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SPATIOTEMPORAL ANALYSIS OF THERMAL COMFORT IN AZERBAIJAN

(*Представлено членом редакційної колегії д-ром географ. наук, проф. Дмитром ЛЯШЕНКОМ*)

Background. *Understanding spatiotemporal patterns of thermal comfort is crucial for developing sustainable tourism strategies in geographically diverse regions. This comprehensive study investigates Azerbaijan's complex bioclimatic conditions using the Universal Thermal Climate Index (UTCI), with particular emphasis on how the country's remarkable topographic diversity – ranging from the Caspian coastline to mountain zones – creates distinct microclimates that influence visitor comfort and tourism potential. As climate change continues to alter thermal environments globally, this research provides critical baseline data for adaptive tourism planning in transitional climate zones.*

Methods. *The study employed ERA5-HEAT reanalysis data to calculate UTCI values, incorporating four key meteorological parameters: air temperature, relative humidity, wind speed, and mean radiant temperature. Advanced spatial analysis techniques were implemented using ArcGIS, including interpolation for creating continuous UTCI surfaces, zonal statistics for regional comparisons, and elevation-based corrections using SRTM 30 m DEM data.*

Results. *The analysis revealed extreme annual UTCI variations (–21.0 °C in January highlands to 28.4 °C in August lowlands), demonstrating Azerbaijan's exceptional bioclimatic diversity. Mountainous regions (Greater and Lesser Caucasus) showed prolonged cold stress (UTCI<0°C for 4–5 months), while lowland areas (Kura-Aras plain, Caspian coast) experienced significant summer heat stress (UTCI>26°C for 60–90 days). Optimal thermal comfort conditions (UTCI 9–26 °C) were most persistent in spring (April–May) and autumn (September–October), particularly at mid-elevations (500–1000 m).*

Conclusions. *This study demonstrates that Azerbaijan's thermal comfort patterns are fundamentally governed by topographic factors. The findings enable precise, climate-responsive tourism planning: cultural and beach tourism in lowlands during shoulder seasons (April–June, September–October), alpine tourism in mountain zones during summer, and winter sports in high-elevation areas. The UTCI-based framework developed here proves particularly valuable for managing thermal stress extremes in both hot and cold environments. These results have immediate practical applications for tourism infrastructure development, seasonal marketing strategies, and climate adaptation planning.*

Keywords: *UTCI, Azerbaijan, thermal comfort, tourism climatology, sustainable tourism.*

Background

Tourism is one of the fastest-growing economic sectors globally, with its development and sustainability heavily influenced by climatic conditions that directly affect destination attractiveness, visitor comfort, and recreational activities (Scott, 2006). As travelers increasingly prioritize destinations with favorable weather, understanding the complex interplay between climate and tourism demand has become critical for sustainable destination planning and management (Matzarakis, 2006). The relationship between climate and tourism is particularly significant in regions with diverse climatic zones, where seasonal variations can create both opportunities and challenges for tourism development. In this context, thermal comfort indices have emerged as essential tools for evaluating how humans physiologically perceive outdoor weather conditions, providing a more comprehensive understanding of destination suitability across different times of the year (Bröde et al., 2012).

The natural environment plays a dual role in tourism development, serving simultaneously as a limiting factor and a fundamental resource. Different types of recreational activities require specific environmental conditions to be viable and enjoyable. As emphasized by Nepomnyaschiy and Makeeva (2025), reliable assessment of these natural conditions demands detailed climate mapping based on long-term meteorological data, particularly when planning tourist routes and infrastructure.

Solar radiation patterns significantly influence recreational potential. Research by Kotlyarova (2020) identifies optimal conditions for outdoor activities occurring with 2,000–2,300 annual sunshine hours, while regions with less than 1,700 hours face substantial limitations for tourism development. These insolation regimes interact with other climatic factors to create distinct recreational environments.

Bioclimatic parameters are systematically classified by their physiological impact into irritating (adversely stressing human adaptation), training (moderately stressful but beneficial for healthy individuals), and sparing (universally favorable, even for medically supervised rest) categories (Kolotova, 1999). This classification underpins recreational zoning, where territories are categorized as comfortable (sparing/sparing-training regimes), relatively comfortable (mixed sparing/irritating regimes), uncomfortable (persistent irritating regimes), or extreme (year-round irritating conditions) (Kruzhalin et al., 2014). The recreational potential of a region depends critically on the duration of favorable periods permitting unrestricted outdoor activities versus discomfort periods when extreme temperatures, humidity, or wind impose physiological limits (Kuskov, Golubeva, & Odintsova, 2005). This bioclimatic framework guides critical decisions in resort planning, from site selection and seasonal programming to therapeutic design, by identifying areas with optimal sparing/training conditions while mitigating irritating factors. The classification system enables precise matching of recreational activities and health treatments to local bioclimatic conditions, though modern approaches now augment these traditional categories with more comprehensive indices that integrate multiple atmospheric parameters.

Azerbaijan's exceptional climatic diversity, spanning semi-arid lowlands to alpine zones, creates unique opportunities for year-round tourism, though systematic assessment of thermal comfort remains understudied. The country's solar energy potential is particularly notable, with the Kura-Aras Lowland and Absheron Peninsula receiving 2,700–2,800 annual sunshine hours. Radiation patterns show altitudinal gradients–lowlands receive 125–145 cal/cm² total radiation (45–60 cal/cm² balance) while highlands gain 150–160 cal/cm² total radiation but with reduced balance (10–20 cal/cm²) (National Atlas of the Republic of Azerbaijan, 2014). These physical parameters interact with human comfort thresholds, where Equivalent Effective Temperature (EET) defines optimal conditions at 17.3–21.7 °C, with hot (>22 °C) and cold (<17 °C) discomfort zones (Ayyubov, 1987).

However, despite its growing tourism sector, there is a notable lack of empirical studies examining thermal comfort suitability for recreation in Azerbaijan. This gap in research limits the ability of policymakers and tourism planners to make evidence-based decisions that could enhance visitor experiences and optimize seasonal tourism strategies. While previous research has successfully applied Universal Thermal Climate Index (UTCI) in Mediterranean and Central European destinations to assess tourism climate potential (Pantavou et al., 2013; Rutty, & Scott, 2014), its application in the South Caucasus, particularly in Azerbaijan, remains unexplored, leaving a critical research void.

This study seeks to address this gap by conducting a comprehensive spatiotemporal analysis of thermal comfort across Azerbaijan. Specifically, the research aims to calculate UTCI values for each month of the year to map variations in thermal comfort, identify optimal periods and regions for different types of tourism activities–such as beach tourism in the summer and cultural tours in the spring and autumn. By doing so, the study will help mitigate vulnerabilities associated with thermal stress, such as extreme heat in lowland areas or cold stress in mountainous regions, while promoting sustainable tourism practices. The UTCI's robustness as a biometeorological metric – integrating air temperature, humidity, wind speed, and mean radiant temperature into a single indicator (Jendritzky, De Dear, & Havenith, 2012) – makes it particularly suitable for evaluating Azerbaijan's climatic suitability for tourism.

The implications of this study extend beyond academic interest, offering practical value for stakeholders in Azerbaijan's tourism sector. By bridging climatology and tourism geography, the research contributes to sustainable tourism planning by helping policymakers and industry leaders develop strategies to mitigate seasonality challenges, such as promoting shoulder seasons when thermal conditions are most favorable. Additionally, the findings will enhance the visitor experience by enabling tourists to make informed decisions based on anticipated thermal comfort conditions. From a broader perspective, the study also addresses climate adaptation, providing insights into how shifting comfort zones under global warming (Change, Intergovernmental Panel on Climate, 2007) may impact tourism in Azerbaijan and similar regions. The methodological framework developed in this research can be applied to other climatically diverse areas, offering a replicable approach for assessing tourism climate potential worldwide.

While this study provides a novel assessment of thermal comfort for Azerbaijan, its findings are contextualized within a growing body of regional research that underscores the critical influence of climate on tourism potential. Similar methodological approaches have been successfully applied in neighboring regions with comparable climatic challenges. For instance, research in the arid landscapes of Khorasan Razavi, Iran (Baaghideh et al., 2016), demonstrates the utility of the UTCI index in evaluating heat stress. Further north, studies on the continental climate of Northern Kazakhstan (Pashkov et al., 2023) have employed climate indices to assess and zone territorial suitability for tourism. The application of alternative indices like the Physiologically Equivalent Temperature (PET), as demonstrated in a comprehensive national-scale study of Iran (Daneshvar, Bagherzadeh, & Tavousi, 2013), further enriches the regional framework for bioclimatic analysis. This study contributes to this regional discourse by providing the first comprehensive UTCI-based analysis for the South Caucasus, offering comparative insights for similar topographically diverse and climatically transitional regions and addressing a significant gap in the literature between the well-studied Mediterranean and Central Asian zones.

Methods

Study Area. Azerbaijan is situated in the South Caucasus region at the intersection of Eastern Europe and Western Asia, encompassing a wide range of physiogeographic and climatic zones. Geographically, the country lies approximately between 38°24′ to 41°54′ N latitude and 44°46′ to 50°51′ E longitude (Fig. 1). It shares borders with Russia to the north, Georgia to the northwest, Turkey and Armenia to the west, Iran to the south, and the Caspian Sea to the east. Azerbaijan's landscape is characterized by contrasting terrain, from the low-lying Kura-Aras Lowland in the central part of the country to the towering peaks of the Greater Caucasus in the north and the Lesser Caucasus in the west and southwest. Elevations range from −28 meters below sea level along the Caspian shoreline to over 4,466 meters above sea level at Mount Bazarduzu, the country's highest point (Jabrayilov, 2022).

The country experiences considerable climatic diversity, influenced by elevation, latitude, and proximity to the Caspian Sea. In the central lowlands, the climate is predominantly semi-arid, with hot, dry summers and mild winters. The southeastern region, especially around the Lankaran lowland near the Caspian coast, has a humid subtropical climate, supporting rich forest vegetation. The mountainous areas exhibit alpine and subalpine conditions, with cooler temperatures, increased precipitation, and seasonal snow cover.

This combination of climatic zones and diverse relief makes Azerbaijan an ideal natural laboratory for investigating spatial and temporal variations in thermal comfort, especially in the context of climate change, urban development, and ecological sustainability. The complexity of its microclimates across short distances enhances the relevance of climate and thermal perception modeling in both urban and rural contexts.

Data Collection. This study utilized the ERA5-HEAT (Human thErmAl comforT) dataset (Di Napoli et al., 2021) from the Copernicus Climate Data Store (CDS) to assess thermal comfort conditions across Azerbaijan. The dataset, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), represents the current state-of-the-art in bioclimatological data, providing global coverage of human thermal stress indices derived from ERA5 reanalysis. We focused on two key variables: the Mean Radiant Temperature (MRT) and Universal Thermal Climate Index (UTCI), which integrates air temperature (°C) at 2 m height, relative humidity (%), wind speed (m/s) measured at 10 m height (adjusted to 1.1 m for UTCI), and solar radiation (W/m²) into a physiologically relevant metric. The dataset offers comprehensive temporal coverage from 1940 to near real-time at 0.25° × 0.25° spatial resolution, with data available in hourly, daily, monthly, seasonal, and yearly aggregations.

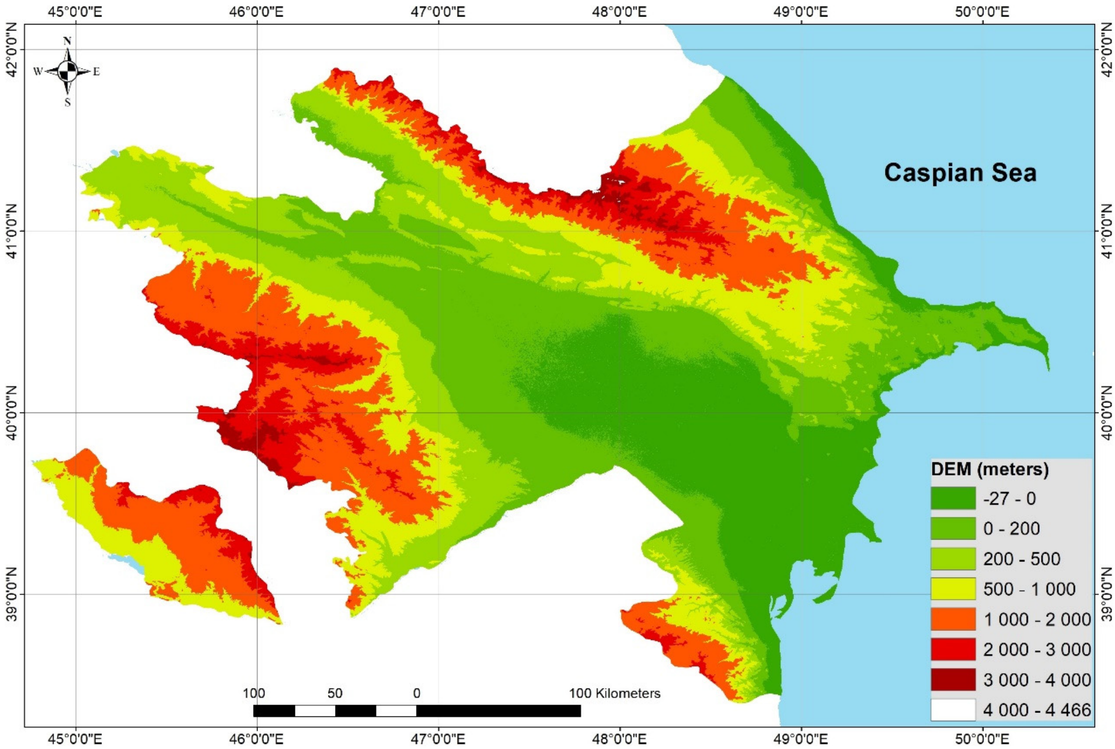

Fig. 1. Digital Elevation Model of Azerbaijan showing topographic variation (Data source: NASA SRTM v3)

Data processing began with the retrieval of UTCI values for Azerbaijan's geographic extent (38°N–42°N, 44°E–51°E) from 2004 to 2024 using the Copernicus CDS API. The UTCI values, originally in Kelvin, were converted to Celsius for practical interpretation. Monthly averages and seasonal summaries were computed to analyze temporal patterns in thermal comfort. To enhance spatial resolution, we applied bilinear interpolation in ArcGIS, downscaling the data from 25 km to 1 km resolution while incorporating elevation adjustments from SRTM DEM and land-cover weights from ESA WorldCover 2021. This approach allowed us to account for local topographic and urbanization effects on thermal conditions.

While the dataset provides robust global coverage, we acknowledge limitations including its 25 km resolution, which may overlook microclimatic variations in mountainous areas, and its assumption of standard clothing insulation (0.9 clo), which may not fully reflect local attire practice.

UTCI Calculation

The Universal Thermal Climate Index (UTCI) was calculated using ArcGIS's geospatial processing tools to assess thermal comfort conditions across Azerbaijan. The computation incorporated four key meteorological parameters prepared as raster layers: air temperature (Ta in °C), mean radiant temperature (Tmrt in °C), relative humidity (RH in %), and wind speed at 10 m height (v10 in m/s).

First, wind speed was adjusted from 10 m to 1.1 m height (approximating human height) using the logarithmic wind profile formula: $v1.1=v10\times(\ln(1.1/z_0)/\ln(10/z0))$, where z_0 represents surface roughness length (0.03 m for open terrain). This adjustment was implemented through ArcGIS's Raster Calculator tool.

The UTCI was then calculated using the simplified polynomial approximation developed by Bröde et al. (2012). The formula applied in ArcGIS was:

$$UTCI=Ta+0.348\times(RH/100)-0.70\times v1.1+0.70\times(Tmrt-Ta)/(1+0.155\times v1.1)-0.0023\times(Tmrt-Ta)\times(RH/100)$$

where all input variables were processed as continuous raster layers.

The resulting UTCI raster was reclassified into nine thermal stress categories following international standards, with particular attention to the optimal comfort range (9–26°C) for tourism activities. This ArcGIS-based approach provided spatially explicit UTCI mapping suitable for regional tourism climate analysis while maintaining computational efficiency. The methodology leveraged ArcGIS's robust raster processing capabilities to handle large datasets across Azerbaijan's diverse climatic zones.

Classification of Thermal Comfort. UTCI values were categorized into thermal stress classes (Table 1) per international standards (Di Napoli et al., 2018; Blazejczyk et al., 2012).

Results

The analysis of monthly UTCI values across Azerbaijan from 2004 to 2024 revealed distinct spatiotemporal patterns of thermal comfort conditions. The UTCI maps, showed values ranging from extreme cold stress (–21 °C in January) to moderate heat stress (28.4 °C in August) (Fig. 2–4). During winter months, the mountainous regions of Greater and Lesser Caucasus exhibited the coldest conditions, while relatively milder thermal comfort (UTCI 0–9 °C) prevailed in central lowland areas including the Kura-Aras plain, Southeastern Shirvan plain, Mil plain, Mugan plain, and Lankaran lowland, as well as along the Caspian Sea coasts. Summer months presented a contrasting pattern, with August showing the most pronounced heat stress, particularly in low-lying regions. The persistent thermal comfort conditions in central plains during winter and coastal areas suggest these regions may offer more favorable conditions for year-round outdoor activities and tourism compared to the extreme seasonal variations experienced in mountainous zones. These findings provide valuable insights for tourism planning and highlight the importance of considering microclimatic variations when assessing human thermal comfort across Azerbaijan's diverse landscapes. The comprehensive 20-year dataset offers a robust basis for understanding long-term thermal comfort trends in the region.

Table 1

UTCI thermal stress categories

UTCI Range (°C)	Thermal Perception	Physiological Impact
< -40	Extreme cold stress	High risk of frostbite
-40 to -27	Very strong cold stress	Significant discomfort
-27 to -13	Strong cold stress	Shivering likely
-13 to 0	Moderate cold stress	Mild discomfort
0 to 9	Slight cold stress	Neutral for active individuals
9 to 26	No thermal stress	Comfortable for most
26 to 32	Moderate heat stress	Increased sweating
32 to 38	Strong heat stress	Risk of heat exhaustion
> 38	Very strong heat stress	Danger of heat stroke

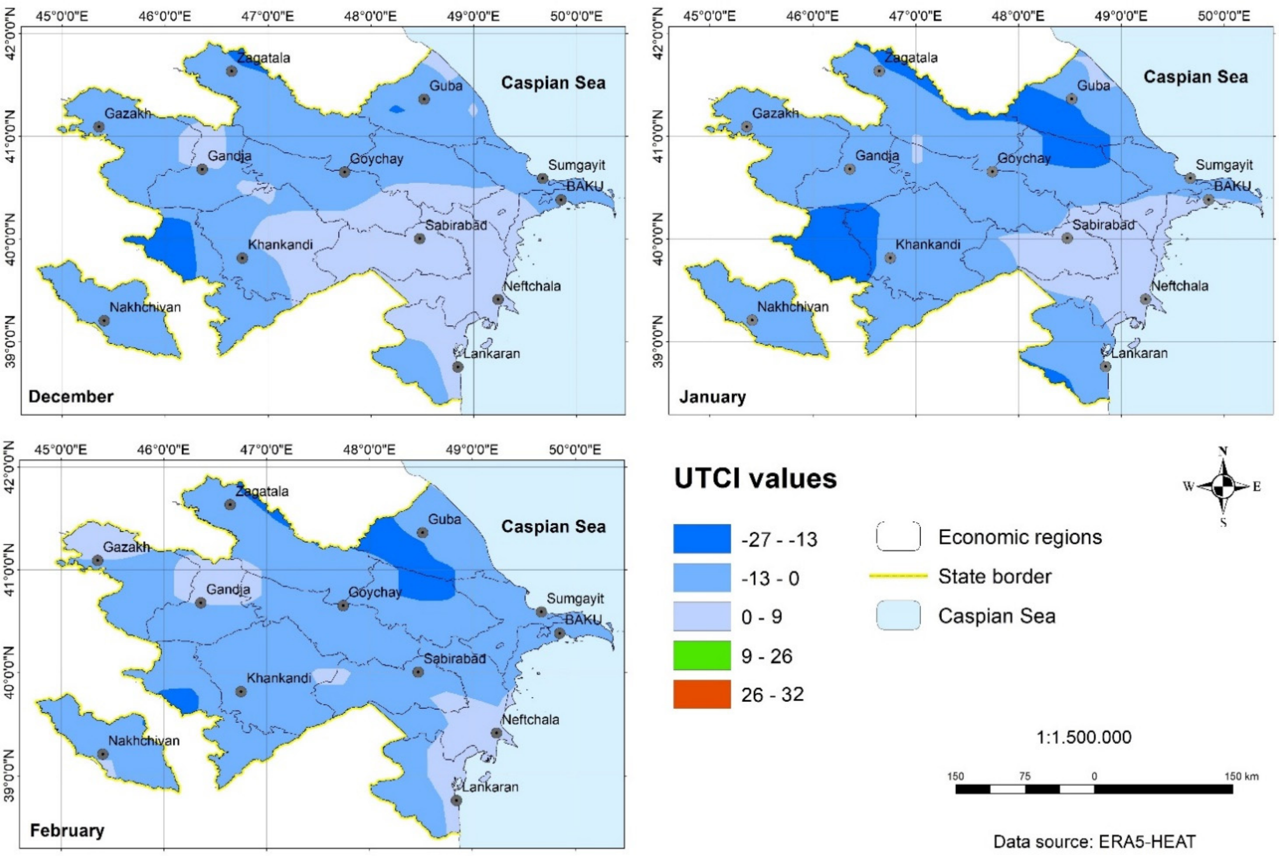

Fig. 2. Monthly values for UTCI in winter

The analysis of UTCI values during spring months revealed distinct spatial patterns across Azerbaijan's varied topography. UTCI values ranged from –13 °C in mountainous areas to 15.5 °C in lowland plains (Fig. 3), demonstrating the significant influence of elevation on thermal comfort conditions. Spring emerged as the most favorable season for tourism and outdoor activities, with particularly comfortable conditions (UTCI 9–26 °C) prevailing across most of the country during April and May. The spatial distribution showed a clear elevation gradient, with optimal thermal comfort conditions concentrated in lower-lying areas including the Kura-Aras lowland, Mugan plain, and coastal regions along the Caspian Sea. These low-elevation areas benefited from milder temperatures and reduced cold stress compared to mountainous regions, where winter-like conditions persisted into early spring. The consistent pattern of more favorable thermal conditions at lower elevations suggests these areas may be particularly suitable for springtime tourism development and outdoor recreational planning.

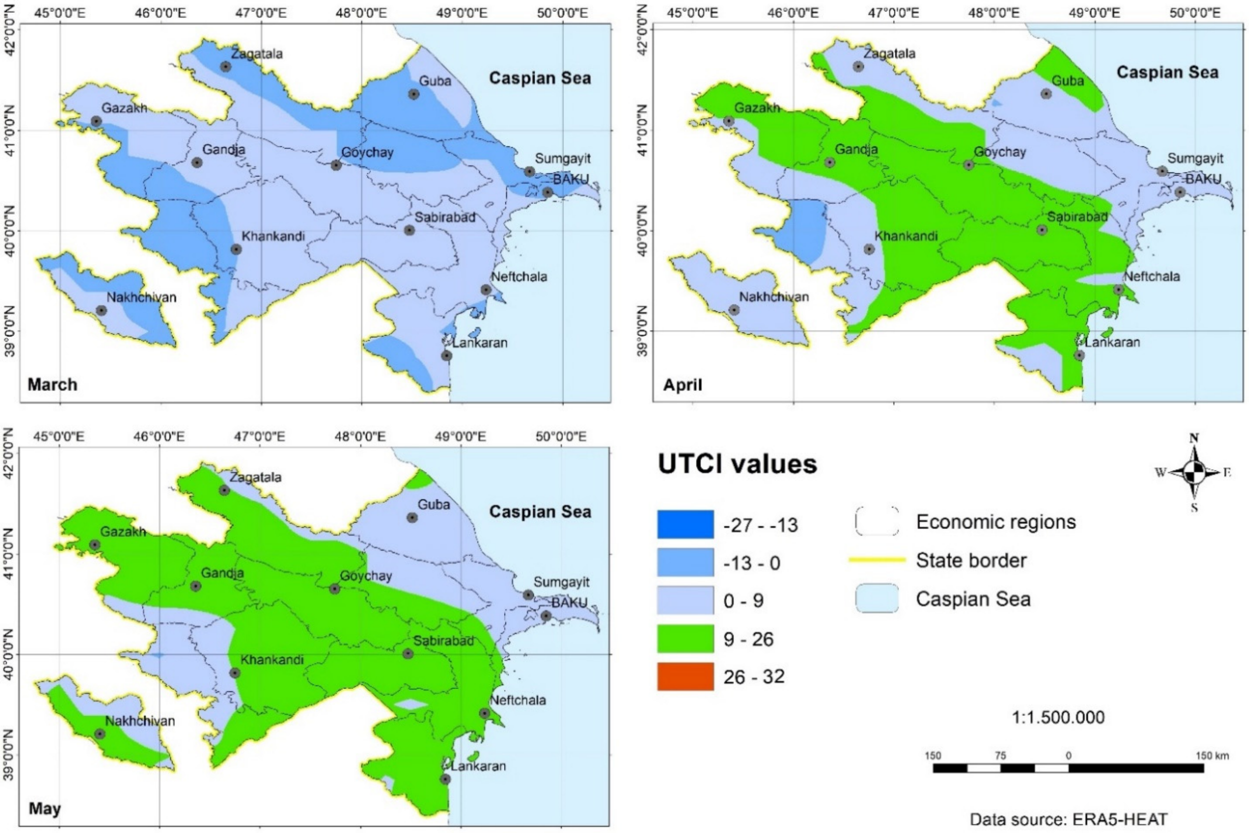

Fig. 3. Monthly values for UTCI in spring

During summer months, Azerbaijan exhibited a wide range of UTCI values from 5.3 °C to 28.4 °C (Fig. 4). While most regions experienced no thermal stress (UTCI 9–26 °C), creating favorable conditions for summer tourism, distinct spatial patterns emerged. June showed transitional conditions with slightly cold stress persisting in upper mountain regions, particularly in the Greater and Lesser Caucasus ranges. The most intense heat stress occurred in central and eastern lowland areas, with peak UTCI values recorded in urban centers like Baku and Sumgait, as well as in the southern districts of Neftchala, Sabirabad, Saatli, and Imishli. These areas, characterized by their low elevation, consistently demonstrated the highest UTCI values during summer months, often reaching the upper thresholds of thermal comfort or entering moderate heat stress conditions. The spatial distribution of summer UTCI values reveals an important consideration for tourism planning, with coastal areas along the Caspian Sea and higher elevation regions offering more moderate thermal conditions compared to the intense heat of central lowlands. This pattern suggests that while much of the country experiences physiologically comfortable conditions in summer, careful consideration of microclimatic variations is essential for optimizing tourist experiences and managing heat-related health risks.

The autumn months in Azerbaijan exhibited a gradual transition from warm to cold thermal conditions, with distinct spatial variations in UTCI values ranging from 20 °C to –16 °C (Fig. 5). September and October maintained optimal thermal comfort (UTCI 9–26 °C) across all lowland and plain regions, including the Kura-Aras lowland, Mugan plain, and the Caspian coastal zone, providing ideal conditions for outdoor tourism activities. By November, thermal comfort levels became comparable to those of December, with cooler conditions extending across the central plains, while mountainous regions began experiencing cold stress (UTCI <0 °C). This seasonal shift highlights the narrowing window of comfortable conditions as winter approaches, with early autumn (September–October) offering the most favorable period for tourism in lowland regions before colder temperatures set in. The persistence of no thermal stress in plain areas during early autumn underscores their suitability for extended seasonal tourism compared to higher-elevation zones, where colder conditions arrive earlier. These findings emphasize the importance of timing for tourism planning, with September and October representing peak comfort months for most of the country before thermal stress increases in November.

The monthly UTCI extremes in Azerbaijan demonstrate how topography drives thermal comfort variations across different elevations (Fig. 6). The data reveals that mountain regions experience severe cold stress in winter (UTCI –21.0 °C in January), while lowland areas reach moderate heat stress in summer (UTCI 28.4 °C in August). This 49.4 °C annual UTCI range primarily reflects elevation differences rather than continental effects alone, with three key patterns emerging:

• High-altitude zones maintain prolonged cold stress due to radiative cooling and persistent inversion layers, particularly in the Greater and Lesser Caucasus where January's UTCI matches extreme continental climates.

• Lowland basins show accentuated summer heat stress (UTCI >26 °C June–August) from combined temperature-humidity effects in the Kura-Aras and Caspian coastal plains.

• Transitional months (April–May, September–October) reveal the strongest relief-induced contrasts, where mountain valleys can simultaneously experience thermal comfort (UTCI 9–15 °C) while nearby peaks remain in cold stress.

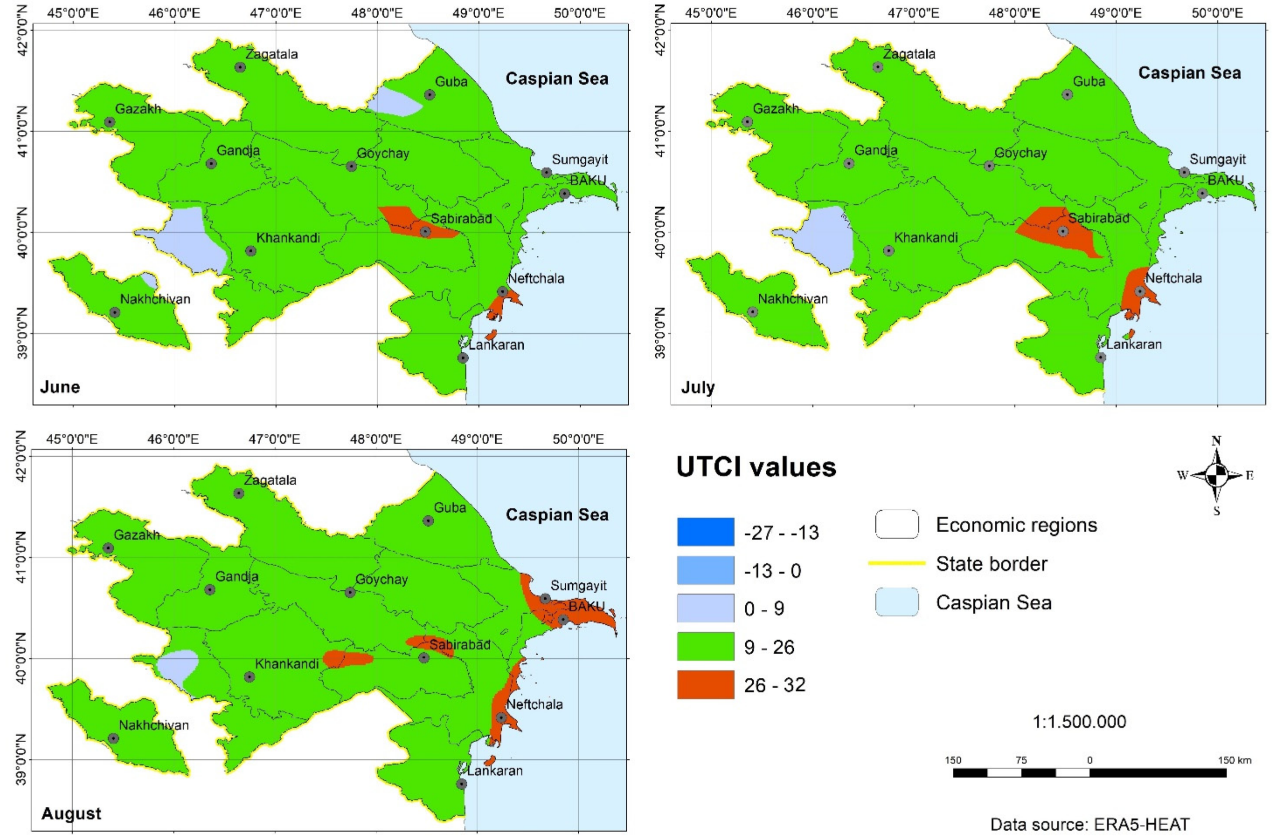

Fig. 4. Monthly values for UTCI in summer

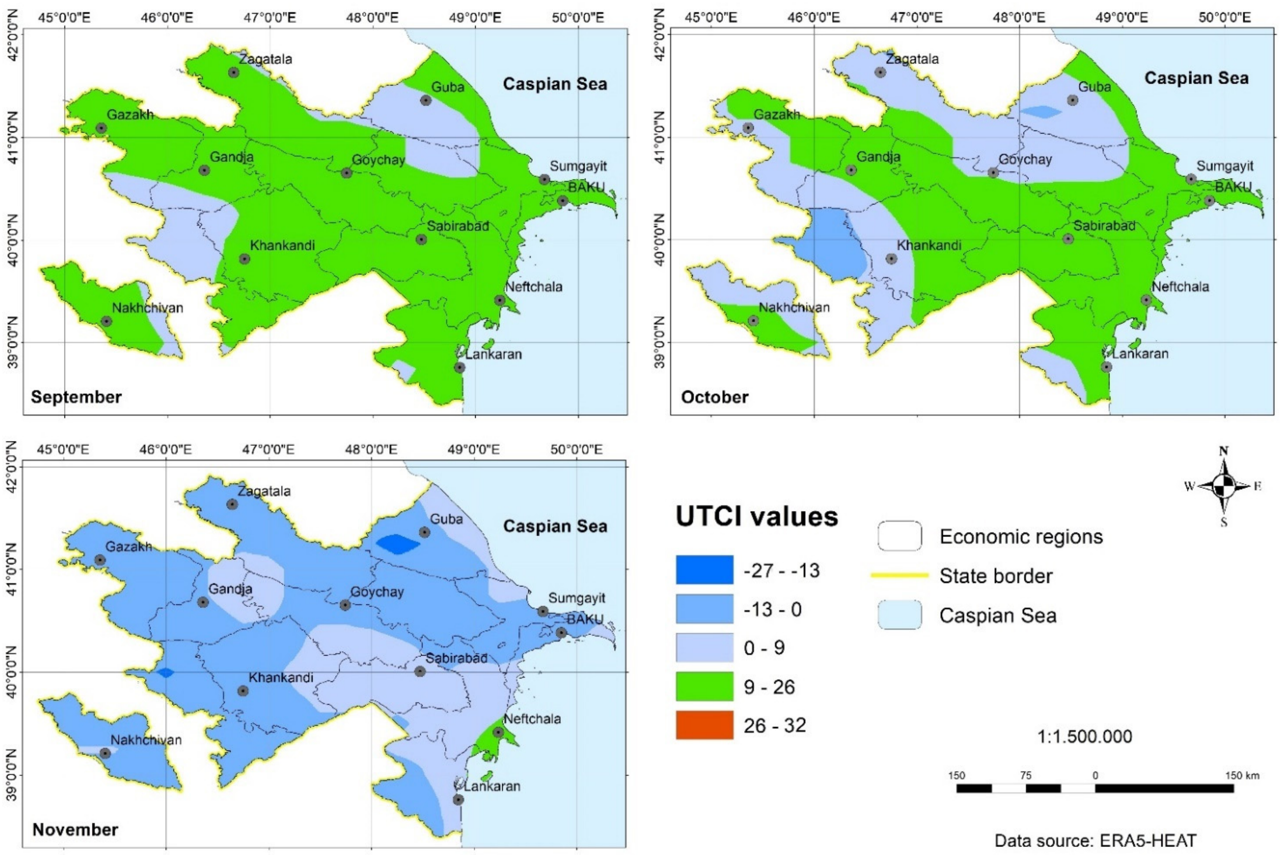

Fig. 5. Monthly values for UTCI in autumn

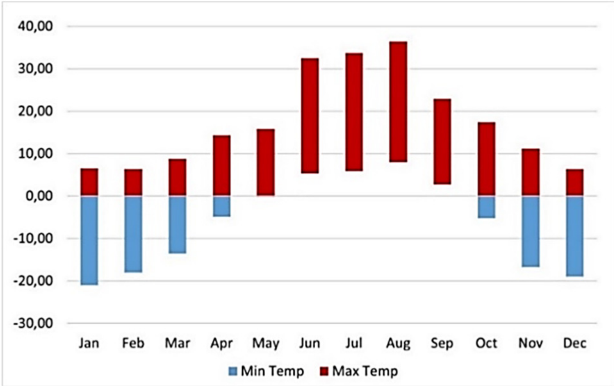

Fig. 6. Mean monthly values of UTCI

The mean annual UTCI across Azerbaijan ranges from –4.3 °C to 14.1 °C, demonstrating significant spatial variation tied to elevation and geography (Fig. 7). High-altitude regions of Greater and Lesser Caucasus Mountains experience moderate cold stress conditions (UTCI –4.3 °C to 0 °C), while transitional zones including Ganja, Gazakh, Khankandi, Goychay, Guba, Nakhchivan show moderate conditions (0 °C to 9 °C). The most favorable thermal environments (9 °C to 14.1 °C) are found in lowland and coastal areas such as Lankaran, Neftchala, Sabirabad districts, and the Kura-Aras plain. Notably, Lankaran's subtropical coastal climate maintains the highest mean annual UTCI values (12–14.1 °C), making it particularly suitable for year-round tourism, while Nakhchivan exhibits greater seasonal variability due to its continental highland climate. These patterns highlight how Azerbaijan's diverse topography creates distinct thermal comfort zones, with lower elevations generally offering more favorable conditions for tourism and outdoor activities compared to mountainous regions that require specialized seasonal adaptations.

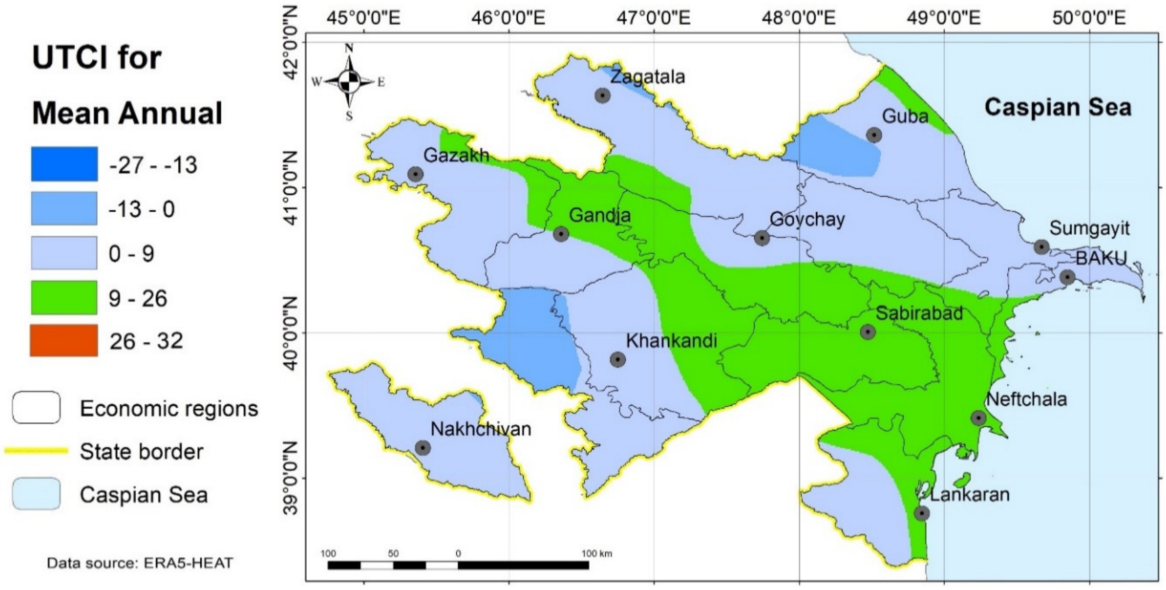

Fig. 7. Distributions of UTCI based on mean annual values

The analysis of district-level mean UTCI values reveals clear spatial patterns in thermal comfort conditions across Azerbaijan. Two distinct clusters emerge from the data: mountainous districts exhibit significantly lower values, while lowland areas demonstrate consistently higher thermal comfort levels. Among the cooler regions, Kalbajar (–2.5 °C) and Lachin (–1.5 °C) districts represent the most extreme cases of cold stress, characteristic of high-altitude zones in the Lesser Caucasus. Transitional districts such as Guba (0.6 °C), Gusar (1.8 °C), and Shusha (2.6 °C) show progressively milder conditions, though still below optimal comfort thresholds (Fig. 8). The warmer cluster presents a striking contrast, with all lowland districts exceeding 10 °C. Mingachevir (10.4 °C) and Lankaran (10.6 °C) mark the lower boundary of this group, while central and southeastern plains districts – particularly Neftchala (12.7 °C), Salyan (12.4 °C), and Sabirabad (12.3 °C) – record the highest values (Fig. 9). This pronounced thermal gradient between highland and lowland areas, spanning nearly 15 °C from coldest to warmest districts, underscores the critical role of elevation and geography in shaping local microclimates. The consistent warmth of southern and central lowlands suggests greater potential for year-round tourism development compared to mountainous regions, where thermal conditions impose significant seasonal limitations on outdoor activities. These spatial variations in UTCI values provide valuable insights for regional tourism planning and infrastructure development tailored to local climatic realities.

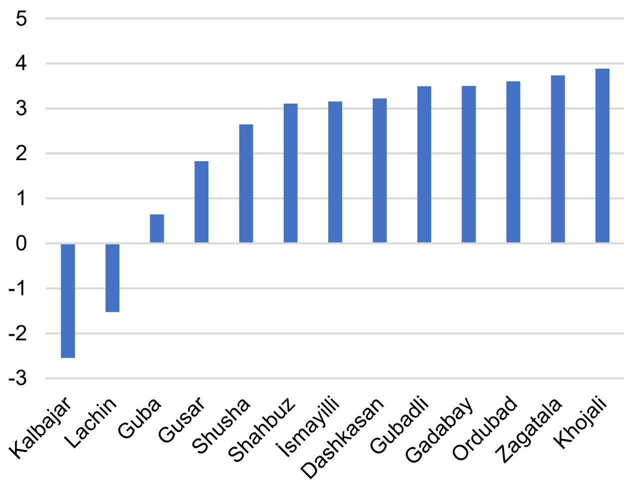

Fig. 8. Districts with lower UTCI values

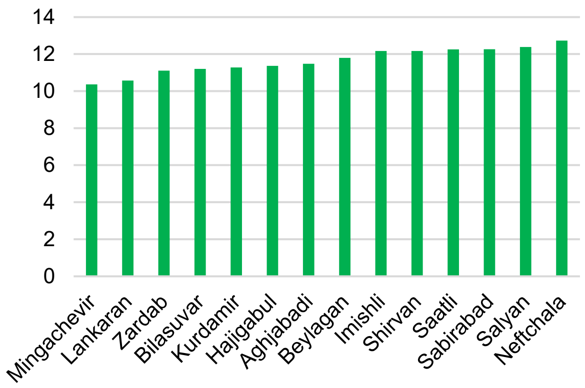

Fig. 9. Districts with higher UTCI values

Discussion and conclusions

This study comprehensively analyzed the spatiotemporal patterns of thermal comfort in Azerbaijan using the Universal Thermal Climate Index (UTCI), revealing significant variations driven primarily by topographic diversity. The results demonstrate that elevation plays a crucial role in shaping thermal comfort conditions, with mountainous regions experiencing prolonged cold stress while lowland areas face moderate heat stress. The transitional seasons of spring and autumn exhibit the most favorable conditions for tourism, particularly in mid-elevation zones where thermal comfort persists longest. These findings highlight how Azerbaijan's complex relief creates distinct microclimates, enabling diverse tourism opportunities within relatively small geographical areas.

The research underscores three key recommendations for sustainable tourism development: First, tourism planning should adopt a seasonally differentiated approach that aligns activities with optimal thermal conditions. This involves concentrating outdoor cultural and nature-based activities during transitional seasons when comfort levels are highest, while developing climate-adapted solutions for peak summer and winter periods. Second, infrastructure development should incorporate bioclimatic design principles, prioritizing passive cooling strategies in warmer regions and thermal protection measures in colder zones. Third, destination management organizations should develop predictive models using UTCI data to anticipate shifting comfort zones under climate change scenarios.

Future studies could expand this work by integrating visitor perception data with physiological comfort metrics. Practical applications should focus on developing real-time comfort advisory systems and training programs for tourism operators on microclimate-aware service design. This UTCI-based framework provides policymakers with evidence to optimize resource allocation, ensuring tourism development aligns with regional bioclimatic advantages while mitigating thermal stress challenges.

Ultimately, the study establishes a replicable approach for balancing visitor comfort with environmental resilience in topographically diverse regions. The findings offer strategic insights for enhancing seasonal tourism offerings while maintaining ecological integrity across Azerbaijan's varied landscapes.

Authors' contribution: Gunesh Agakishiyeva – conceptualization, formal analysis, methodology; Emil Jabrayilov – conceptualization, methodology, writing (original draft), analysis of results; Jahan Mammadova – data validation, writing (review and editing).

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ПРОСТОРОВО-ЧАСОВИЙ АНАЛІЗ ТЕПЛОВОГО КОМФОРТУ В АЗЕРБАЙДЖАНІ

В с т у п ***. Розуміння просторово-часових закономірностей теплового комфорту має вирішальне значення для розробки стратегій сталого туризму в географічно різноманітних регіонах. Це комплексне дослідження вивчає складні біокліматичні умови Азербайджану за допомогою Універсального теплового кліматичного індексу (УТКІ), з особливим акцентом на те, як вражаюча топографічна різноманітність країни – від узбережжя Каспійського моря до гірських зон – створює різні мікроклімати, які впливають на комфорт відвідувачів та туристичний потенціал. Оскільки зміна клімату продовжує змінювати теплове середовище в усьому світі, це дослідження надає критично важливі базові дані для адаптивного планування туризму в перехідних кліматичних зонах.***

М е т о д и ***. У дослідженні використовувалися дані повторного аналізу ERA5-HEAT для розрахунку значень УТКІ, включаючи чотири ключові метеорологічні параметри: температуру повітря, відносну вологість, швидкість вітру та середню радіаційну температуру. Розширені методи просторового аналізу було впроваджено за допомогою ArcGIS, включаючи інтерполяцію для створення безперервних поверхонь УТКІ, зональну статистику для регіональних порівнянь та корекції на основі висоти з використанням даних SRTM 30 m DEM.***

Р е з у л ь т а т и ***. Аналіз виявив екстремальні річні коливання UTCI (від –21,0 °C у високогір'ї у січні до 28,4 °C у низовинах у серпні), що демонструє виняткове біокліматичне різноманіття Азербайджану. Гірські регіони (Великий та Малий Кавказ) демонстрували тривалий холодовий стрес (UTCI <0 °C протягом 4–5 місяців), тоді як низовини (рівнина Кура-Аракс, узбережжя Каспійського моря) зазнавали значного літнього теплового стресу (UTCI >26 °C протягом 60–90 днів). Оптимальні умови теплового комфорту (UTCI 9–26 °C) були найбільш стійкими навесні (квітень–травень) та восени (вересень–жовтень), особливо на середніх висотах (500–1000 м).***

В и с н о в к и ***. Це дослідження демонструє, що моделі теплового комфорту Азербайджану фундаментально визначаються топографічними факторами. Отримані результати дають змогу здійснювати точне планування туризму з урахуванням клімату: культурний та пляжний туризм у низовинах протягом міжсезоння (квітень–червень, вересень–жовтень), гірський туризм у гірських зонах влітку та зимові види спорту у високогірних районах. Розроблена тут структура на основі UTCI виявляється особливо цінною для управління екстремальними термальними навантаженнями як у жаркому, так і в холодному середовищі. Ці результати мають безпосереднє практичне застосування для розвитку туристичної інфраструктури, сезонних маркетингових стратегій та планування адаптації до зміни клімату.***

К л ю ч о в і с л о в а : ***UTCI, Азербайджан, тепловий комфорт, туристична кліматологія, топографічний вплив, сталий туризм.***

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