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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

Insufficiency in thorough evaluations of spatial thermal comfort parameters throughout the country of Iraq, even though the risks of excessive heat and climate change are on the rise. This work analyzes the spatial distribution of outdoor human thermal comfort in Iraq using Physiologically Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI). Monthly meteorological data from 38 stations (1981–2024) were downloaded from the NASA POWER database and calculated using the RayMan model for PET and UTCI. Then, monthly/seasonal/annual comfort maps were obtained through GIS-based kriging interpolation. The results represent a remarkably seasonal pattern: in winter situation are characterized by levels of mild to moderate cold stress and the greatest cold impact covers northern and Alpine territory, while summer conditions points towards strong to very strong heat stress, particularly on southern and south-eastern provinces. Spring and fall yielded the most comfortable results overall with many places at neutral to low-stress levels in April or October. The spatial patterns of PET and UTCI are in good agreement, considering that the two values are steady under idealized conditions, which indicates their reasonable representation even in hot-dry areas. In general, air temperature and solar radiation are the main enhancing factors of heat stress, whereas wind speed and relative humidity are second-order drivers. The importance of evaluating PET and UTCI patterns to support public health awareness, urban planning, and climate adaptation strategies in Iraq.

INTRODUCTION

Weather conditions impact 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 crucial organs and systems of the body. It will predispose to heart disease and industrial accidents (Zare *et al.*, 2018) . Bioclimatic changes such as heat and cold waves will increase in frequency under the influence of global warming (IPCC, 2013, Pecelj et al., 2025). This is a key issue in providing information about the health effects of weather and bioclimatic changes between times and places (Varentsov *et al.*, 2020) . Various indices have been developed to measure the degrees of thermal discomfort perceived by humans (Burton and McGregor, 2009). There have been several studies on human thermal comfort and the physical environment from both indoor and outdoor environments in relation to houses and pavilions (Abdel-Ghany et al., 2013).

Some 60 heat stress indices have been suggested to examine hot places and forecast the probability of occurrence of heat stress. According to Burton et al. (2009), each of these surrogacy indices has its own advantages and limitations (Zare *et al.*, 2018A). Municipalities and architects want quantitative figures about the effects of city planning, open space development, and reconstruction for choosing adequate strategies in reducing man-made climate changes. It was difficult to obtain this data; now, numerical models can generate it readily. The models should also be simple and fast enough for non-experts, so that will make them to use by the relevant planners. At the same time, they also need to provide all relevant data in a comprehensive and easy-to-understand fashion (Pecelj et al., 2025; Zare et al., 2018). The use of thermal indices should be the most suitable approach to reduce the impact of thermal rather than thermal comfort (Matzarakis, Gangwisch and Herbert, 2021). The majority of bioclimatic indices are based on empirical meteorological features. These indices are referred to as simple or empirical indices. Only a handful of the indices include humans, not bad indicators for energy balance models (Bartoszek, 2018). An index based on real measurements of weather parameters, including air temperature, wind speed, and relative humidity, is more convenient for use and is practical. (Varentsov *et al.*, 2020). Although a number of indices have been developed, only four among them (PET, PMV, UTCI and SET) are commonly used in outdoor thermal sensation studies (Potchter et al., 2018) . During the last two decades, physically equivalent temperature (PET) has been used as a thermal index at the body level(Mayer and Höppe, 1987; Höppe, 1997; Matzarakis, Mayer and Iziomon, 1999) . PET was a measure of how that level had changed over time for people's thermal comfort. It is defined as that air temperature in the indoor space (i.e., no wind or solar radiation) where for an adult at rest, equal activity of both heat production and dry heat loss at core and skin corresponds to those experienced under the more complex outdoor conditions being studied.(Matzarakis, Muthers and Rutz, 2015) . A further development in this field is the development of the Universal Thermal Climate Index (UTCI) under the auspices of ISB (International Society on Biometeorology) and COST Action 730 (Cooperation in Science and Technical Development, supported by the EU RT D Framework Program). You can read the index here: www.utci.org(Matzarakis, Muthers and Rutz, 2015) . Possible developments would draw on the thermo-physiological model of human reaction to the climatic conditions, including the acclimatization problem as a basis for a worldwide standard index.

All rating results of the ecologies of outdoor temperatures, in the main human biometeorological zones, are considered as „universal" (Matzarakis, Mayer and Iziomon, 1999). PET and UTCI may both be readily calculated from the RayMan software program, for which there is no charge for use of this product by the developers. The RayMan model is a simplification of the two-node model that can take simple experimental input such as air dry-bulb temperature (Td), relative humidity (RH), wind speed (V) and mean radiant temperature (Tmrt) or global solar radiation (So) (Matzarakis, Rutz and Mayer, 2007). The RayMan model provides reasonable results in hot, sunny areas when Tmrt > 60°C around solar noon. The temperatures at which PET occurs in Celsius degrees for a few grades of human thermal perception are given in(Abdel-Ghany, Al-Helal, and Shady, 2013b). A number of studies have evaluated two or three simple thermal indicators(Dunjić *et al.*, 2025; Pecelj and Matzarakis, 2025). Furthermore, some other studies related simple indices to PET index (AL-Lami, 2023; Pantavou *et al.*, 2025). Recent years have seen a number of studies that compare and evaluate indices derived from energy budget models. Results have shown a marked similarity between the outcomes of different indices(Zare *et al.*, 2018; Pecelj et al., 2025). In the last decades, biometeorology and tourism climate research have progressed with the help of computer software programs to elucidate the impact of weather on human paleohistological comfort. Zare et al. (2018) (Abdel-Ghany, Al-Helal, and Shady, 2013) compared the UTCI to PET, SET, and WBGT heat indices for 1 year. Revealing the link between these measurements and ecological characteristics was the primary aim. Results showed that UTCI-index and PET index are positively well-correlated (0.96), indicating validity of these criteria for evaluating human heat stress (Zare *et al.*, 2018). Tyagi and Danish, 2025. examines how reflective building materials exacerbate the Urban Heat Island (UHI) effect in tropical regions like India. It finds that these façades significantly increase outdoor thermal discomfort, with simulations in Greater Noida registering peak air temperatures of over 43.77°C. In Sulaimani province of Iraq, Sharef and Oguz (2020) define bioclimatic comfortable areas for outdoor recreational planning. Spatial variability of the bioclimatic comfort indicator PET. The minimum PET was 4.8°C in Penjwin during January, while the maximum was 59.6°C in northern Sulaimani and Halabja in July (SHAREF and OĞUZ, 2020). This study aimed to assess the spatial distribution of two heat comfort indices, specifically PET and UTCI, utilizing the RayMan model for Iraq. Meteorological data from 1980-2024, obtained from the NASA Power Data Platform, were used, and the correlation between these indices and meteorological parameters was also analyzed.

2. MATERIALS AND METHODS

2.1 Study area

Geography of Iraq in the Middle East, measuring about 437,072 km² (168,754 sq mi), and located at 33°00′N 44°00′E / 33.000°N 44.000°E, lies to the north of Saudi Arabia and to the south of Turkey, Syria, and northwest of Kuwait; it shares a small border with Iran to the east through Kurdistan (Al-Jibouri and Al-Kassie,2018). It has a 58-km-long coastline along the northern part of the Arabian Gulf, see Figure 1. Iraq has a varied physiography that can be described into four main zones: –Mesopotamian alluvial plain –Western desert plateau –Northern and northeastern mountainous areas, including Zagros Mts…Physiographic features of the Study Area Iraq consist of a couple of distinct regions including low, level plains in the southeastern part, but less so farther to the northwest; there are significant stretches with relatively uniform hummocks (Muter, et al., 2024). The central and southern parts of Iraq are part of the fertile Mesopotamian Plain, which is formed by the Tigris and Euphrates rivers in these areas, and this is the most important agricultural area as well as a population center. It has a helpless topography, being only slightly above sea level with flat land and rich alluvial soil, and many irrigation canals (Muter, et al., 2024).

Western Iraq is mostly an arid desert plateau that descends to the Euphrates River Valley. The area is predominantly rocky/sandy, with little surface water and low vegetation. Northern and northeastern Iraq consists of hilly mountainous land apart from the alluvial plain, extending up to 3000 meters above sea level, associated with the Zagros Mountains. This area presents a more complex orography and concealment due to its slopes, narrow valleys, and precipitation levels higher than those of the rest of the country.

The southern part of the study area is occupied by the Mesopotamian Marshes, one of the largest and most famous wetland systems situated close to where the Tigris and Euphrates come together. These wetlands perform an ecological function and affect hydrology and land use to a high extent (Al-Yasiry, et al., 2023).

Iraq is characterized by a hot, dry climate with very little rainfall year-round. Due to variation in altitude and geographic locale, there is a wide range of climatic systems.

Summer temperatures are extremely hot, especially in the central and southern parts of the country, where daytime temperatures commonly surpass 45°C. Winters are generally mild in the lowlands with average minimum and maximum temperatures averaging around 5 °C to 15 °C, but northern highland areas are considerably cooler with frosts occurring regularly and occasional snowfall.

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

Wind systems play a major role in the climate, especially the northwesterly shamal winds, which are highest in July and August. These winds tend to create dust and sandstorms in particular, e.g. in desert and semi-desert terrain, which impacts the quality of air and visibility (Ibraheem *et al.*, 2023).

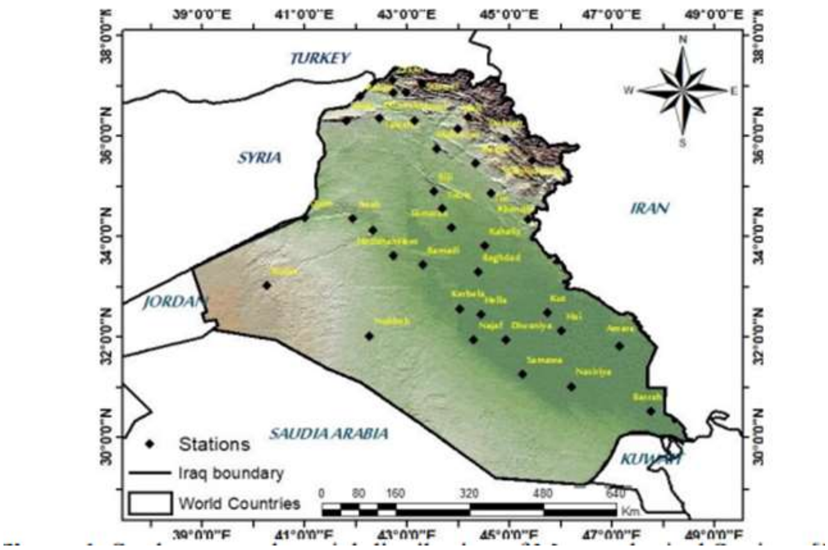


Figure 1: Study area and spatial distribution of Meteorological Stations

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), to promote renewable energy, climate, and environmental research, planning, and decision-making. and is accessible at no cost from the POWER data portal (https://power.larc.nasa.gov/data-access-viewer/). The raw data for regional-to-global-scale studies are provided by the Prediction of Worldwide Energy Resources (POWER) dataset. POWER data are generated at a spatial resolution of 0.5° × 0.5° in latitude–longitude and are collected mainly from satellite detectors and global reanalysis products. This resolution has the advantage of producing planetary-scale uniformity, particularly in areas where very few surface meteorological observations exist. The validation of NASA power data has been tested by comparing it to ground meteorological observations in previous studies in Iraq. Indicatively, Tayyeh and Mohammed (2023) found that NASA POWER data were in good agreement with station measurements in the Euphrates River Basin with coefficients of determination (R2) between 0.74 and 0.95, indicating that NASA POWER is the right choice in climate studies of the region.(Tayyeh and Mohammed, 2023)

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 the locations corresponding to 38 stations in Iraq. Surface temperature (Ts), global radiation (G), and mean radiant temperature (Tmrt) are optional input parameters that can be determined by the model. global radiation (G) can be calculated from time, date, geographic position and a cloud cover observation in octas. From these parameters an initial global radiation G0 ($W \cdot m^{-2}$) is calculated. The amount of clothing insulation for different seasons and meteorological conditions in the study area was considered as per Table 1. The metabolic rate was estimated at 80 W/m^2. the body charactrestic configuration in the model window was (length: 1.72 m, weight : 75 Kg, and Age : 35) The stations are located as shown in Figure 1. Spatial statistical techniques, using a GIS package, were used to model the station-based measurements onto pixel values. GIS enables the creation of spatial maps of PET and UTCI in Iraq. The kriging technique was used in the present study to map and assess the spatial interpolation of monthly, seasonal, and annual values of two indices, PMT and UTCI. In the particular case, after considering the spatial structure of the data, a spherical variogram model was used and a spatial autocorrelation was measured with the help of the experimental variogram. A leave-one-out cross-validation was used to measure the performance of the interpolation and common measures used to measure accuracy such as the Root Mean Square error (RMSE) and Mean Error (ME) were calculated. The additions enhance transparency and reproducibility of the spatial interpolation process of creating the PET and UTCI maps. The findings demonstrated Mean Error (ME) of −0.03°C and a Root Mean Square Error (RMSE) of 1.42°C,which means that the generated PET and UTCI spatial maps have low bias and acceptable prediction error. The correlation between the two indices and meteorological parameters was analyzed as well.

Table (1) Metabolic rate and Clothing insulation inputs in RayMan model for different months in the study area.

Months	Metabolic rate (w/ m2)	Clothing insulation (Clo)
Jan.- March	80	1.5
Apr. – Jun.	80	0.7
July. – Sep.	80	0.5
Oct. – Dec.	80	1.2

2.3 RayMan Model

RayMan is a micro-scale model created by the Chair for Environmental Meteorology, previously known as the Chair for Meteorology and Climatology at Albert-Ludwigs-University Freiburg. A RayMan model was developed to calculate the short and long-wave radiation fluxes received by the body. The model handles complex building geometries and is suitable for performance assessment of different planning designs from the micro to the regional level scales. The model provides a calculation of the mean radiant temperature, which is necessary for the human energy balance model of heat transfer to humans and thus also for assessing human thermal bioclimate. The SET, PET, UTCI, PT and modified PET (mPET) thermal indices can be estimated. Thermal indices can be generated by manual input of weather data or uploaded as custom time series files. The outcomes are communicated by graphs and lists in comma-separated values (CSV) files. RayMan allows the import of long-term comprehensive datasets of meteorological variables , which can be used for statistical investigations (Matzarakis, et al., 2021).

2.4 Physiologically Equivalent Temperature (PET)

PET is an indicator based on the human energy balance equation (Hoppé, 1999, 1984). PET is calculated using dry temperature, relative humidity, wind speed, and mean radiant temperature. The index was developed in Rayman Version 1.2 (Matzarakis, Rutz and Mayer, 2007b). Since measurements of air temperature and wind speed are taken at a height of 10m, we had to correct the input data. An air temperature was approximated by applying a factor of 0.6 K/100 m (Matzarakis, et al., 2015). Based on Hellman's exponential law, wind speed was adjusted to a height of 1.1m above the ground surface (Urban and Kyselý, 2014; Zare et al., 2018a)

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

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

Grade of physical stress	Thermal Perception	PET (◦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

2.5 Universal Thermal Climate Index (UTCI)

UTCI is a weighted temperature relative to the given environment that derives directly from the reference environment. It is the reference environment air temperature to which an equivalent strain index value corresponds in relation to a response in the actual environment for the reference individual. It is a classic of the most comprehensive heat stress index for outdoor environments (Pantavou *et al.*, 2024). This index was developed to establish a common definition of the severity of heat stress in the area of human biometeorology. The UTCI calculation involves both meteorological factors and non-meteorological elements like metabolic rate and clothing thermal resistance. UTCIs are calculated based on dry-bulb temperature, mean radiant temperature, water vapor pressure or relative humidity, and wind speed at 10 m height. Classes of the UTCI The UTCI is divided into 10 classes, ranging from extreme cold stress to extreme heat stress (Table 3). To calculate UTCI, Wind speed is to be between 0.5 m/s and 17 m/s. (Zare *et al.*, 2018a)

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

UTCI (Cº)	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

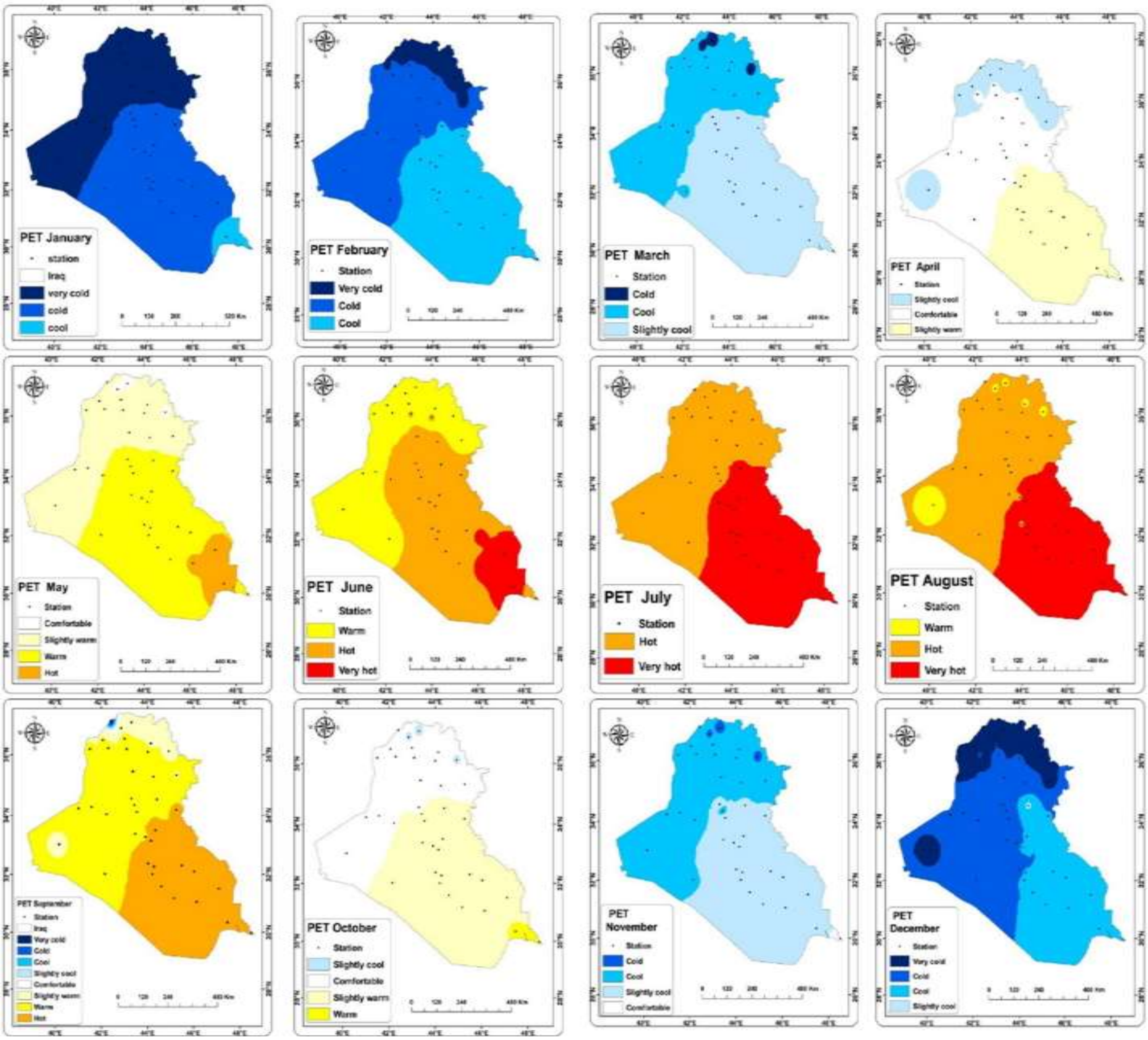
3. RESULTS AND DISCUSSIONS

During the climatic normal era from 1981 to 2024, PET and UTCI values were mapped monthly. These maps show the average monthly values of the two indices determined by the following variables: air temperature, relative humidity, wind speed, and cloud cover. Figures 3–4 depict the monthly mean PET and UTCI maps for the study region. For better month-to-month comparisons, we utilize the same map legend in every instance. The PET values in Iraq varied from –1.1°C to 45.2°C. According to Figure 3, the southern regions of Iraq, specifically Basra, Faw, and Amarah, had the highest PET levels during the summer months. This is because these areas experience the highest air temperature and the lowest mean relative humidity. In contrast, the northeast and northwest of Iraq, which includes Duhok and Sulaymaniyah, had the lowest PET levels during the winter months of December, January, and February. Moreover, the findings show that the comfort condition (18-22) was not present throughout the whole winter but became apparent in the spring (April and May), especially in the central portion of Iraq. In the spring, most of Iraq experienced temporary comfort conditions, with April showing the highest levels. In spring, advantageous conditions at geographical latitudes are observed in elevated regions. During the summer months, the PET values fluctuated between 29.9 and 45.2°C, predominantly indicating a physiological state of significant heat stress. June represents a transitional period toward the peak summer heat, with increasing thermal stress rather than truly temperate conditions, especially during afternoon hours. (Fig. 4). The highest PET values during the summer months were observed in the southeast, southwest, and several locations on the central plateau of the country. Throughout the summer months of July and August, the majority of Iraq lacked thermal comfort conditions. During autumn, October showed a physiological stress level of thermal comfort comparable to that of April, with this thermal comfort extending to most of western and northern Iraq and to the majority of densely populated areas conducive to tourism in the central and northern parts of Iraq. Figure 5 shows PET maps for the four seasons, along with the annual mean. The findings revealed that the most comfortable conditions occurred during the spring months across all parts of Iraq.

The UTCI value in Iraq ranges from -0.6 to 40.8, with most regions experiencing slight cold stress (0-+9) during the winter months, except for two stations, Ducan and Sumail, which exhibit moderate cold stress, particularly in

January. No thermal stress conditions (9-26) were observed during all spring months and in October over most regions of Iraq, in addition to isolated locations during the last months of winter. The finding also shows that the very strong heat stress condition (38–46) was concentrated in the southern and southeastern parts of Iraq during the summer months (June, July, and August), while strong heat stress was recorded in most central and northern parts of Iraq during the same period. The spatial distribution of monthly UTCI values can illustrate changes in human thermal stress across regions at the country level over a year. Taken together, the maps revealed a cyclic annual.

Fig 3: The monthly spatial distribution mean of PET for the study region.



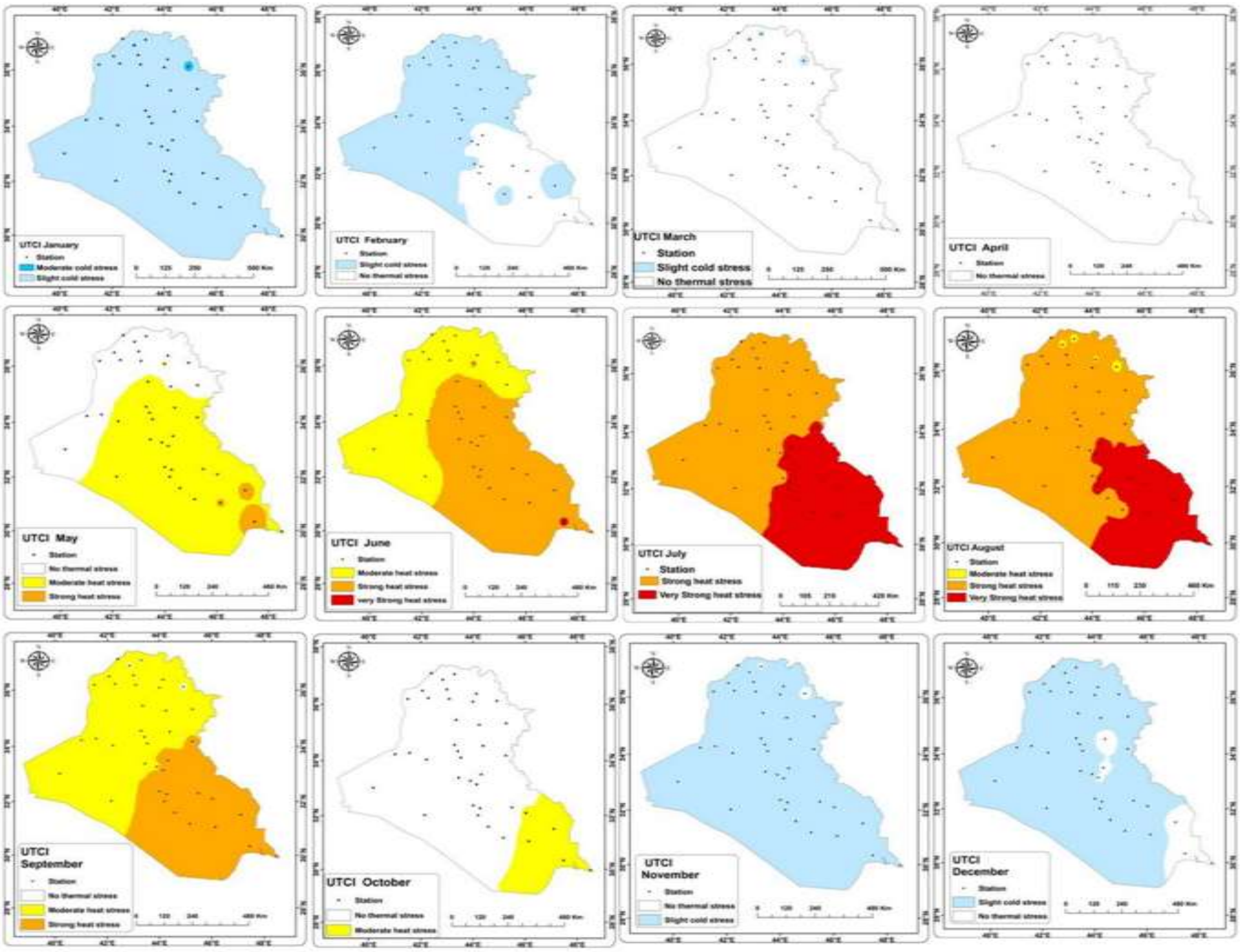


Fig 4: The monthly spatial distribution mean of UTCI for the study region.

fluctuation of cold stress from winter to high heat stress in summer, and relative comfort in spring and autumn. Iraq faces mild to moderate cold stress in January and February. It is stronger in the north and west (where mountains and continental influence dominate) because asperities under cold stress are more common. In February, there is less cold stress than in January, reflecting seasonal warming. December is comparable to January, with more space and less heat in the south.

Winters are usually mild, with acceptable cold stress in most places but problematic in some.

Comfortable species due to non-thermal stress (i.e., comfort) were reported in March. Most of the area experiences neutral thermal conditions in April, except when there is little cold stress. A significant rise in heat stress in May. The majority of areas experience slight heat stress; meanwhile, some pockets of severe heat stress are found in the south and southeast. And this shows very high discomfort, indicating the beginning of the hot season. During the Summer extremes (June–August), temperature stress is already high, with some areas in the south and east experiencing extreme temperatures. July and August are the hottest months, when heat stress is pronounced throughout much of the area, particularly in the south and southeast. In the north, too, it's been brutally hot, with little comfort. Heat extremes in July and August could increase the risk of heat stress. Warm weather affects health, outdoor labor, and energy. In the Autumn transition (September–October), it remains hot in the south in September (with heat stress), but the north is cooling. By October, most locations have returned to no thermal stress, while others are experiencing slight heat stress. Thermal comfort slowly returns during the fall, but (except in southerly locations) it is summer, when rainfall often increases. By late autumn (November), thermal stress is largely neutral, though pockets of brisk chill begin to re-emerge. This is March or April weather, perfect thermal without overdoing it. The spatial patterns revealed that Heat stress is most prevalent during the summer months in southern and southeastern regions. Cold-stress risk is higher, and comfort arrives earlier in the colder north and west. The results identify the seasonal predictability of heat stress and the relevance of measures to mitigate heat in summer, including planning outdoor activities and addressing public health issues. The spatial distributions of PET and UTCI values during the four seasons and the annual mean are illustrated in Figures 5 and 6.

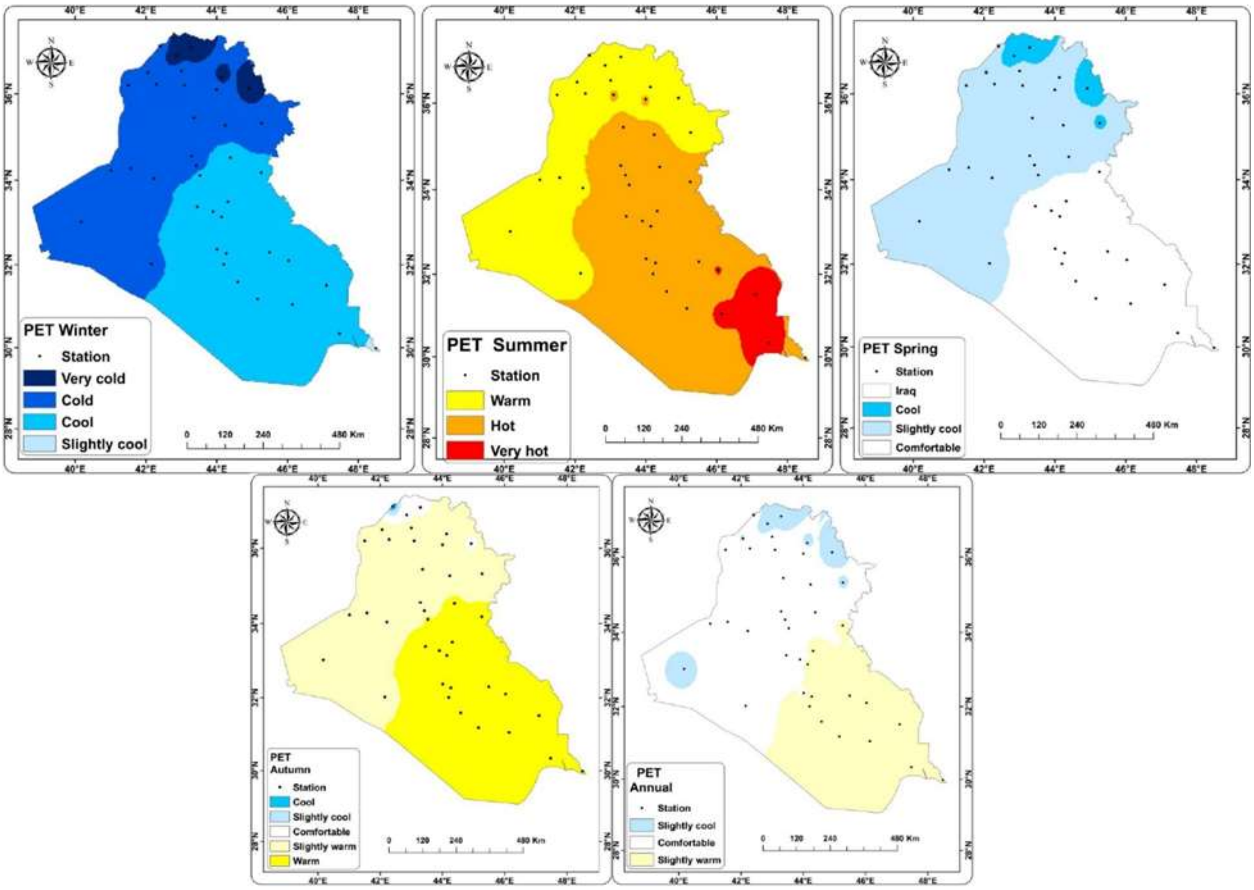


Fig 5: The seasonal and annual spatial distribution mean of PET for the study region.

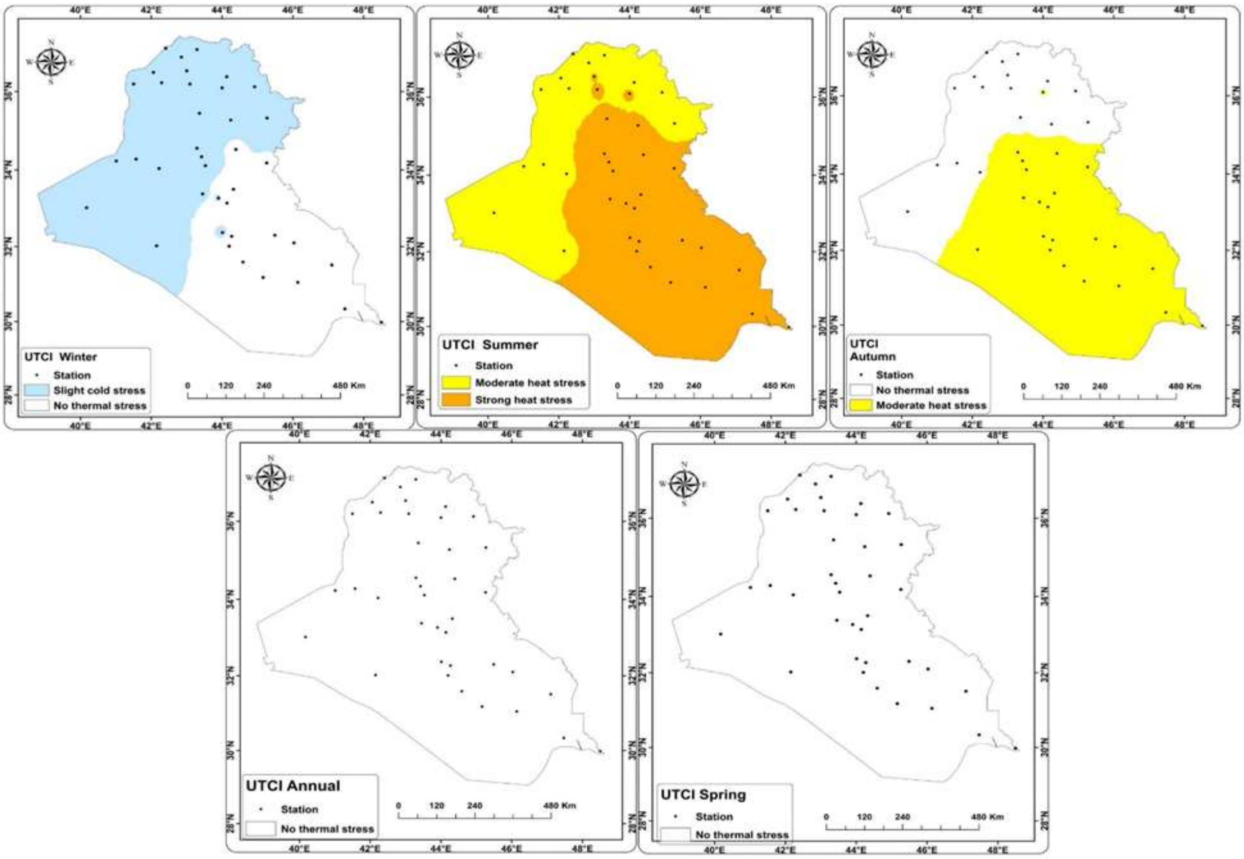


Fig 6: The seasonal and annual spatial distribution mean of UTCI for the study region.

A bioclimate diagram for spatially deriving monthly PET and UTCI conditions (percentages of surface area) is illustrated in Figure 7. The findings indicate that strong seasonal fluctuations in thermal comfort are observed across all four seasons. In Winter (December–February), PET classes range from cold to very cold, and slight to moderate levels of cold stress are identified in the UTCI, suggesting generally cool but not extreme conditions. The Spring (March – April) results show moderate thermal comfort, with surface PET mostly comfortable to slightly cool, and UTCI showing no heat stress. In Early summer (May–June), there is a Clear indication of warming, with warm-to-hot PET classes and moderate to high heat stress for UTCI.

Timeframe of full summer (July–August) indicated that the immediate impact conditions correspond to peak summer, showing hot to very hot PET and strong to very strong heat stress following UTCI that induces substantial thermal discomfort and serious health hazard, while in

In fall (September–October), debilitating heat stress wanes, and September is warm to hot, while October is mostly comfortable or low-stress. Generally, heat stress dominates the climate, with summer as the main thermal stressor and spring and autumn conducive to outdoor activities.

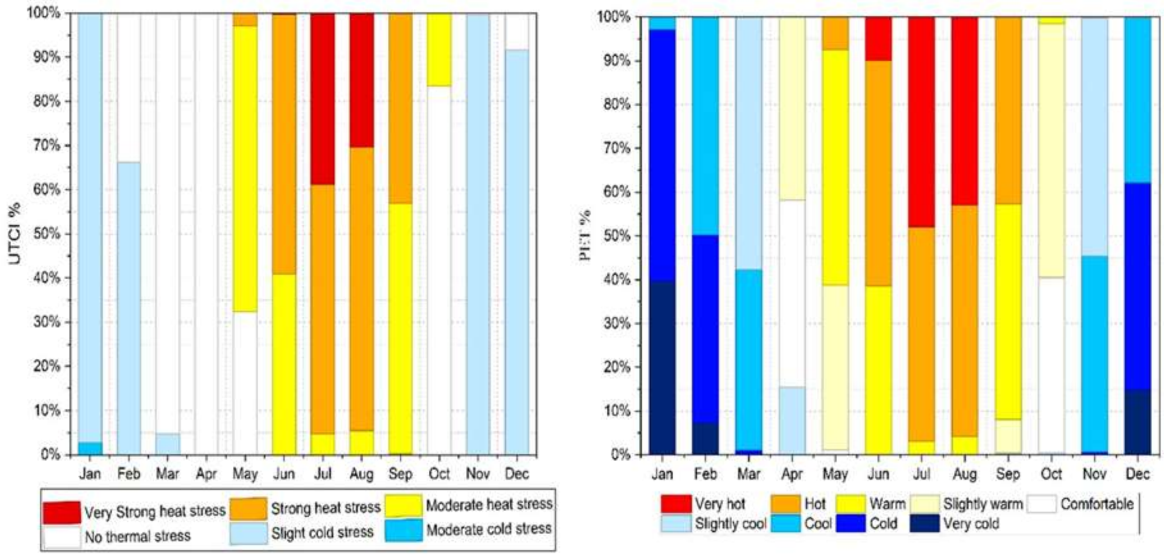


Fig (7): A bioclimate diagram for spatially deriving monthly PET and UTCI conditions (percentages of surface area) for Iraq

To examine the relationship between the two indices, PET and UTCI, with the controlling meteorological parameters, such as air temperature, relative humidity, wind speed, and solar radiation, Baghdad station was chosen as a case study for this calculation, as shown in Figure 8. Results indicate that both PET and UTCI exhibit an apparent seasonal pattern, from a winter minimum to a summer maximum, then back to another winter minimum, with highest values in Jul–Aug and lowest in Jan–Feb. Air temperature controls PE T and UTCI. Both PET and UTCI closely follow the monthly Ta. Solar radiation (G) then significantly contributes to thermal stress, particularly between the end of spring and the beginning of summer, due to an increased radiant heat burden on human beings. Factor V has a moderate influence; however, its cooling effect is too weak to prevent the high temperatures and strong radiation in summer. The inverse relation between 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. In general, discomfort due to thermal load is dominated by summer heat stress, in which high air temperature and insolation are predominant.

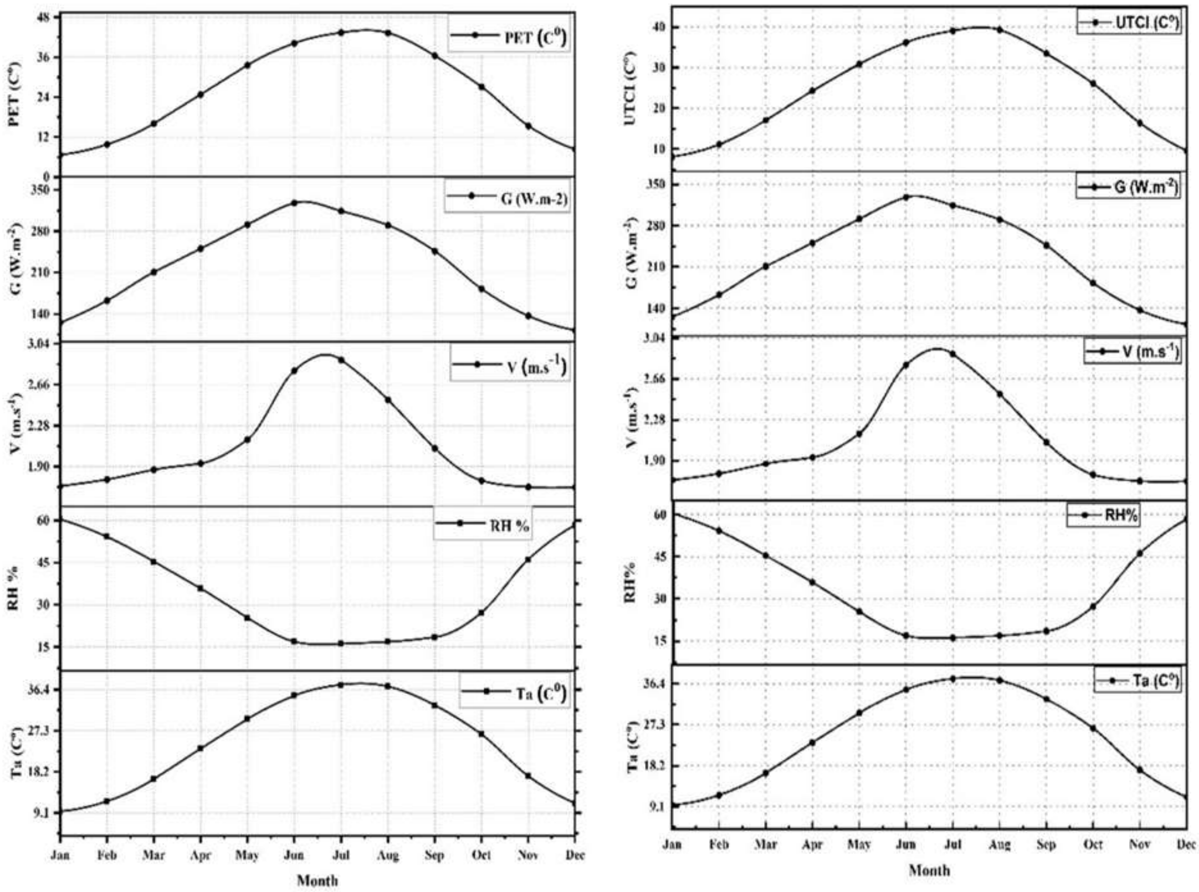


Fig 8: The relationship between the two indices, PET and UTCI, with the controlling meteorological parameters

Based on the data of three uploaded stations (Baghdad, Basra, and Mosul), which represent different climate zones in iraq, Pearson correlation coefficients (r) between PET/UTCI with the primary meteorological variables (temperature of air Ta, relative humidity RH, speed of wind V, and solar radiation G) have been examined as shown in Table 4 . The findings are always very strong positive correlations with air temperature (r = 0.998-1.000) and strong positive correlations with solar radiation (r = 0.913-0.941), whereas relative humidity presents strong negative correlations (r = −0.979 to −0.992). The wind speed has a moderate to strong correlation (r = 0.785-0.957). These findings affirm that thermal stress variation in the various climatic regions in Iraq is mostly caused by air temperature and sun radiation, which reinforces the deduction of the spatial patterns of comfort in the study.

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

Stations	**Ta- PET**	**Ta- 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
Basrah	0.999	0.999	-0.991	-0.992	0.796	0.785	0.919	0.913
Mousal	0.998	0.998	-0.981	-0.971	0.957	0.944	0.941	0.940

5. Conclusions

This study assessed spatial and seasonal variation of human thermal comfort in Iraq with two commonly used bioclimatic indices, Physiologically Equivalent Temperature (PET) and the Universal Thermal Climate Index (UTCI), simulated through the modeling platform RayMan, based on long-term meteorology data from NASA POWER.. The findings reveal that thermal comfort conditions in Iraq are primarily influenced by the change of seasonal, geographical position and physiographic attributes. The two indices show a strong annual cycle of cold to moderate cold stress in winter, particularly in the north and mountainous areas, and strong to very strong heat stress in summer for southern and southeastern Iraq. Spring and autumn are the most favorable times for outdoor human comfort, where sporadically April and October indicate the larger area of thermally comfortable or near-neutral conditions throughout the country. Such intercalary seasons thus constitute the perfect opportunities in which to travel, work outdoors, or engage in intense labor. Spatially However, the southern part of Iraq is perpetually affected by higher thermal stress resulting from severe air temperature and high solar radiation, while in the north and northeastern regions, they encounter subjugation of temperature due to altitude gradient moderation, especially during non-summer. The good agreement and high correlation between PET and UTCI confirm the applicability of both indices for human thermal stress evaluation under Iraq's hot (very hot) arid climatic conditions. Air temperature and solar radiation were found to be the main controlling factors of heat stress, although wind speed did not particularly mitigate heat during peak summer; relative humidity was negatively related to thermal stress.

The implications of the results for public health, urban planning, energy demand management, and climate-sensitive sectors are discussed. Rising summer heat stress, particularly in more populated southern areas, where adaptation measures such as urban design, shading, green infrastructure and heat-health warning systems are important. In addition, the spatially explicit comfort maps produced in this study can be used as a benchmark to estimate impacts of climate change and plan for sustainable development and outdoor activities in Iraq.

In general, this study shows the validity of using PET and UTCI integrated 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.**

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