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Evaluation of the Spatial Distribution of Some Thermal Comfort Indices in Iraq Using the RayMan Model

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ABSTRACT

Lack of comprehensive evaluations of spatial thermal comfort parameters across Iraq remains a concern as the risks of excessive heat and climate change increase. This study analyzes the spatial distribution of outdoor human thermal comfort in Iraq using the Physiologically Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI). Monthly meteorological data from 38 stations (1981–2024) were obtained from the NASA POWER database and used in the RayMan model to calculate PET and UTCI. Monthly, seasonal, and annual comfort maps were then generated using GIS-based kriging interpolation. The results show a marked seasonal pattern: winter conditions are characterized by mild to moderate cold stress, with the greatest cold stress in northern and mountainous areas, whereas summer conditions indicate strong to very strong heat stress, particularly in the southern and southeastern provinces. Spring and autumn yielded the most comfortable conditions overall, with many areas showing neutral to low-stress levels in April or October. The spatial patterns of PET and UTCI are in good agreement, indicating reasonable consistency between the two indices even in hot, dry areas. In general, air temperature and solar radiation are the main factors enhancing heat stress, whereas wind speed and relative humidity are secondary drivers. Evaluating PET and UTCI patterns is important for supporting public health awareness, urban planning, and climate adaptation strategies in Iraq.

1. INTRODUCTION

Weather conditions affect human activity. Humans are highly sensitive to ambient heat, and exposure to high temperatures can lead to serious health consequences. Heat stroke may cause sudden death or injury to vital organs and body systems. It may also predispose individuals to heart disease and industrial accidents (Zare et al. 2018). Bioclimatic changes such as heat and cold waves are expected to increase in frequency under global warming (IPCC 2013, Pecelj et al. 2025). This is a key issue for understanding the health effects of weather and bioclimatic changes across times and places (Varentsov et al. 2020). Various indices have been developed to measure the degree of thermal discomfort perceived by humans (Burton et al. 2009). Several studies have examined human thermal comfort and the physical environment in both indoor and outdoor settings, including houses and pavilions (Abdel-Ghany et al. 2013).

Approximately 60 heat-stress indices have been proposed to examine hot environments and forecast the probability of heat stress. According to Burton et al. (2009), each of these surrogate indices has its own advantages and limitations (Zare et al. 2018). Municipalities and architects require quantitative information

on the effects of urban planning, open-space development, and reconstruction to select appropriate strategies for reducing anthropogenic climate impacts. Such data were previously difficult to obtain, but numerical models can now generate them readily. These models should also be simple and fast enough for non-experts so that relevant planners can use them, while providing the required data in a comprehensive and easy-to-understand form (Pecelj et al. 2025, Zare et al. 2018). Thermal indices provide a suitable approach for assessing thermal impacts and human thermal comfort (Matzarakis et al. 2021). Most bioclimatic indices are based on empirical meteorological variables and are therefore referred to as simple or empirical indices. Only a limited number explicitly incorporate human parameters in energy-balance models (Bartzokas 2013). An index based on measured weather parameters, including air temperature, wind speed, and relative humidity, is convenient and practical for use (Varentsov et al. 2020). Although many indices have been developed, only four, PET, PMV, UTCI, and SET, are commonly used in outdoor thermal sensation studies (Potchter et al. 2018). During the last two decades, Physiologically Equivalent Temperature (PET) has been widely used as a body-level thermal index (Mayer & Höppe 1987, Höppe 1997, Matzarakis et al. 1999). PET represents the air temperature of a reference indoor environment without wind or solar radiation at which the heat balance of an adult at rest is equivalent to that experienced under the outdoor conditions being studied (Matzarakis et al. 2015). A further development in this field is the Universal Thermal Climate Index (UTCI), developed under the auspices of the International Society on Biometeorology (ISB) and COST Action 730 (Cooperation in Science and Technical Development, supported by the EU RTD Framework Program). The index is available from: www.utci.org (Matzarakis et al. 2015). Further developments may draw on thermophysiological models of human responses to climatic conditions, including acclimatization, as a basis for a worldwide standard index.

Ratings of outdoor thermal conditions across major human biometeorological zones are considered 'universal' (Matzarakis et al. 1999). PET and UTCI can both be calculated using the RayMan software, which is provided free of charge by its developers. The RayMan model is a simplification of the two-node model and can use basic meteorological inputs such as dry-bulb air temperature (T_d), relative humidity (RH), wind speed (V), and mean radiant temperature (T_{mrt}) or global solar radiation (S_o) (Matzarakis et al. 2007). The RayMan model provides reasonable results in hot, sunny areas when $T_{mrt} > 60^\circ\text{C}$ around solar noon. PET temperature ranges corresponding to different grades of human thermal perception are provided

by Abdel-Ghany et al. (2013). Several studies have evaluated two or three simple thermal indicators (Dunjić et al. 2025, Pecelj et al. 2025). Other studies have related simple indices to PET (Al-Lami 2023, Pantavou et al. 2024). Recent studies have also compared and evaluated indices derived from energy-budget models. Their results show marked similarity among the outcomes of different indices (Zare et al. 2018, Pecelj et al. 2025). In recent decades, biometeorology and tourism-climate research have advanced with the use of computer software to elucidate the effects of weather on human physiological comfort. Studies have compared UTCI with PET, SET, and WBGT heat indices over a 1-year period (Abdel-Ghany et al. 2013, Zare et al. 2018). The primary aim was to examine the relationship between these indices and environmental characteristics. The results showed that UTCI and PET were strongly positively correlated ($r = 0.96$), supporting their validity for evaluating human heat stress (Zare et al. 2018). Tyagi and Danish (2025) examined how reflective building materials exacerbate the Urban Heat Island (UHI) effect in tropical regions such as India. They found that these façades significantly increased outdoor thermal discomfort, with simulations in Greater Noida registering peak air temperatures above 43.77°C . In Sulaimani Province, Iraq, Hama Shareef and OĞUZ (2020) identified bioclimatically comfortable areas for outdoor recreational planning using the spatial variability of PET. The minimum PET was 4.8°C in Penjwin in January, whereas the maximum was 59.6°C in northern Sulaimani and Halabja in July (Hama Shareef & OĞUZ 2020). This study aimed to assess the spatial distribution of two thermal-comfort indices, PET and UTCI, using the RayMan model for Iraq. Meteorological data from 1980–2024, obtained from the NASA POWER Data Platform, were used, and the correlations between these indices and meteorological parameters were analyzed.

2. MATERIALS AND METHODS

2.1. Study Area

Iraq is located in the Middle East, covers approximately $437,072\text{ km}^2$ ($168,754\text{ sq mi}$), and is centered near $33^\circ00'\text{N}$, $44^\circ00'\text{E}$ (33.000°N , 44.000°E). It lies north of Saudi Arabia, south of Turkey and Syria, northwest of Kuwait, and west of Iran (Al-Jibouri & Al-Kassie 2018). It has a 58 km long coastline along the northern Arabian Gulf (Fig. 1). Iraq has varied physiography that can be described in four main zones: the Mesopotamian alluvial plain; the western desert plateau; and the northern and northeastern mountainous areas, including the Zagros Mountains. The study area includes low, level plains in the southeast and more undulating terrain toward the northwest (Muter et al. 2024). The central

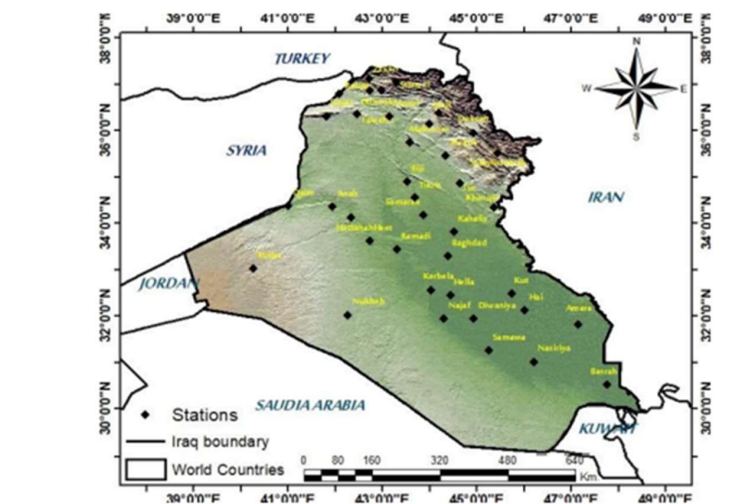


Fig. 1: Study area and spatial distribution of meteorological stations.

and southern parts of Iraq form the fertile Mesopotamian Plain, created by the Tigris and Euphrates rivers. This is the country's principal agricultural area and a major population center. It has low-relief topography, lies only slightly above sea level, and contains flat land, rich alluvial soils, and numerous irrigation canals (Muter et al. 2024).

Western Iraq is mostly an arid desert plateau that descends toward the Euphrates River Valley. The area is predominantly rocky and sandy, with little surface water and sparse vegetation. Northern and northeastern Iraq consist of hilly and mountainous terrain outside the alluvial plain, extending to approximately 3,000 m above sea level in association with the Zagros Mountains. This region has more complex orography because of its slopes and narrow valleys, and it receives more precipitation than the rest of the country.

The southern part of the study area contains the Mesopotamian Marshes, one of the largest and best-known wetland systems near the confluence of the Tigris and Euphrates rivers. These wetlands perform important ecological functions and substantially affect hydrology and land use (Al-Yasiry et al. 2023).

Iraq is characterized by a hot, dry climate with very little rainfall throughout the year. Variations in altitude and geographic location produce a wide range of climatic conditions.

Summer temperatures are extremely high, especially in the central and southern parts of the country, where daytime temperatures commonly exceed 45°C. Winters are generally mild in the lowlands, with temperatures commonly ranging from approximately 5–15°C, while northern highland areas

are considerably cooler, with regular frosts and occasional snowfall.

Seasonal rainfall in Iraq is scarce and largely confined to November–April, when mild Mediterranean weather systems predominate. Annual precipitation ranges from less than 150 mm in the southern and western deserts to more than 600 mm in the northern mountains. Moderate precipitation occurs over the Mesopotamian Plain, although intensive irrigation is essential for reliable agriculture (Al-Timimi & Baktash 2024).

Wind systems play a major role in Iraq's climate, particularly the northwesterly shamal winds, which are strongest in July and August. These winds frequently generate dust and sandstorms, especially over desert and semi-desert terrain, affecting air quality and visibility (Ibraheem et al. 2023).

2.2. Data Source and Analysis

The study used the Prediction of Worldwide Energy Resources (POWER) dataset released by the National Aeronautics and Space Administration (NASA) for renewable-energy, climate, and environmental research, planning, and decision-making. The dataset is freely available from the POWER Data Access Viewer (<https://power.larc.nasa.gov/data-access-viewer/>). POWER data support regional-to-global studies and are provided at a spatial resolution of 0.5° × 0.5° latitude-longitude, derived mainly from satellite observations and global reanalysis products. This resolution provides spatially consistent coverage, particularly in regions with few surface meteorological observations. NASA POWER data have been validated against ground-based meteorological observations in previous studies in Iraq. Tayyeh and

Mohammed (2023) found good agreement between NASA POWER data and station measurements in the Euphrates River Basin, with coefficients of determination (R^2) ranging from 0.74 to 0.95, supporting the suitability of NASA POWER for regional climate studies.

The monthly mean values of five meteorological parameters (air temperature, relative humidity, wind speed, percentage cloud cover, and surface temperature) were obtained from the NASA POWER database for locations corresponding to 38 stations in Iraq. Surface temperature (T_s), global radiation (G), and mean radiant temperature (T_{mrt}) are optional input parameters that can be determined by the model. Global radiation (G) can be calculated from time, date, geographic position, and cloud-cover observations in oktas. From these parameters, an initial global radiation G_0 ($W\ m^{-2}$) is calculated. Clothing insulation for different seasons and meteorological conditions in the study area was assigned as shown in Table 1. The metabolic rate was estimated at $80\ W\ m^{-2}$. The body characteristics entered in the model were length, 1.72 m; weight, 75 kg; and age, 35 years. The stations are located as shown in Fig. 1. Spatial statistical techniques implemented in a GIS package were used to interpolate station-based measurements to gridded values, enabling the creation of spatial PET and UTCI maps for Iraq. Kriging was used to map and assess the spatial interpolation of monthly, seasonal, and annual values of PET and UTCI. After considering the spatial structure of the data, a spherical variogram model was used, and spatial autocorrelation was assessed using the experimental variogram. Leave-one-out cross-validation was used to evaluate interpolation performance, and common accuracy measures, including root mean square error (RMSE) and mean error (ME), were calculated. These procedures improve the transparency and reproducibility of the spatial interpolation used to create the PET and UTCI maps. The analysis yielded an ME of $-0.03^\circ C$ and an RMSE of $1.42^\circ C$, indicating low bias and acceptable prediction error in the generated spatial maps. Correlations between the two indices and meteorological parameters were also analyzed.

2.3. RayMan Model

RayMan is a microscale model created by the Chair for Environmental Meteorology, previously known as the

Table 1: Metabolic rate and clothing insulation inputs in the RayMan model for different months in the study area.

Months	Metabolic rate ($W\ m^{-2}$)	Clothing insulation (clo)
Jan.–Mar.	80	1.5
Apr.–Jun.	80	0.7
Jul.–Sep.	80	0.5
Oct.–Dec.	80	1.2

Chair for Meteorology and Climatology at Albert-Ludwigs-University Freiburg. The RayMan model was developed to calculate the short- and long-wave radiation fluxes received by the human body. It handles complex building geometries and is suitable for assessing different planning designs from microscale to regional scales. The model calculates mean radiant temperature, which is required for human energy-balance calculations and for assessing the human thermal bioclimate. The SET, PET, UTCI, PT, and modified PET (mPET) thermal indices can be estimated. Thermal indices can be generated by manually entering weather data or by uploading custom time-series files. Outputs are provided as graphs and lists in comma-separated values (CSV) files. RayMan allows the import of comprehensive long-term datasets of meteorological variables for statistical investigations (Matzarakis et al. 2021).

2.4. Physiologically Equivalent Temperature (PET)

PET is an index based on the human energy-balance equation (Höppe 1997). PET is calculated using dry-bulb air temperature, relative humidity, wind speed, and mean radiant temperature. The index was implemented in RayMan Version 1.2 (Matzarakis et al. 2007). Because measurements of air temperature and wind speed are taken at a height of 10 m, the input data were corrected. Air temperature was adjusted using a factor of $0.6\ K/100\ m$ (Matzarakis et al. 2015). Based on Hellmann's exponential law, wind speed was adjusted to a height of 1.1 m above the ground surface (Zare et al. 2018).

Table 2 presents PET data corresponding to different levels of thermal perception and physiological stress (Matzarakis et al. 1999).

2.5. Universal Thermal Climate Index (UTCI)

UTCI is an equivalent temperature derived from a reference environment. It is defined as the air temperature of the reference environment that produces an equivalent physiological strain response in a reference individual under

Table 2: PET data corresponding to different levels of thermal perception and physiological stress (Matzarakis et al. 1999).

Grade of physiological stress	Thermal perception	PET ($^\circ C$)
Extreme heat stress	Very hot	> 41
Strong heat stress	Hot	35–41
Moderate heat stress	Warm	29–35
Slight heat stress	Slightly warm	23–29
No thermal stress	Comfortable	18–23
Slight cold stress	Slightly cool	13–18
Moderate cold stress	Cool	8–13
Strong cold stress	Cold	4–8
Extreme cold stress	Very cold	≤ 4

Table 3: UTCI data corresponding to different levels of thermal perception and physiological stress (Matzarakis et al. 1999).

UTCI (°C)	Thermal stress category
+40 ≥	Extreme heat stress
+38 – +46	Very strong heat stress
+32 – +38	Strong heat stress
+26 – +32	Moderate heat stress
+9 – +26	No thermal stress
0 – +9	Slight cold stress
–13 – 0	Moderate cold stress
–27 – –13	Strong cold stress
–40 – –27	Very strong cold stress
< –40	Extreme cold stress

the actual environmental conditions. It is one of the most comprehensive heat-stress indices for outdoor environments (Pantavou et al. 2024). The index was developed to provide a common definition of heat-stress severity in human biometeorology. UTCI calculation considers meteorological factors and nonmeteorological elements such as metabolic rate and clothing thermal resistance. UTCI is calculated from dry-bulb air temperature, mean radiant temperature, water vapor pressure or relative humidity, and wind speed at a height of 10 m. UTCI is divided into 10 classes ranging from extreme cold stress to extreme heat stress (Table 3). For UTCI calculation, wind speed should range from 0.5 to 17 m s⁻¹ (Zare et al. 2018).

3. RESULTS AND DISCUSSION

During the study period from 1981 to 2024, PET and UTCI values were mapped monthly. These maps show the monthly mean values of the two indices as determined from air temperature, relative humidity, wind speed, and cloud cover. Figs. 2 and 3 depict the monthly mean PET and UTCI maps for the study region. The same map legend was used throughout to facilitate month-to-month comparisons. PET values in Iraq ranged from –1.1 to 45.2°C. According to Fig. 2, the southern regions of Iraq, specifically Basra, Faw, and Amarah, had the highest PET values during summer because these areas experience the highest air temperatures and lowest mean relative humidity. In contrast, northeastern and northwestern Iraq, including Duhok and Sulaymaniyah, had the lowest PET values during December, January, and February. The findings show that the comfort condition (18–22) was absent throughout winter but became apparent in spring (April and May), especially in central Iraq. Most of Iraq experienced temporary comfort conditions in spring, with April showing the greatest extent. More favorable conditions were observed at higher elevations. During summer, PET

values ranged from 29.9 to 45.2°C, predominantly indicating significant heat stress. June represents a transition toward peak summer heat, with increasing thermal stress rather than truly temperate conditions, especially during afternoon hours (Fig. 3). The highest summer PET values were observed in the southeast, southwest, and several locations on the central plateau. During July and August, most of Iraq lacked thermally comfortable conditions. In autumn, October showed thermal comfort comparable to April, extending across most of western and northern Iraq and many densely populated areas favorable for tourism in central and northern Iraq. Fig. 4 shows PET maps for the four seasons and the annual mean. The most comfortable conditions occurred during spring across Iraq.

UTCI values in Iraq ranged from –0.6 to 40.8°C. Most regions experienced slight cold stress (0–9°C) during winter, except Dukan and Sumail stations, which exhibited moderate cold stress, particularly in January. No thermal stress (9–26°C) was observed during all spring months and in October across most of Iraq, with isolated areas also occurring during the final winter months. Very strong heat stress (38–46°C) was concentrated in southern and southeastern Iraq during June, July, and August, while strong heat stress was recorded across most central and northern regions during the same period. The monthly spatial distribution of UTCI illustrates changes in human thermal stress across the country over the year. Taken together, the maps reveal a cyclic annual pattern.

The annual cycle shifts from cold stress in winter to high heat stress in summer, with relative comfort in spring and autumn. Iraq experiences mild to moderate cold stress in January and February. Cold stress is stronger in the north and west, where mountainous terrain and continental influences dominate. February shows less cold stress than January, reflecting seasonal warming. December is comparable to January, with a broader spatial extent of cooler conditions and lower temperatures in the south.

Winters are generally mild, with acceptable cold stress in most locations, although some areas experience problematic conditions.

Comfortable conditions with no thermal stress were observed in March. Most of the country experiences neutral thermal conditions in April, except in areas with slight cold stress. Heat stress increases markedly in May. Most areas experience slight heat stress, while pockets of severe heat stress occur in the south and southeast. This indicates increasing discomfort and the onset of the hot season. During the summer extremes (June–August), thermal stress is high, with some southern and eastern areas experiencing extreme conditions. July and August are the hottest months, when heat stress is pronounced across much of the country, particularly

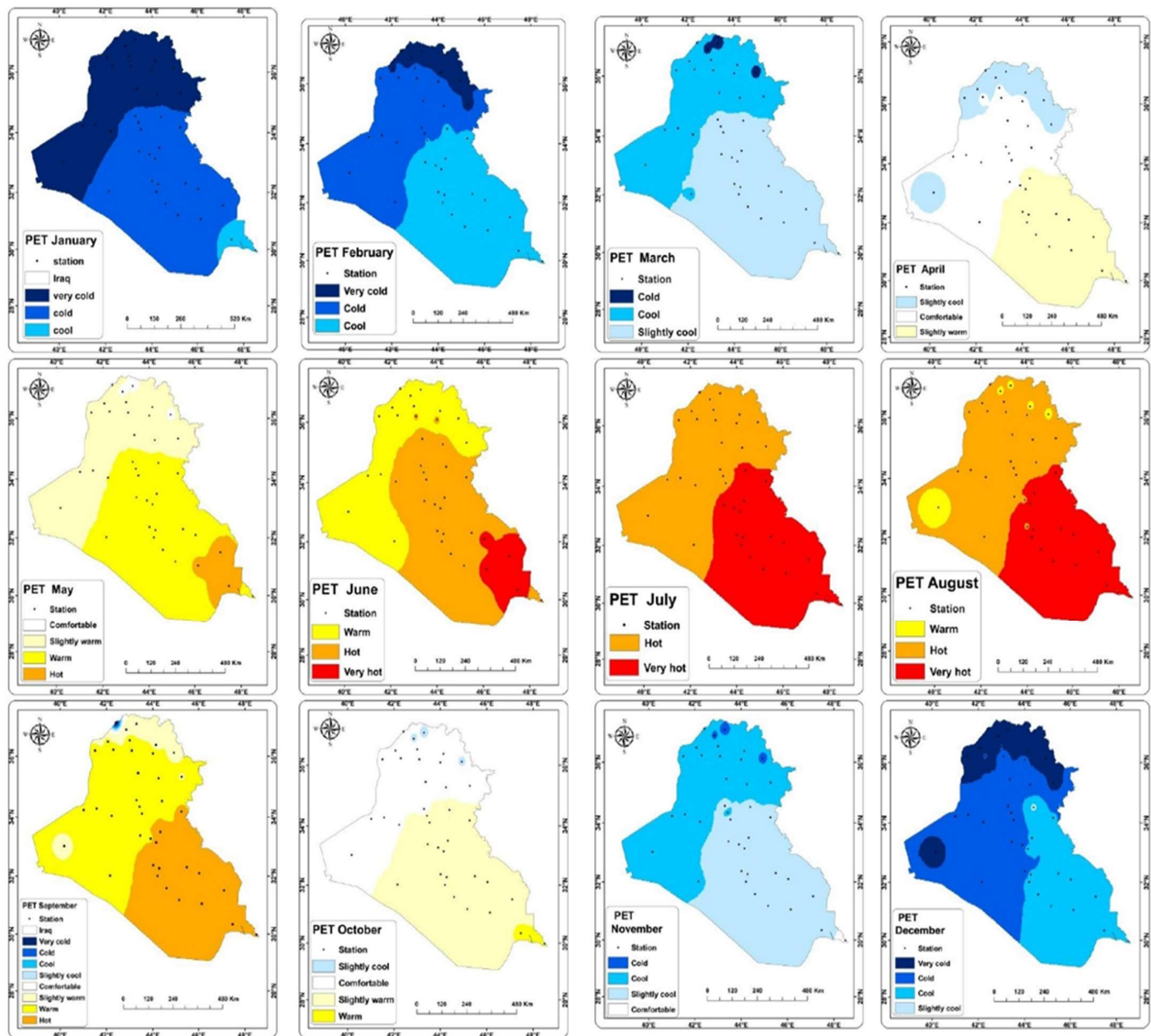


Fig. 2: Monthly mean spatial distribution of PET in the study region.

in the south and southeast. The north also experiences substantial heat stress, with limited thermal comfort. Heat extremes in July and August can increase the risk of heat-related stress and affect health, outdoor labor, and energy demand. During the autumn transition (September–October), the south remains hot in September while the north begins to cool. By October, most locations return to no thermal stress, although some areas still experience slight heat stress. Thermal comfort gradually returns during autumn, except in the southernmost locations, while rainfall begins to increase. By late autumn (November), thermal stress is largely neutral, although pockets of cold conditions begin to re-emerge. These conditions are comparable to those in March or April and are generally thermally comfortable.

Heat stress is most prevalent during summer in southern and southeastern regions. Cold-stress risk is higher in the colder north and west, where comfortable conditions also return earlier. The results demonstrate the seasonal predictability of heat stress and the relevance of summer heat-mitigation measures, including the planning of outdoor activities and public-health interventions. The spatial distributions of PET and UTCI during the four seasons and the annual mean are shown in Figs. 4 and 5.

A bioclimate diagram showing the monthly spatial distribution of PET and UTCI conditions as percentages of surface area is presented in Fig. 6. The findings show strong seasonal fluctuations in thermal comfort. In winter (December–February), PET classes range from cold to

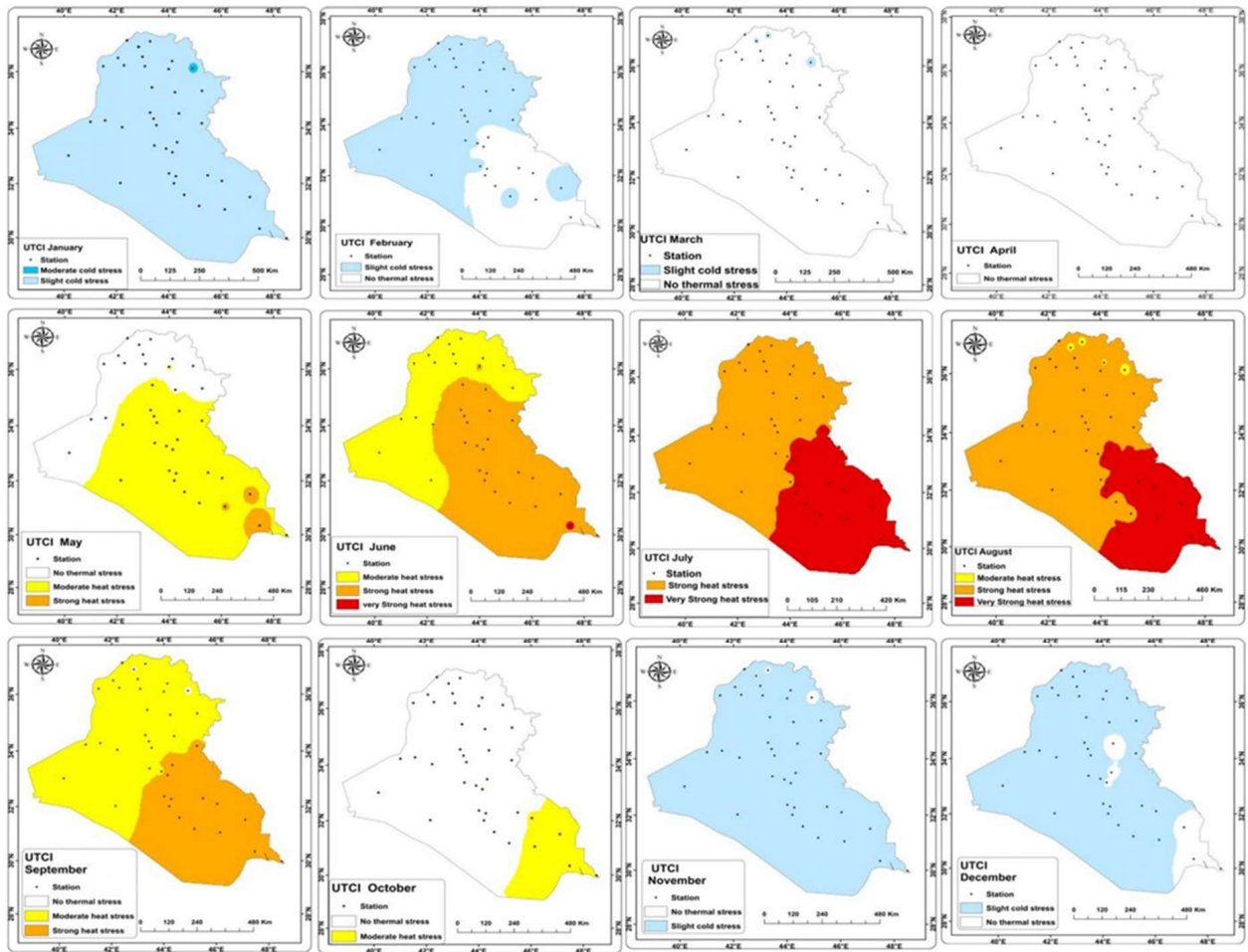


Fig. 3: Monthly mean spatial distribution of UTCI in the study region.

very cold, while UTCI indicates slight to moderate cold stress, suggesting generally cool but not extreme conditions. In spring (March–April), PET conditions are mostly comfortable to slightly cool, and UTCI indicates no thermal stress. In early summer (May–June), warming becomes evident, with warm-to-hot PET classes and moderate to high UTCI heat stress.

During full summer (July–August), conditions reach their annual peak, with hot to very hot PET classes and strong to very strong heat stress according to UTCI, resulting in substantial thermal discomfort and serious health hazards.

In autumn (September–October), heat stress declines. September remains warm to hot, while October is mostly comfortable or low-stress. Overall, heat stress dominates the climate, with summer as the principal thermal stressor and spring and autumn more conducive to outdoor activities.

To examine the relationships of PET and UTCI with the controlling meteorological parameters, including air

temperature, relative humidity, wind speed, and solar radiation, Baghdad station was selected as a case study (Fig. 7). Both PET and UTCI show a clear seasonal pattern, increasing from winter minima to summer maxima and then decreasing toward winter, with the highest values in July–August and the lowest in January–February. Air temperature (T_a) strongly controls PET and UTCI, and both indices closely follow the monthly pattern of T_a . Solar radiation (G) also contributes substantially to thermal stress, particularly from late spring to early summer, because of the increased radiant heat load on the human body. Wind speed (V) has a moderate influence; however, its cooling effect is insufficient to offset high summer temperatures and strong solar radiation. The inverse relationship between relative humidity (RH) and PET/UTCI is also evident: higher RH in winter corresponds to lower thermal stress, while lower RH in summer corresponds to peak stress. Overall, summer heat stress dominates thermal discomfort, driven primarily by high air temperature and solar radiation.

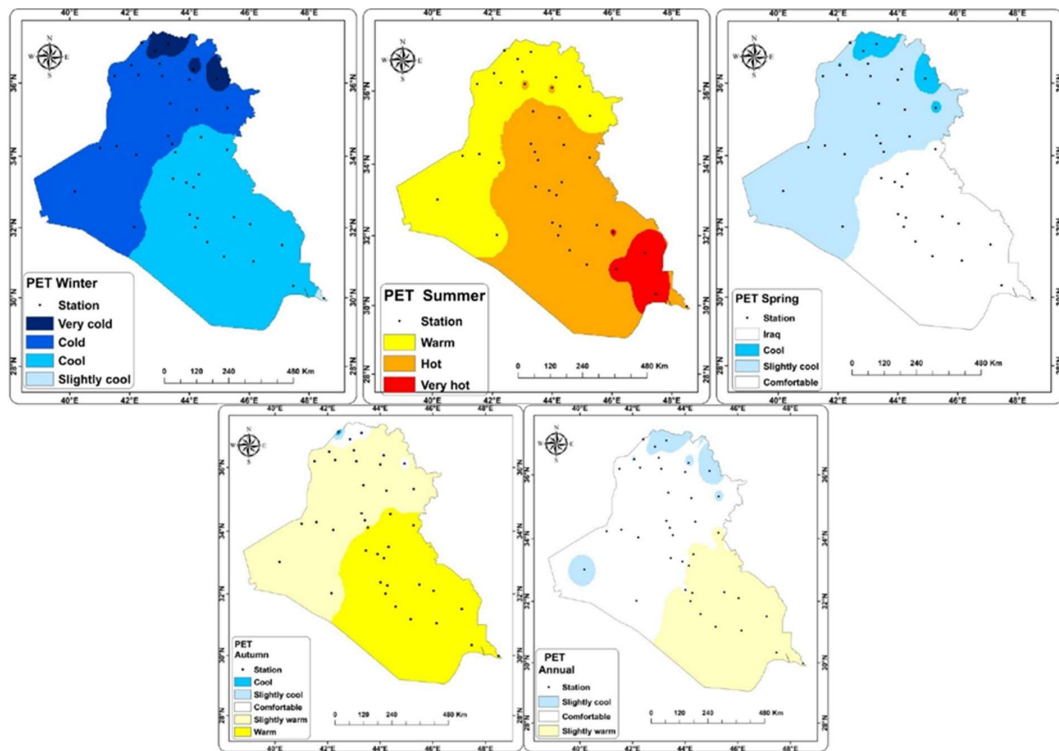


Fig. 4: Seasonal and annual mean spatial distribution of PET in the study region.

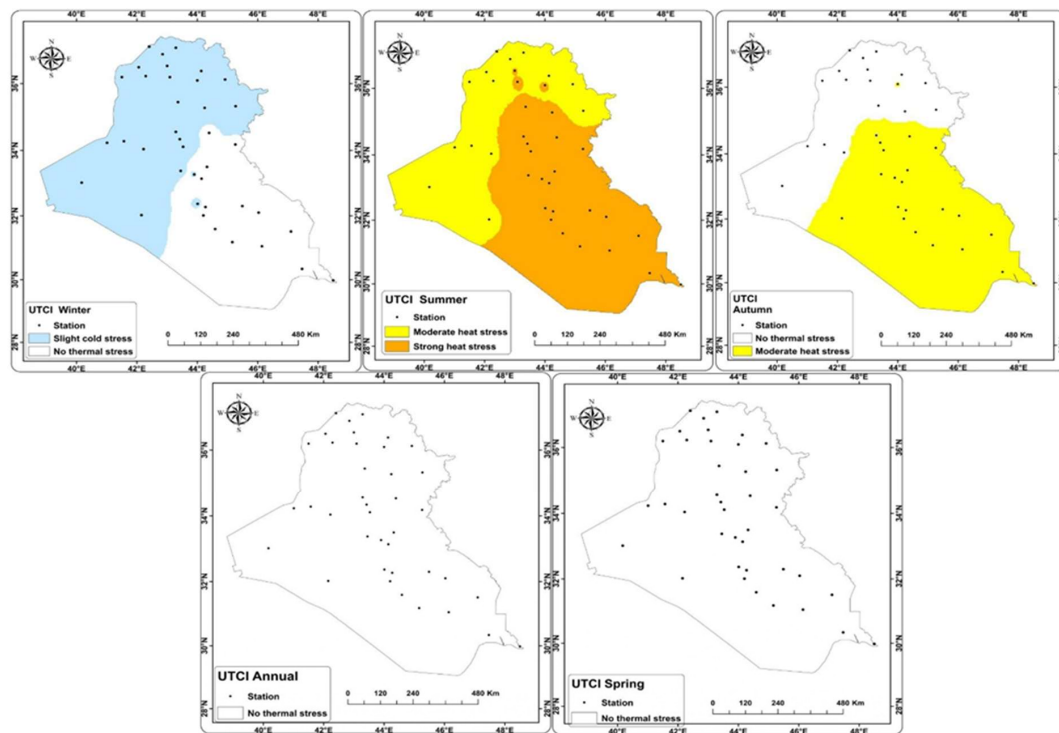


Fig. 5: Seasonal and annual mean spatial distribution of UTCI in the study region.

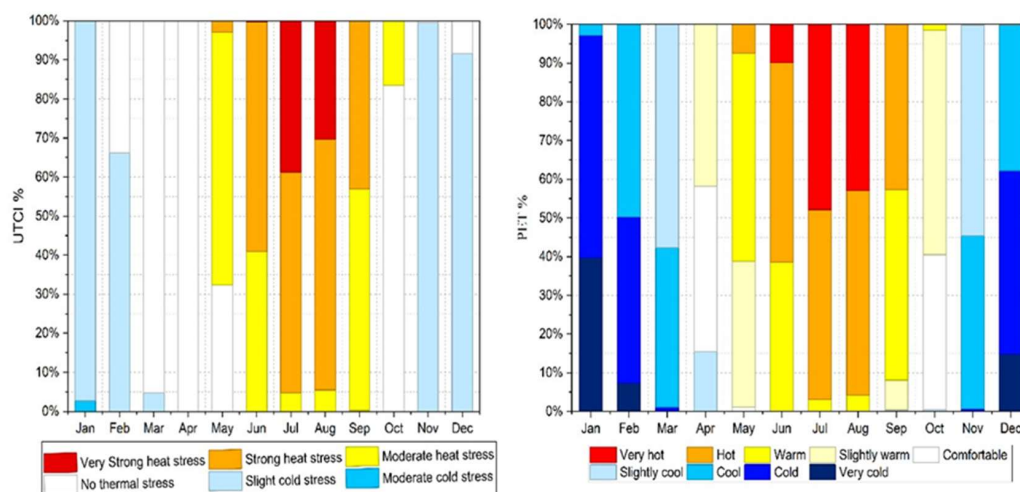


Fig. 6: Bioclimate diagram showing monthly PET and UTCI conditions as percentages of surface area in Iraq.

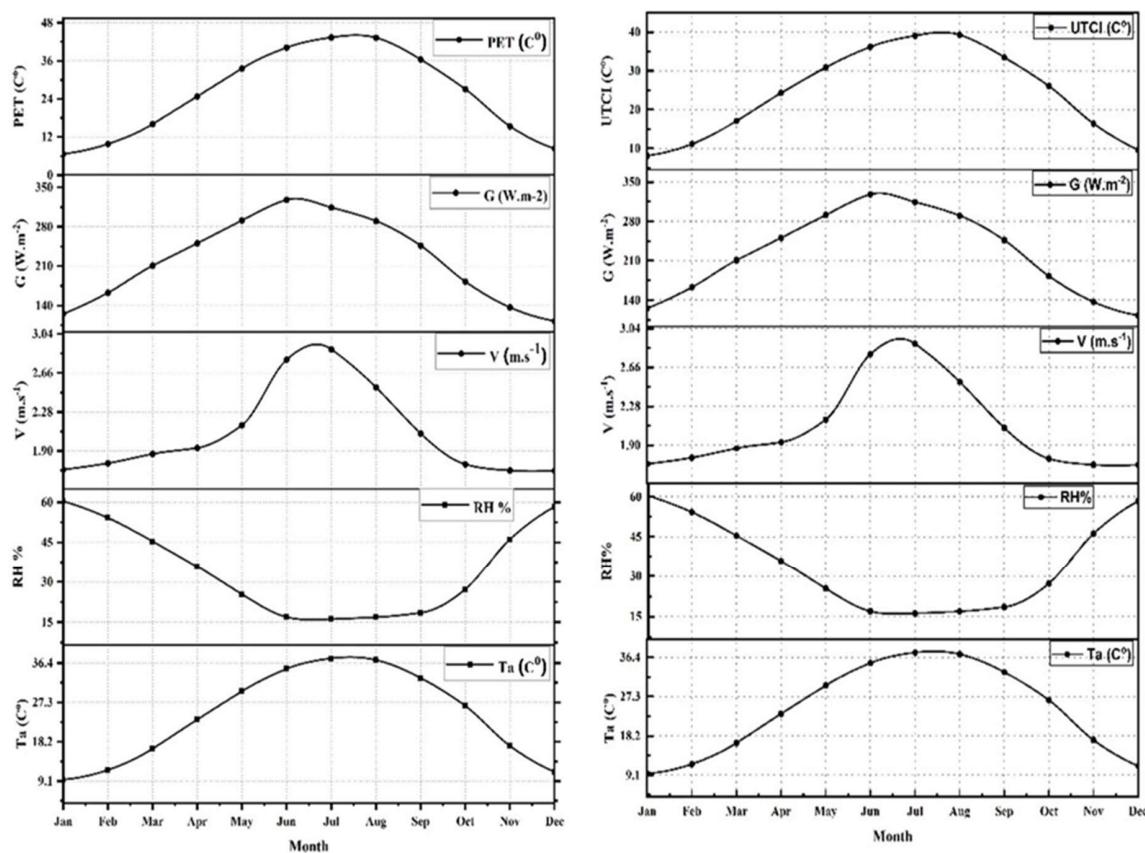


Fig. 7: Relationship of PET and UTCI with the controlling meteorological parameters.

Based on data from three selected stations (Baghdad, Basra, and Mosul), representing different climatic zones in Iraq, Pearson correlation coefficients (r) between PET/UTCI and the primary meteorological variables, air temperature (T_a), relative humidity (RH), wind speed (V),

and solar radiation (G), were calculated as shown in Table 4. Both indices showed very strong positive correlations with air temperature ($r = 0.998$ – 0.999) and strong positive correlations with solar radiation ($r = 0.913$ – 0.941), whereas relative humidity showed strong negative correlations ($r =$

Table 4: Pearson correlation coefficients (r) of PET and UTCI with the primary meteorological variables, air temperature (T_a), relative humidity (RH), wind speed (V), and solar radiation (G), at three selected stations (Baghdad, Basra, and Mosul).

Stations	T_a -PET	T_a -UTCI	RH-PET	RH-UTCI	V-PET	V-UTCI	G-PET	G-UTCI
Baghdad	0.999	0.999	-0.988	-0.990	0.861	0.851	0.920	0.918
Basra	0.999	0.999	-0.991	-0.992	0.796	0.785	0.919	0.913
Mosul	0.998	0.998	-0.981	-0.971	0.957	0.944	0.941	0.940

-0.992—0.971). Wind speed showed moderate to strong positive correlations ($r = 0.785$ –0.957). These findings indicate that spatial variation in thermal stress across Iraq's climatic regions is driven primarily by air temperature and solar radiation, supporting the observed spatial patterns of thermal comfort.

4. CONCLUSIONS

This study assessed the spatial and seasonal variation of human thermal comfort in Iraq using two widely used bioclimatic indices, Physiologically Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI), simulated with the RayMan modeling platform using long-term meteorological data from NASA POWER. The findings show that thermal comfort in Iraq is primarily influenced by seasonal changes, geographic location, and physiographic characteristics. Both indices show a strong annual cycle, with cold to moderate cold stress in winter, particularly in northern and mountainous areas, and strong to very strong heat stress in summer across southern and southeastern Iraq. Spring and autumn are the most favorable periods for outdoor thermal comfort, with April and October showing the largest areas of thermally comfortable or near-neutral conditions across the country. These transitional seasons therefore provide favorable opportunities for travel, outdoor work, and other outdoor activities. Spatially, however, southern Iraq is persistently affected by higher thermal stress because of high air temperatures and strong solar radiation, whereas temperatures in northern and northeastern regions are moderated by elevation, particularly outside summer. The good agreement and high correlation between PET and UTCI confirm the applicability of both indices for evaluating human thermal stress under Iraq's hot, arid climatic conditions. Air temperature and solar radiation were the main controlling factors of heat stress. Wind speed did not substantially mitigate heat during peak summer, while relative humidity was negatively related to thermal stress.

The results have implications for public health, urban planning, energy-demand management, and climate-sensitive sectors. Rising summer heat stress, particularly in more populated southern areas, highlights the importance of adaptation measures such as climate-sensitive urban design, shading, green infrastructure, and heat-health warning

systems. The spatially explicit comfort maps produced in this study can also serve as a benchmark for estimating climate-change impacts and planning sustainable development and outdoor activities in Iraq.

Overall, this study demonstrates the utility of integrating PET and UTCI with GIS-based spatial analysis and long-term datasets to investigate human thermal comfort at the national level. The approach provides useful preliminary insights for climate and biometeorological studies in Iraq.

5. ACKNOWLEDGEMENT

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