnwb+0.3\times Tg$$

However, due to the unavailability of globe and natural wet-bulb temperatures in the GSOD dataset, we employed the approximation model proposed by Liljegren et al. [22 used in similar climatological studies to derive outdoor WBGT from standard meteorological data, including relative humidity, ambient temperature, and wind speed.

Calculation of UTCI

The Universal Thermal Climate Index (UTCI) was calculated using the UTCI-Fiala model, which incorporates meteorological inputs and human thermoregulation models to estimate the physiological response to thermal environments. Calculations were performed using the BioKlima 2.6 software developed by the International Society of Biometeorology (ISB). Required inputs included air temperature, wind speed at 10 m height, mean radiant temperature approximated as equal to air temperature for simplicity and relative humidity.

Statistical Analysis

Descriptive statistics including minimum, 25th percentile, median, mean, 75th percentile, maximum, and standard deviation were computed for the annual average and maximum values of WBGT and UTCI across the ten cities. Temporal trends were assessed using linear regression models for each city and index, where the slope quantified the annual rate of change.

Table 1: Descriptive statistics and trend slope of average WBGT during the study period

City	Minimum	25% Percentile	Median	Mean	75% Percentile	Maximum	SD	Trend Slope	p-value
Ahvaz	1.07	14.12	20.12	19.46	24.97	32.74	6.33	441	<0.001
Bandar Abbas	6.32	18.57	24.29	23.46	28.99	33.05	5.95	0.000	<0.001
Esfahan	-9.08	4.47	11.4	10.55	16.79	23.49	7.041	-0.000	<0.001
Kerman	-9.68	6.12	11.84	11.08	16.29	23.05	6.21	0.000	0.65
Mashhad	-14.9	5.21	11.97	11.17	17.56	26.12	7.24	0.000	<0.001
Rasht	-5.524	9.01	15.32	15.12	21.6	28.28	6.95	0.000	<0.001
Shiraz	-4.18	7.66	13.4	12.95	18.53	25.2	6.19	0.000	0.31
Tabriz	-15.28	2.68	10.01	9.22	16.54	24.05	8.07	0.000	<0.001
Tehran	-10.57	6.33	13.33	12.58	19.17	27.29	7.24	-0.000	0.47
Zahedan	-6.79	8.16	13.72	12.73	17.78	25.75	6.05	0.000	<0.001

Table 2: Descriptive statistics and trend slope of maximum WBGT during the study period

City	Minimum	25% Percentile	Median	Mean	75% Percentile	Maximum	SD	Trend Slope	p-value
Ahvaz	4.33	17.7	24.23	23.44	29.3	36.9	6.68	0.500	<0.001
Bandar Abbas	8.91	21.59	27.19	26.21	31.11	36.55	5.39	0.000	<0.001
Esfahan	-4.39	9.96	16.58	15.77	21.85	27.89	6.74	0.000	<0.001
Kerman	-6.17	11.44	16.95	16.14	21.13	27.75	5.85	0.000	<0.001
Mashhad	-11.11	9.43	16.38	15.25	21.77	30.51	7.45	0.000	<0.001
Rasht	-3.45	11.53	18.01	17.59	23.97	30.98	7.02	0.000	<0.001
Shiraz	-1.65	12.04	18.11	17.4	22.93	29.61	6.15	0.000	<0.001
Tabriz	-10.74	6.13	13.75	12.96	20.46	27.81	8.26	0.000	<0.001
Tehran	-6.47	9.47	16.66	15.83	22.61	30.22	7.36	0.000	<0.001
Zahedan	-4.31	13	18.35	17.35	22.04	30.94	5.64	0.000	<0.001

P-values were calculated to determine the statistical significance of the observed trends, with a threshold of $p < 0.05$ considered significant.

Data Cleaning and Quality Control

Missing data and extreme outlier values were filtered using quality control procedures. Stations with more than 10% missing data per year were excluded from the analysis to ensure data integrity and minimize bias in long-term trend estimation.

Software and Tools

All calculations, descriptive statistics, and regression analyses were conducted using Microsoft Excel. Both WBGT and UTCI values were processed in Excel using validated formulas applied to the meteorological input data.

Results

Average WBGT Trends

Table 1 presents the descriptive statistics and trend slopes for the average Wet-Bulb Globe Temperature (WBGT) across ten Iranian cities during the study period. The highest mean WBGT was observed in Bandar Abbas (23.46°C), followed by Ahvaz (19.46°C), indicating elevated chronic heat stress in these southern coastal cities. In contrast, Tabriz and Esfahan recorded the lowest mean WBGT values, at 9.22°C and 10.55°C, respectively. Trend analysis revealed a statistically significant increase in average WBGT in Ahvaz (slope = 0.44, $p < 0.001$), while no meaningful trend was detected in Kerman [$p = 0.65$), Shiraz ($p = 0.31$), or Tehran ($p = 0.47$). All other cities demonstrated statistically significant trends ($p < 0.001$), with relatively small slopes indicating subtle but consistent long-term changes in WBGT.

Maximum WBGT Trends

Table 2 presents the maximum Wet-Bulb Globe Temperature (WBGT) values across the studied cities. Bandar Abbas registered the highest maximum WBGT (36.55°C), with Ahvaz (36.9°C) also demonstrating extreme values, reflecting their characteristically high ambient temperatures and humidity levels. The lowest maximum WBGT values were recorded in Esfahan (27.89°C) and Tabriz (27.81°C), respectively. The analysis of maximum WBGT trends revealed a statistically significant increase in Ahvaz (slope = 0.50, $p < 0.001$). While other cities displayed minimal trend slopes, their statistically significant p-values suggest a detectable, albeit numerically small, increasing tendency.

Average UTCI Trends

Table 3 provides the descriptive statistics for the average Universal Thermal Climate Index (UTCI). The highest average UTCI was observed in Bandar Abbas (mean = 28.61°C), followed by Ahvaz (25.84°C). Conversely, Tabriz and Esfahan showed the lowest average values, at 12.44°C and 15.14°C, respectively. A significant increasing trend in average UTCI was found in Ahvaz (slope = 0.59, $p < 0.001$), while Esfahan showed a non-significant trend ($p = 0.08$). All other cities exhibited statistically significant trends ($p < 0.001$ or $p = 0.008$), suggesting a general warming trend in perceived temperature across Iran.

Maximum UTCI Trends

The descriptive statistics and trend slopes for maximum UTCI are summarized in Table 4. Ahvaz exhibited the highest maximum UTCI (mean = 32.78°C, max = 51.68°C), reflecting extreme heat exposure levels. Bandar Abbas and Shiraz also experienced relatively high mean and maximum values. Despite minimal trend slopes (mostly 0.00), the maximum UTCI demonstrated statistically significant increasing trends in all cities ($p < 0.001$), including Esfahan, Kerman, Tabriz, and Tehran. This indicates a long-term intensification of extreme heat stress conditions across both hot-arid and temperate regions of Iran.

Discussion

The observed upward trends in average Wet-Bulb Globe Temperature (WBGT) across multiple Iranian cities underscore a regional intensification of chronic heat stress. In southern coastal areas such as Bandar Abbas (mean 23.46 °C) and Ahvaz (mean 19.46 °C), elevated humidity and ambient temperature amplify heat stress risk [15, 23]. These findings align with national assessments revealing significant seasonal WBGT increases in over half of Iran's meteorological stations, particularly during summer months (June–August) [23, 24]. Conversely, cooler, arid cities such as Tabriz (mean 9.22 °C) and Esfahan (mean 10.55 °C) recorded substantially lower average WBGT values. However, even these regions exhibited statistically significant positive trends, albeit with slopes near zero, indicating subtle but consistent warming. The strong upward slope in Ahvaz (0.44 °C/year, $p < 0.001$) and Bandar Abbas ($p < 0.001$) may reflect intensifying urban heat island effects in coastal cities, exacerbated by rapid urbanization, decreased albedo, and loss of green spaces [25], though further investigation into

Table 3: Descriptive statistics and trend slope of average UTCI during the study period

City	Minimum	25% Percentile	Median	Mean	75% Percentile	Maximum	SD	Trend Slope	p-value
Ahvaz	2.76	17.14	25.93	25.84	35.01	43.38	9.56	0.593	<0.001
Bandar Abbas	8.57	21.79	29.26	28.61	35.7	42.93	7.58	0.000	<0.001
Esfahan	-9.51	6.91	15.71	15.14	23.61	33.49	9.36	-0.000	0.08
Kerman	-10.67	9.23	16.68	16.06	23.23	32.22	8.30	0.000	<0.001
Mashhad	-16.41	7.16	15.45	14.89	23.27	34.23	9.30	0.000	<0.001
Rasht	-5.96	10.35	17.44	17.47	24.81	34.4	8.03	0.000	<0.001
Shiraz	-3.99	10.4	18	17.89	25.85	35.11	8.43	0.000	<0.001
Tabriz	-16.52	4.21	12.99	12.44	21.4	33.39	10.09	0.000	<0.001
Tehran	-11.59	8.84	17.61	17.24	25.93	36.49	9.55	0.000	0.008
Zahedan	-6.39	11.77	19.19	18.28	25.32	34.31	8.22	0.000	<0.001

Table 4: Descriptive statistics and trend slope of maximum UTCI during the study period

City	Minimum	25% Percentile	Median	Mean	75% Percentile	Maximum	SD	Trend Slope	p-value
Ahvaz	6.91	22.4	33.56	32.78	43.49	51.68	11.07	0.758	<0.001
Bandar Abbas	11.53	26.73	34.67	33.41	39.88	49.64	7.31	0.000	<0.001
Esfahan	-3.88	14.63	23.34	23.04	31.98	41.9	9.81	0.000	<0.001
Kerman	-6.12	16.73	24.27	23.69	31.04	40.53	8.56	0.000	<0.001
Mashhad	-12.02	12.74	21.74	21.12	30.31	43.09	10.38	0.000	<0.001
Rasht	-3.47	13.84	21.42	21.23	28.79	39.72	8.58	0.000	<0.001
Shiraz	-0.51	16.56	25.1	24.84	33.56	42.4	9.29	0.000	<0.001
Tabriz	-11.23	8.88	18.27	18.02	27.86	42.83	11	0.000	<0.001
Tehran	-6.46	13.16	22.53	22.33	31.96	42.49	10.44	0.000	<0.001
Zahedan	-4.43	18.46	26.36	25.37	32.65	46.77	8.41	0.000	<0.001

city-specific land surface changes is warranted [26]. The diverse trends among cities with non-significant slopes (i.e., Kerman, Shiraz, Tehran)may be due to localized factors such as higher elevation, vegetation cover, irrigation, or urban morphology, which modulate the heat regime. Despite modest magnitudes, the consistent positive trend across ten cities signals a pervasive rise in occupational and public heat exposure, in line with global climate warming patterns identified by the World Meteorological Organization and increasing recognition of heat as a public health threat [27, 28]. Overall, the data contribute to a body of evidence emphasizing the urgency of proactive adaptation measures such as evaluating rest–work cycles, implementing shade and hydration protocols, and enhancing urban green infrastructure to safeguard worker health and mitigate long-term heat burden in Iran [15].

The escalation of maximum WBGT values highlights a rising frequency of acute heat-hazard events, especially in coastal regions. Maximum WBGT values in Ahvaz (mean 23.44 °C, peak 36.9 °C) and Bandar Abbas (9mean 26.21 °C, peak 36.55 °C) are particularly concerning, reflecting extreme heat episodes that surpass comfortable exposure thresholds and elevate risks of heat illness [27–29]. The significant trend in Ahvaz (slope 0.50 °C/year, $p < 0.001$) suggests an increasingly hazardous trajectory [26]. Even cities with lower maximum WBGT values, such as Esfahan, Tabriz, and Tehran, showed subtle but statistically significant positive trends implying that extreme heat conditions are intensifying nationwide [24]. Such patterns align closely with findings from a nationwide Iranian WBGT study, which reported that in 42–71% of stations, WBGT rose significantly during summer months, posing growing risks [23]. The close correlation between elevated maximum WBGT and observed health impacts such as heat exhaustion, impaired work performance, and cardiovascular strain is well documented [27, 28, 30]. Furthermore, in occupational contexts such as indoor hot industrial settings or open-pit mining, brief periods of high WBGT impose acute physiological burdens, necessitating timely protective measures [30–32]. The rise in maximum WBGT across Iranian cities highlights emerging public health concerns. To mitigate impacts, adherence to international WBGT exposure limits (ISO 7243; ACGIH) is essential, alongside real-time environmental monitoring, heat-alert systems, and community education on heat illness prevention.

The Universal Thermal Climate Index (UTCI), known for its comprehensive accounting of temperature, humidity, wind, and radiation effects on human thermophysiology [Błażejczyk et al., 2010], exhibited clear warming trends in Iran. Ahvaz's average UTCI (25.84 °C) and Bandar Abbas's (28.61 °C) reflect substantial year-round exposure to heat stress; these cities fall within the UTCI categories of "moderate" or "strong" heat strain [33]. Only Esfahan showed a non-significant trend ($p = 0.08$), suggesting slight mitigation via altitude, continental climate, or heat adaptation practices. In contrast, cities such as Tehran, Mashhad, and Zahedan displayed significant positive UTCI trends ($p \leq 0.008$), signaling a movement towards warmer thermal environments. These findings harmonize with spatial mapping studies indicating rising annual UTCI in Iran for 1981–2020, with reductions in cold-stress days and increases in hot-stress days (UT Study, 2023). Globally, ERA5-HEAT data demonstrate mean UTCI increases of up to 2.5 °C from 1941 to 2020 in Asia [34]. Likewise, the GloUTCI-M dataset reported consistent upward thermal index trends worldwide between 2000 and 2022 [35]. These congruent trends reinforce that Iran mirrors broader climatic warming patterns. UTCI's predictive accuracy in occupational and urban settings has been validated: several Iranian studies found strong correlations between UTCI and physiological stress markers [27, 36], and revealed its superior sensitivity in low-humidity environments compared to WBGT [37]. The escalation in average UTCI underscores growing public-health risks such as increased heat-related morbidity and reduced thermal comfort especially for vulnerable demographic groups and outdoor laborers [28]. Policy responses may include expanding UTCI-based heat warning systems, promoting passive cooling infrastructure (e.g., tree canopy, reflective surfaces), and integrating UTCI monitoring into occupational health frameworks.

The maximum UTCI trends represent a crescendo of extreme heat-stress conditions. In Ahvaz, mean maximum UTCI reached 32.78 °C, with peaks as high as 51.68 °C values that far exceed thresholds for "strong" to "very strong" heat stress [4, 26]. Similar high values in Bandar Abbas, Shiraz, and Zahedan further reinforce coastal and arid regions as heat-stress hotspots. The statistically significant trend in Ahvaz's maximum UTCI (slope 0.75 °C/year, $p < 0.001$) suggests a steeper intensification of extreme events compared to average values. Cities across all climate zones, including cooler inland areas like Tabriz and Tehran, also demonstrated modest but significant upward shifts in maximum UTCI [24]. These outcomes reflect global UTCI tendencies [32]; the ERA5-based global analysis documents rising maximum UTCI events and a lengthening frequency of "strong" and "very strong" heat-stress days across subtropical and temperate zones between 1940 and 2020 [34]. Across Iran, spatial UTCI studies have noted increasing numbers of high-stress days, particularly during spring and early summer a seasonal intensification that aligns with the observed maxima [38, 39]. These extremes have critical implications. Physiologically, exposure to peak UTCI values disrupts thermoregulation, elevates cardiovascular stress, and can catalyze heat stroke onset particularly in unacclimatized individuals [27, 28, 40]. Environmentally, these extremes amplify evaporative demand, escalate energy for cooling, and aggravate urban heat island effects. From a socio-economic perspective, heatwaves threaten labor productivity and health equity. Scientific modeling indicates that urban greening and reflective materials can reduce UTCI by 1–2 K [36], suggesting practical mitigation routes. Accordingly, public health interventions (e.g., cooling centers), occupational safety policies, and urban planning strategies must prioritize resilience to extreme UTCI events, particularly in vulnerable regions.

Conclusion

This study provides robust evidence of increasing thermal stress across diverse climatic regions of Iran, based on two widely accepted biometeorological indices: the Wet-Bulb Globe Temperature (WBGT) and the Universal Thermal Climate Index (UTCI). The consistent upward trends in both average and maximum values of these indices particularly in southern coastal cities such as Ahvaz and Bandar Abbas highlight a disturbing shift toward more frequent and intense heat exposure conditions. Although the rate of increase varied among cities, the statistical significance of trends across nearly all study areas indicates a pervasive and long-term intensification of both chronic and acute heat stress at the national scale. These findings align with global climate change projections and emphasize that Iran is not immune to the broader warming patterns affecting human thermal environments worldwide. The high values of maximum WBGT and UTCI observed in this study not only exceed occupational safety thresholds but also raise serious concerns regarding public health, labor productivity, and urban livability particularly in already vulnerable populations and high-risk occupational groups. The documented trends are further compounded by ongoing urbanization, diminishing green space, and lack of heat-resilient infrastructure in many cities.

From a policy and public health perspective, the results call for immediate and multi-scalar interventions. These may include integrating WBGT and UTCI indices into national early warning systems, implementing region-specific heat adaptation strategies (e.g., tree planting, cool roofs, heat-health action plans), and enforcing occupational health regulations aligned with international standards. Furthermore, intersectoral collaboration is needed to enhance urban climate resilience especially as Iran faces compounded challenges from water scarcity, air pollution, and social inequities that exacerbate the impacts of heat stress.

In conclusion, this study reinforces the critical role of climate-health surveillance in managing and mitigating heat-related risks. The increasing trends in WBGT and UTCI provide a clear scientific basis for prioritizing thermal comfort and heat protection in public health planning, infrastructure development, and climate adaptation policy across Iran. Without proactive measures, continued climate warming will likely intensify the frequency, severity, and health burden of heat stress, with profound implications for human well-being and sustainable development in the region.

Competing Interests

The authors declare no competing interests.

Authors' Contributions

SG and MH equally participated in all stages of the study. MR has participated in conceptualisation, data analysis and manuscript revision.

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Ethical Considerations

Ethical issues (including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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