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Tourism climate indices in tourism geography: A systematic review of their development, applications, and research trends

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Weather and climate strongly influence tourism demand, destination attractiveness, seasonality, and the spatial distribution of tourism activities. Tourism climate indices (TCIs) provide a way to combine climatic variables into synthetic measures of tourism suitability, but their development and application within tourism-geographical research remain fragmented. This review systematically synthesizes the use of TCIs in tourism geography, with particular attention to their development, spatial distribution, application contexts, and methodological approaches. The study is based on a systematic literature review of 94 peer-reviewed studies published between 1985 and 2025, identified through Web of Science and Scopus and analysed according to PRISMA guidelines. The results show that the Tourism Climate Index remains the most frequently used index, although recent research increasingly applies modified, perception-based, activity-specific, and scenario-oriented approaches. TCI research expanded markedly after 2020 and is concentrated mainly in Köppen temperate (class C) climate regions, European and Asian contexts, and coastal and urban tourism environments, while tropical, island, nature-based, and other climate sensitive contexts remain less represented. Methodologically, descriptive index application still dominates, but comparative, model-based, and projection-

oriented studies are becoming more visible. The review shows that TCIs remain useful tools for analysing climatic suitability, seasonality, and tourism-climate relations, but their explanatory value is limited when they are weakly connected to observed tourist behaviours, visitor flows, and destination characteristics. Future development of TCIs should therefore place greater emphasis on empirical validation, spatial context, tourism activity, and the transferability of indices across different climatic regions and tourism environments.

Keywords: tourism climate indices; tourism geography; methodological approaches; thermal comfort; spatial patterns

INTRODUCTION

Weather and climate are among the most important factors influencing tourists' destination choices and the development of tourism. They affect tourism both directly, such as in case of the decisions about where and when to travel (Gössling & Hall, 2006), and indirectly, through their impact on activity patterns, daily scheduling, and spatial distribution of visitor flows within destinations (Cavallaro et al., 2017; Gómez-Martín et al., 2014). While good weather conditions enhance destination attractiveness, extreme or adverse conditions often prompt tourists to modify plans, shorten stays, or choose alternative destinations, demonstrating the high sensitivity of tourism demand to weather variability (Becken & Wilson, 2013; Rutty & Scott, 2014). These conditions also play a significant role in shaping tourists' overall satisfaction and intention to revisit (Scott & Lemieux, 2010). However, the perception of 'good' or 'bad' weather is not universal, but it varies according to cultural, geographical, and experiential factors (Limb & Spellman, 2001; Scott et al., 2008). For example, Scandinavian tourists prefer higher beach temperatures compared to visitors from Canada or New Zealand, while British tourists may perceive rain as a natural part of the experience rather than a negative factor (Scott et al., 2008). These differences highlight the importance of considering diverse tourist segments and acclimatization when evaluating climate suitability.

Beyond shaping tourists' perceptions and behaviour, climate also represents a key driver supporting tourism development. It may be perceived either as a primary tourism resource, such as in the case of beach and ski destinations (Kozak et al., 2008), or as a factor that supports tourism activities and overall satisfaction (Gómez-Martín, 2006) and is considered as one of the most important drivers of tourism. Consequently, climate change is expected to change the spatial and seasonal distribution of climatic resources relevant to tourism, with uneven regional

consequences (Becken, 2010; IPCC, 2021; Scott et al., 2012). Projections suggest that northern destinations may experience improved climatic suitability, while parts of the Mediterranean and other already warm regions could face reduced summer comfort and increased heat stress (Amelung et al., 2007; Ciscar et al., 2011; García-León et al., 2025; Moreno & Amelung, 2009; Porter, 2019). Meta-analyses further suggest that while global tourism flows may experience marginal declines in response to weather changes, regional and seasonal variations are likely to be more noticeable (Zhou et al., 2024). Sustainable management can help reduce vulnerability to climate change, though adaptation remains constrained by limited research and resources (Jamaliah et al., 2021; Mandić et al., 2025).

In tourism climatology, different types of climate indices have been used to assess climatic conditions relevant to tourism activities and visitor comfort. A commonly used classification groups climate indices into elementary, bioclimatic, and combined indices (Abegg, 1996, modified; Matzarakis, 2006). Elementary climate indices are based on the direct or synthetic use of one or only a few meteorological variables, most commonly air temperature, sunshine duration and precipitation. Bioclimatic indices represent a more advanced group of indicators, as they are based on the human energy balance and thermal physiology. These indices explicitly model the interaction between meteorological conditions and human thermal comfort. Finally, combined indices explicitly integrate and weight several climatic elements, often with a direct focus on tourism suitability. The Tourism Climate Index introduced by Mieczkowski (1985) represents the foundational combined index and provided the basis for later modified approaches. This review focuses primarily on combined climate indices because they are explicitly designed to compare climatic suitability across destinations, seasons, tourism environments, and climatic contexts. The main characteristics and examples of these three groups of indices are summarized in Table 1.

Tablica 1. Klimatski indeksi (prema Abegg, 1996; Matzarakis, 2006, prilagođeno)
Table 1 *Climate indices (after Abegg, 1996; Matzarakis, 2006, modified)*

Kategorija / ***Category***	**Obilježja /** ***Characteristics***	**Uključeni parametri /** ***Parameters included***	**Indeksi i autori /** ***Indices and Authors***
Elementarni / ***Elementary***	→ izravna ili sintetička uporaba jedne ili vrlo malo meteoroloških varijabli / *direct or synthetic use of single or very few meteorological variables* → bez fiziološkog modela, bez sustava ponderiranja za turizam / *no physiological model, no weighting system for tourism*	Temperatura zraka, trajanje sijanja sunca, oborine (sintetičke vrijednosti) / *Air temperature, sunshine duration, precipitation (synthetic values)*	• Poulterov indeks/*The Poulter Index* (Poulter, 1962) • Indeks vremenskog stresa / *Weather Stress Index* (Fergusson, 1964) • Indeks optimalnog ljetnog vremena / *Optimum summer weather index* (Davies, 1968) • Jednostavni ljetni indeks / *A simple summer index* (Murray, 1972) • Dnevne klasifikacije tipova vremena / *Daily Weather-type classifications* (Besancenot, 1990)
Bioklimatski/ ***Bioclimatic***	→ temeljeni na energetskoj bilanci čovjeka / toplinskoj fiziologiji / *based on human energy balance / thermal physiology* → izravno modelirani/*explicitly modelled*	Indeksi osjeta hladnoće (temperatura zraka, brzina vjetra) – temeljeni na energetskoj bilanci čovjeka / *Windchill (air temperature, wind speed) Indices – based on human energy balance*	• Predviđena srednja ocjena / *Predicted Mean Vote* (PMV) (Fanger, 1972) • Humidex (Masterton & Richardson, 1979) • Standardna efektivna temperatura / *Standard Effective Temperature* (SET) (Gagge et al., 1986) • Fiziološki ekvivalentna temperatura / *Physiologically Equivalent Temperature* (PET) (Höppe, 1999) • Univerzalni toplinski klimatski indeks / *Universal Thermal Climate Index* (UTCI) (Jendritzky et al., 2012)

Kombinirani/ *Combined*	→ izravno kombiniranje i ponderiranje više klimatskih elemenata / *explicit combination and weighting of several climatic elements* → često specifični za turizam / *often tourism-specific*	Ugoda tijekom dana, dnevna ugoda, oborine, trajanje sijanja sunca, brzina vjetra, fiziološki ekvivalentna temperatura i predviđena srednja ocjena / *Daytime comfort, daily comfort, precipitation, sunshine duration, wind speed, physiologically equivalent temperature, and predicted mean vote*	• Turistički klimatski indeks / *Tourism Climate Index* (TCI) (Mieczkowski, 1985) • Klimatski indeks za plaže / *Beach Climate Index* (BCI) (Morgan et al., 2000) • Klimatski indeks za turizam / *Climate Index for Tourism* (CIT) (de Freitas et al., 2008) • Klimatski indeks za odmor / *Holiday Climate Index* (HCI) (Scott et al., 2016) • Klimatski indeks za kampiranje / *Camping Climate Index* (Ma et al., 2020)

Tourism climate indices (TCIs) have proven valuable, especially in tourism geography, both as the tools for researchers and planners and as resources for the tourism industry. They allow comparisons of climatic suitability across destinations and times, the assessment of potential climate change impacts, and the projection of visitor flows based on climatic conditions (de Freitas et al., 2008; Matzarakis, 2007; Moore, 2010; Rogerson & Rogerson, 2020; Scott & Lemieux, 2010). By integrating multiple weather parameters, such indices can also help identify regions or periods that may experience reduced comfort or attractiveness, providing a basis for adaptation and planning. With global tourism continuing to expand, the accurate assessment of climatic conditions and their influence on tourist behaviour remain a central concern for both scholars and stakeholders (Gössling & Scott, 2025).

Despite the extensive development and application of tourism climate indices, a comprehensive review focusing specifically on their role in tourism geography has not yet been conducted. While existing reviews have addressed thermal and climate indices in historical contexts (Kumar & Sharma, 2020; Tatulli & Pezzoli, 2025), a critical gap remains in synthesising indices specifically tailored to evaluate tourism-relevant climatic suitability. Such an integrative review is essential for understanding the evolution, methodological approaches, and potential applications of tourism climate indices in current and future tourism research.

Therefore, the main goal of this review is to systematically synthesize the development and application of tourism climate indices within tourism geography research spanning from

1985 to 1 September 2025. The review examines temporal and spatial patterns of TCI research, the geographical and climatic contexts in which indices have been applied, the tourism environments most frequently analysed, and the methodological characteristics of the most used indices. By doing so, it identifies key conceptual and methodological gaps in the existing literature and outlines directions for future research.

With that, the review addresses the following research questions:

1. How did the use of tourism climate indices evolve temporally within tourism geography research between 1985 and 2025?
2. Which tourism climate indices dominate tourism-geographical research, and what are their key methodological characteristics?
3. How does the application of tourism climate indices vary across climatic zones and tourism environments?
4. What conceptual and methodological gaps remain in tourism climate index research?

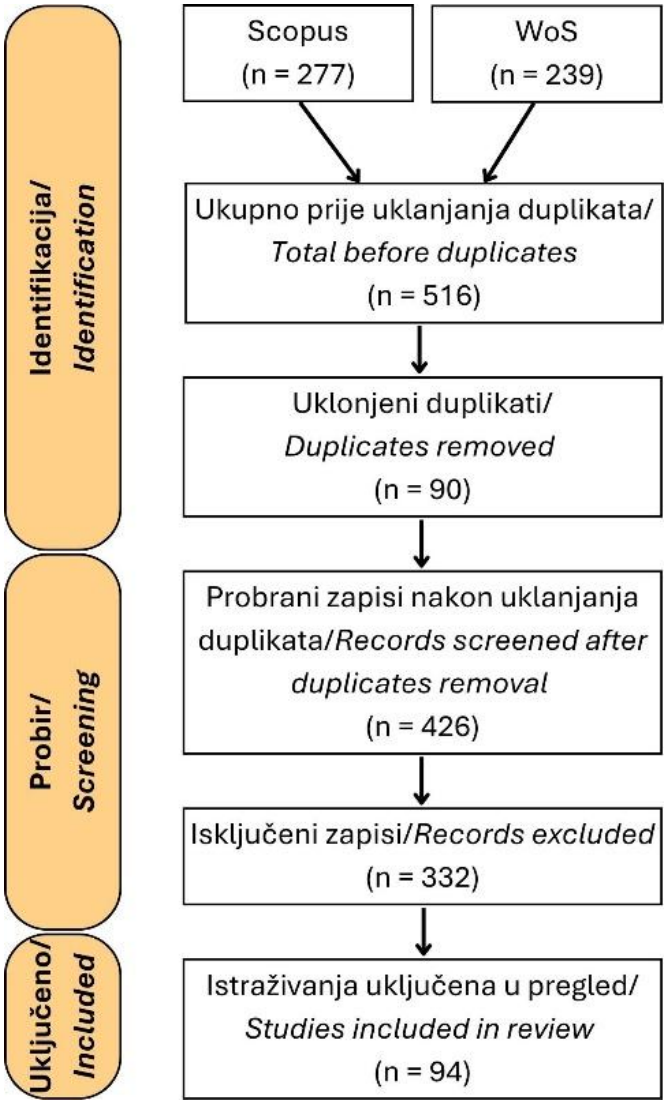
MATERIALS AND METHODS

A systematic literature review, based on the PRISMA guidelines, was conducted to identify the tourism climate indices used in tourism geography research (Figure 1). The review followed a three-stage process: identification, screening, and analysis. During the first stage, records were retrieved from Web of Science and Scopus, merged, and deduplicated, while publications clearly unrelated to the research focus were removed. During the second stage, titles and abstracts were assessed against the inclusion criteria, followed by full-text verification of index application and relevance to tourism geography. In the final analysis stage, the included studies were coded by the index applied, publication year, geographical and climatic context, tourism environment, research focus and methodological approach. The most frequently used indices, together with indices representing important methodological developments, were then compared according to their purpose, temporal resolution, climatic parameters, application, strengths, and limitations.

The identification phase aimed to collect relevant scientific publications applying tourism climate indices within the field of tourism geography. The review included journal articles and book chapters indexed in Web of Science and Scopus. No language restriction was applied, and publications were included regardless of language if they met the defined eligibility criteria. The literature search was based on searches of two major academic databases, Web of Science

(WoS) and Scopus, covering the period from January 1985 to 1 September 2025. The starting year was selected deliberately because Mieczkowski's (1985) study introduced the foundational Tourism Climate Index and marked the beginning of the combined TCI framework examined in this review. In the Web of Science database, the search was restricted to the categories Hospitality, Leisure, Sport & Tourism and Geography (including Geography, Physical). In Scopus, the search was limited to the Social Sciences subject area (specifically Geography, Planning and Development) and Business, Management and Accounting (specifically Tourism, Leisure, and Hospitality Management). In all cases, the keyword 'tourism climate index' was used as the primary search term. All records retrieved from both databases were exported and merged into a single dataset using Zotero. A deduplication process was conducted to remove duplicate records identified across the two databases, resulting in a dataset comprising only unique publications for further screening.

In the screening phase, the titles and abstracts of all identified studies were reviewed to assess their relevance. Studies were included if they applied and used tourism climate indices (TCIs) in their research and fell within the field of tourism geography. Publications that only mentioned the TCIs conceptually, without actual application in the analysis, or applied it in research outside the scope of tourism geography, were excluded. Full-text screening was then performed for the included records (n = 94) to confirm the application of TCIs and to extract relevant methodological details. For this review, TCIs were defined as composite or activity-specific indices explicitly developed to assess the climatic suitability of destinations or periods for tourism activities.



Slika 1. PRISMA dijagram tijeka odabira studija

Figure 1 *PRISMA flow diagram of the study selection process*

Izvor: izradila autorica prema PRISMA 2020 (Haddaway i sur., 2022) / *Source: created by the author based on PRISMA 2020 (Haddaway et al., 2022)*

In the analysis phase, the reviewed studies were systematically examined and coded across several predefined analytical categories, including the tourism climate index applied, publication year, temporal coverage, spatial scale and study area, tourism environment, Köppen climate class, research focus, methodological approach, and study type. Motivational and methodological categories were identified through repeated and systematic reading of abstracts and full texts, followed by thematic grouping of similar research objectives and methodological approaches. All TCIs identified in the selected studies were recorded and classified according to their conceptual type and application context. The most frequently applied indices were selected for detailed comparative analysis; however, indices representing important conceptual

shifts or methodological turning points in the evolution of tourism climate assessment (e.g., the Climate Index for Tourism) were also included, even when their frequency of application was lower. These indices were then analysed according to index type, purpose, calculation method (parameters), application, strengths, and limitations.

Following the methodological procedure described above, the results of the review are presented in several steps. First, the main types of climate indices relevant to tourism research are outlined to provide the conceptual background for the analysis. The review then synthesizes the development and application of the most frequently used tourism climate indices. Finally, it examines temporal and spatial research patterns, specific climatic and tourism-environment contexts, and the primary research focuses and methodological approaches identified in the literature.

RESULTS

Detailed analysis of TCIs

The development of tourism climate indices is closely linked to the attempt to translate complex climatic conditions into comparable measures of tourism suitability. The TCI introduced by Mieczkowski (1985) established the first widely used framework for such comparisons, but later research increasingly questioned its subjective weighting system, monthly temporal resolution, and limited sensitivity to different tourism activities and tourist preferences. These limitations encouraged the development of alternative and modified indices, including perception-based, activity-specific, regionally adapted, and higher-resolution approaches (de Freitas et al., 2008; Ma et al., 2020; Morgan et al., 2000; Scott et al., 2016; Yu et al., 2009). These developments provide the basis for comparing selected TCIs according to their purpose, data requirements, parameters, application context, strengths, and limitations.

The indices included in the detailed comparison were selected according to their frequency of use in the reviewed literature, their role in the methodological development of tourism climate assessment, and their relevance for illustrating different approaches to measuring climatic suitability for tourism. The selection therefore combines widely applied benchmark indices with examples of perception-based, activity-specific, and higher-resolution approaches. The TCI was included as the foundational and most frequently used index, while the BCI, CIT, MCIT, HCI, and CCI were selected because they represent later attempts to address some of its

limitations, particularly in relation to tourist preferences, specific tourism activities, temporal resolution, and contextual applicability.

Taken together, these indices show that TCI research did not develop through a simple replacement of older models by newer ones. Instead, the field has gradually diversified. General indices remain useful for broad spatial and temporal comparisons; while newer approaches attempt to capture more specific tourism environments, tourist perceptions, and short-term weather variability. This development suggests that the main direction of TCI research is toward more differentiated and context-sensitive assessments, although problems of empirical validation, data availability, and transferability across destinations remain important limitations (Table 2).

Tablica 2. Detaljna analiza odabranih TKI-ja
Table 2 *Detailed analysis of selected TCIs*

Indeks / *Index*	**Svrha / Purpose**	**Izračun / *Calculation***		**Primjena / *Application***	**Prednosti / *Strengths***	**Ograničenja / *Limitations***
		Podaci / *Data*	**Parametri / *Parameters***			
Turistički klimatski indeks / *Tourism Climate Index* (TCI)	Procijeniti ukupnu klimatsku pogodnost za opći turizam / *To evaluate overall climatic suitability for general tourism*	Mjesečni podaci / *Monthly data*	Temperatura (maks., srednja), vlažnost (min., relativna), sijanje sunca, vjetar, oborine / *Temp. (max, mean), humidity (min, relative), sunshine, wind, precipitation* $TCI = 2(4CID + CIA + 2R + 2S + W)$	Razgledavanje / *Sightseeing*	Jednostavan; široko primjenjiv; koristi se globalno / *Simple; broad applicability; global use*	Subjektivan; ne uzima u obzir ekstremne uvjete; neprecizan za pojedine aktivnosti / *Subjective; does not account for extreme conditions; inaccurate for specific activities*
Klimatski indeks za plaže / *Beach Climate Index* (BCI)	Procijeniti i rangirati plaže s pomoću vrednovanja obilježja plaže ponderiranog prema korisnicima i njihovim preferencijama / *To assess and*	Dnevni podaci / *Daily data*	Toplinski osjet, sijanje sunca, vjetar, oborine, temperatura mora (posebno) / *Thermal sensation, sunshine, wind, precipitation, sea temperature (specifically)*	Pasivni boravak na plaži / *Passive beach stay*	Usmjeren na preferencije korisnika; primjenjiv u marketingu plaža / *Focused on user preferences; applicable to*	Poteškoće s uzorkovanjem; nema trajanja oborina; nije empirijski validiran / *Sampling difficulties; lack of precipitation duration; not empirically validated*

	rank beaches using a user-weighted, preference-based evaluation of beach attributes				*beach marketing*	
Klimatski indeks za turizam / Climate *Index for Tourism* (CIT)	Razviti teorijski utemeljen i praktično primjenjiv klimatski indeks za turizam / *To develop a theoretically grounded and practically applicable climate index for tourism*	Dnevni podaci / *Daily data*	Toplinski, estetski i fizički aspekti / *Thermal, aesthetic, and physical aspects* Temperatura, oborine, vjetar, naoblaka, ekstremni uvjeti / *Temperature, precipitation, wind, cloud cover, extreme conditions* $CIT = f[(T, A) * P]$	3S turizam / *3S tourism*	Teorijski utemeljen; uključuje biometeorologiju / *Theoretically grounded; includes biometeorology*	Ograničena validacija; ne uključuje preferencije / *Limited empirical validation; does not explicitly account for tourist preferences*
Modificirani klimatski indeks za turizam/ *Modified Climate Index for Tourism* (MCIT)	Razviti i testirati indeks koji povezuje stvarna iskustva turista s multivarijatnim klimatskim podacima visoke rezolucije / *To develop and test a quantitative tool that links tourists' actual experiences with high-resolution, multivariate climate data*	Satni podaci / *Hourly data*	Osjetna temperatura (temperatura, vlažnost, vjetar), oborine, vjetar, vidljivost, ekstremni uvjeti / *Perceived temperature (temperature, humidity, wind), precipitation, wind, visibility, extreme conditions* $MCIT = MCIT_{PT} * MCIT_{W} * MCIT_{V} * MCIT_{SW}$	Pojedine turističke aktivnosti / *Specific tourist activities*	Visoka vremenska rezolucija; obuhvaća detaljne vremenske promjene / *High temporal resolution; captures detailed weather variations*	Zanemaruje preferencije turista; dodane varijable bez validacije / *Ignores tourist preferences, added variables without validation*
Klimatski indeks za odmor / *Holiday Climate*	Izraditi indeks temeljen na preferencijama koji poboljšava TCI procjenu	Dnevni podaci / *Daily data*	Temperatura, oborine, vlažnost, vjetar, sijanje sunca, ekstremni uvjeti / *Temperature,*	Turizam odmora (grad i plaža) / *Holiday*	Fleksibilan; obuhvaća ekstremne uvjete; nudi više verzija	Može precijeniti pogodnost ako povoljni uvjeti prikriju ekstreme; temelji se na općim preferencijama turista;

***Index* (HCI)**	klimatske pogodnosti za turizam / *To create a preference-based index improving TCI's assessment of climatic suitability for tourism*		*precipitation, humidity, wind, sunshine, extreme conditions* HCI: Urban = 4(TC) + 2(A) + (3 (P) + W) HCI: Beach = 2(TC) + 4(A) + (3(P) + W)	*tourism (city and beach)*	za različite turističke kontekste / *Flexible; includes extreme conditions; offers multiple versions for different tourism contexts*	zahtijeva mnogo podataka / *Can overestimate suitability if favorable conditions mask extremes; based on general tourist preferences; high data requirements*
Klimatski indeks za kampiranje / *Camping Climate Index* (CCI)	Procijeniti sezonsku klimatsku pogodnost za kampiranje određivanjem broja optimalnih dana za kampiranje / *To assess seasonal climatic suitability for camping tourism by quantifying optimal camping days*	Dnevni podaci / *Daily data*	Toplinska ugoda, sijanje sunca, Tmin, Tmax, oborine, vjetar / *Thermal Comfort, sunshine, Tmin, Tmax, precipitation, wind* $CCI = \begin{cases} \min(CCI, 3) \\ or\ P > \end{cases}$	Kampiranje / *Camping*	Specifičan za aktivnost; obuhvaća sezonalnost; uključuje ekstremne uvjete / *Activity-specific; captures seasonality; includes extreme conditions*	Ne uključuje preferencije turista; pojednostavljena logika ugode; ograničena regionalna prenosivost / *No tourist preferences, simplified comfort logic, limited regional transferability*

Note: R – precipitation; S – sunshine; W – wind; CID – daytime comfort index; CIA – daily comfort index; T – thermal; A – aesthetic; P – physical; TC – thermal comfort; MCITPT – perceived temperature; MCITV - visibility; MCITW – wind; MCITSW – significant weather events; Tmin – minimum temperature; Tmax – maximum temperature.

Source: de Freitas et al. (2008); Ma et al. (2020); Mieczkowski (1985); Morgan et al. (2000); Scott et al. (2016); Yu et al. (2009)

Results of the systematic review

Based on a systematic review of 94 tourism-geography studies, this research identifies the continued dominance of the original TCI and other established general indices, alongside a growing diversification of modified and context-specific approaches. The TCI remains the most

frequently applied index, used in nearly half of all reviewed studies (47.7%), confirming its centrality in tourism and climate research since it was proposed in 1985. More recent developments are reflected in the notable use of the HCI (16.8%), adjusted or modified versions of the TCI (10.3%), and the Camping Climate Index (CCI) (6.5%), which aim to better capture tourist perceptions and activity-specific conditions. Less frequently applied indices include comfort-oriented measures such as the Comprehensive Comfort Index (Dong & Xia, 2021), Tourist Climate Comfort Index (TCCI) (Lukić et al., 2021; Marić Stanković et al., 2022), Climate Comfort Index (CI) (Espín Sánchez & Olcina, 2025; Rong et al., 2024), as well as Climate Index for Tourism (CIT) (Cardell et al., 2023; Tatulli & Pezzoli, 2025). There was also a range of highly specialized indices (e.g., coastal, winter sports, summer comfort, inland tourism, and microclimate-based indices); but each was observed only sporadically; in some cases, only once (Gao et al., 2022; López, 2019; Sacchini et al., 2012; Xie et al., 2024).

Tablica 3. Primjena TKI-ja u istraživanjima turističke geografije (1985.–2025.)

Table 3 *Application of TCIs in Tourism Geography Research (1985–2025)*

Indeks / *Index*	**Reference / *References***
CCI	Fitchett & Meyer, 2023; Ma et al., 2020; Ma et al., 2021a; Ma et al., 2021b; Ma et al., 2023; Mnguni & Fitchett, 2025a
CI	Espín Sánchez & Olcina, 2025; Rong et al., 2024
CIT	Cardell et al., 2023; Tatulli & Pezzoli, 2025
Sveobuhvatni indeks ugode / *Comprehensive Comfort Index*	Dong & Xia, 2021
CTCI	Gao et al., 2022
FAI–NMCI	Yang et al., 2022
HCI	Bausch et al., 2021; Cárdenas-Hernández et al., 2025; Coles et al., 2025; Craig, 2024; Craig, 2025; Díaz-Poso et al., 2023; Jong et al., 2023; Jong et al., 2024; Ma & Craig, 2024; Ma et al., 2023; Magyari-Sáska & Magyari-Sáska, 2023; Magyari-Sáska, 2025; Mazzarano et al., 2025; Mnguni & Fitchett, 2025b; Tanana, 2022; Tatulli & Pezzoli, 2025; Turp et al., 2024; Yu et al., 2022; Yu et al., 2023
Klimatski indeks za sportove na ledu i snijegu / *Ice and Snow Sports Climate Index*	Xie et al., 2024
ICTI	López, 2019; López & García, 2018

Modificirani HCI / *Modified HCI*	Matthews et al., 2021
Modificirani TCI / *Modified TCI*	Bae & Nam, 2020; Cárdenas-Hernández et al., 2025; Cárdenas-Hernández et al., 2026; Espín Sánchez & Olcina, 2025; Kovács & Király, 2021; Li et al., 2023; López, 2023; Roson & Sartori, 2014; Yu et al., 2009; Zhong et al., 2019
RCI	Li et al., 2018
SCI & WTI	Sacchini et al., 2012
TCCI	Čegar et al., 2023; Lukić et al., 2021; Marić Stanković et al., 2022
TCI	Almushayt, 2025; Alonso-Pérez et al., 2021; Amelung & Nicholls, 2014; Amelung et al., 2007; Amelung & Viner, 2006; Aygün Oğur & Baycan, 2023; Aygün Oğur & Baycan, 2024; Baños-Pino et al., 2023; Burrai et al., 2025; Cárdenas-Hernández et al., 2025; Cheng & Zhong, 2019; Cilek, 2022; Derkowska & Araźny, 2022; Dong & Xia, 2021; El-Masry et al., 2022; Eryiğit et al., 2010; Fitchett, 2021; Fitchett & Hoogendoorn, 2019; Fitchett et al., 2016; Fitchett et al., 2017; Fitchett & Roshan, 2020; Hodges et al., 2010; Jong et al., 2023; Jong et al., 2024; Lukić et al., 2021; Ma et al., 2023; Madden et al., 2023; Mahmoud et al., 2019; Mieczkowski, 1985; Mihăilă & Bistricean, 2018; Mihăilă et al., 2018; Mnguni & Fitchett, 2025b; Moore, 2010; Mushawemhuka et al., 2020; Nicholls & Amelung, 2008; Nicholls & Amelung, 2015; Noome & Fitchett, 2019; Noome & Fitchett, 2022; Olya, 2019; Olya & Alipour, 2015; Om et al., 2018; Pashkov et al., 2023; Qiang, 2020; Shahzad et al., 2021; Siedlecki, 2015; Soler et al., 2020; Tanana, 2022; Tanana et al., 2021; Tanana et al., 2021a; Tanana et al., 2021b; Yu et al., 2023
TCSI	Tang et al., 2012
TCI općenito / *TCIs in general*	Hoogendoorn & Fitchett, 2022; Lopes et al., 2021; Rosselló-Nadal, 2014; Wang & Park, 2026

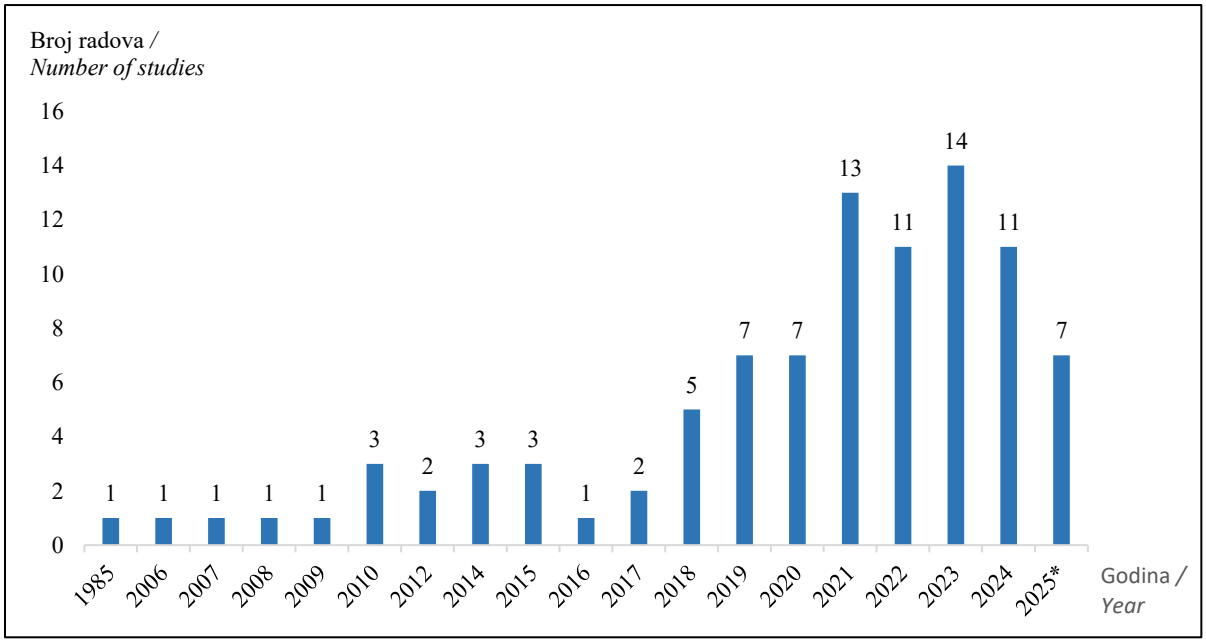
Note: CCI – Camping Climate Index; CI – Climate Comfort Index; CIT – Climate Index for Tourism, CTCI – Coastal Tourism Climate Index; FAI–NMCI – Fresh air–natural microclimate comfort index; HCI – Holiday Climate Index; ICTI – Índice Climático-Turístico de Interior (Inland Tourism Climate Index); RCI – Relative Climate Index; SCI – Summer Tourism Comfort Index; TCCI – Tourist Climate Comfort Index; TCI – Tourism Climate Index; TCSI – Tourism Climate Suitability Index; WTI – Winter Tourism Mildness Index.

Table 3 shows that the application of TCIs in tourism-geographical research is highly uneven. The original TCI remains the most frequently used index, while most other indices appear in a much smaller number of studies. This suggests that the field is still organised around a dominant reference index, with specialised and modified indices used mainly in more specific tourism, climatic, or regional contexts. The reviewed studies were published across tourism,

geography, sustainability, environmental, and regional journals, confirming the interdisciplinary character of TCI research.

Temporal and spatial patterns

An analysis of publication frequency in tourism geography reveals a clear temporal concentration of tourism climate index research in the period after 2020. While only one contribution appeared before 2000 (Mieczkowski, 1985) and relatively limited attention was observed during the 2000-2009 period (4.3%), research activity started picking up between 2010 and 2015 (11.7%) and more noticeably during 2016-2019 (16%). The most significant expansion, however, occurred during the 2020-2025 period, which accounts for most of identified studies (67%), representing a clear increase of research interest in TCIs within tourism geography. Annual publication data further confirm this trend, with particularly high outputs recorded in 2021, 2022, 2023, and 2024 (Fig. 2).



Slika 2. Broj studija koje su u istraživanju uključivale TKI-je od 1985. do 2025. (*do 1. rujna 2025.)

Figure 2 *Number of studies that included TCIs in their research from 1985 to 2025 (*until September 1, 2025)*

Izvor: izradila autorica / *Source: author's own work*

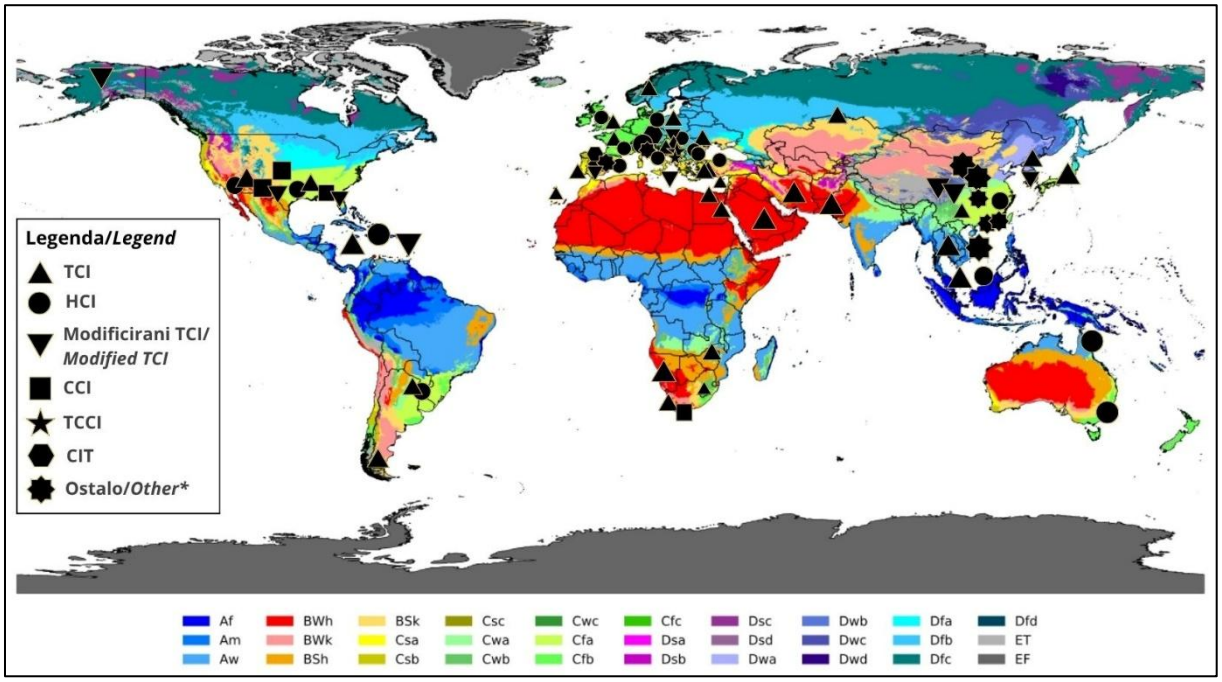
A clear temporal relationship is evident between publication years and the type of TCIs applied. Early studies (1980s-early 2000s) relied almost exclusively on the TCI, whereas more recent research demonstrates increasing methodological diversification, including modified, climate-based, and activity-specific indices. Since 2020, multi-index approaches combining TCI, HCI, and other specialized indices have become increasingly prevalent, reflecting both methodological development and the growing relevance of climate change adaptation in tourism research.

Regarding the spatial distribution of TCIs in tourism geography research, studies show a globally widespread application across all major world regions, with particularly strong representation in Europe, Asia, and Africa. They have been applied in a wide range of national and regional contexts, covering diverse climatic and tourism settings, as well as in specific macro-regions such as alpine areas, the Mediterranean, the Caribbean, and other comparable tourism regions. Overall, this distribution demonstrates the broad applicability of TCIs across different climatic zones, tourism types, and spatial scales, from local to global assessments. However, several large geographic areas, particularly within the Indian and Pacific Oceans, remain underrepresented in TCI research.

When examining the distribution of TCIs according to Köppen climate classes (A–E) (Köppen, 1931), most empirical applications and tests have focused on temperate climates (class C), followed by continental climates (class D), arid climates (class B), and tropical climates (class A), as seen in Figure 3. The TCI remains the most widely used indicator across all climate classes. This is particularly evident in temperate and arid zones, where it serves as a standard tool for assessing seasonality and overall destination climate attractiveness. In tropical climates (class A), modified versions of TCI and HCI are commonly applied, reflecting the limitations of original indices under high humidity, low seasonal temperature variability, and frequent precipitation. While the TCI dominates in arid climates (class B), TCSI and ICTI are also used. In temperate climates (class C), the greatest methodological diversity is observed. Alongside TCI, HCI is frequently used, and specialised indices such as CIT, ICTI, CTCI are applied, especially in destinations with coastal, urban, or mixed tourism types. Finally, in colder climates (class D), indices are often adapted for seasonal or activity-specific purposes, such as winter sports or combined summer-winter indicators (SCI and WTI), reflecting dominant tourism activities.

Furthermore, an analysis of the relationship between TCIs and the type of tourism environment reveals clear patterns in their application, with the indices most frequently applied

in coastal destinations (18.2%), followed by urban areas (15.6%), mountain regions (10.4%), outdoor recreation settings (9.1%), and islands (7.8%). While camping (6.5%) and cultural destinations (5.2%) are moderately represented, nature-based tourism (3.9%) and winter tourism (2.6%) appear less frequently. Other environments – including deserts, inland areas, rural, semi-arid, and spa destinations – are explored in only a few cases. Overall, the TCI is the most widely applied index across diverse destinations, including coastal, island, mountain, rural, resort, and desert areas. The HCI is often used alongside TCI in coastal, urban, and outdoor recreation contexts where thermal comfort is important. Modified and composite indices are typically applied in climate-sensitive regions, such as the Mediterranean region, islands, and high-altitude destinations. The CCI is primarily used for camping and nature-based tourism, reflecting its suitability for low-intensity, outdoor-oriented experiences. Specialized indices (e.g., TCSI, SCI, WTI, TCCI, ICTI) are applied in highly specific contexts such as mountain, winter, spa, and inland tourism. Overall, these patterns show a strong correlation between the type of environment and the choice of TCIs, highlighting both the general applicability of some indices and the necessity of specialized measures in highly climate-dependent or hybrid tourism contexts.



Slika 3. Prostorna raspodjela TKI-ja korištenih u znanstvenim studijama (1985.–2025.) na karti Köppen–Geigerove klimatske klasifikacije (1991.–2020.)

Figure 3 *Spatial distribution of TCIs used in scientific studies (1985–2025) on the Köppen-Geiger climate classification map (1991–2020)*

Crni simboli označavaju turistički klimatski indeks primijenjen na svakoj lokaciji istraživanja. Obojeni pravokutnici i troslovne oznake pri dnu prikazuju podrazrede Köppen–Geigerove klimatske klasifikacije korištene na osnovnoj karti. / *The black symbols identify the tourism climate index applied at each study location. The coloured rectangles and three-letter codes at the bottom represent the Köppen-Geiger climate subclasses used in the underlying map.*

*Ostalo: CI, ICTI, CTCI, FAI-NMCI, prilagođeni HCI / *modified HCI*, Klimatski indeks sportova na ledu i snijegu / *Ice and Snow Sports Climate Index*, RCI, SCI, WTI, TCSI

Izvor: izradila autorica na temelju kartografske podloge Beck i sur. (2023). / *Source: created by the author using the cartographic base map from Beck et al. (2023)*

Research focus and methodological approaches

The reviewed studies were grouped according to two analytical dimensions: their primary research focus and their methodological approach. Research focus refers to the main purpose of the study, such as assessing climatic suitability, developing or validating an index, analysing climate change impacts, or applying TCIs in tourism demand, management, or planning contexts. Methodological approach refers to the way in which TCIs were applied, modified, compared, modelled, or projected in the reviewed studies. Based on this classification, five main research focus categories were identified: (A) assessment of climatic suitability for tourism, (B) methodology development and validation, (C) investigation of climate change impacts, (D) economic, planning, and management applications, and (E) literature reviews and identification of knowledge gaps. These categories often overlap as many studies address multiple research objectives. The reviewed studies were most frequently focused on assessing climatic suitability for tourism (36.2%), which confirms that TCIs are still primarily used to identify favourable or unfavourable seasons, destinations, and tourism activities under existing climatic conditions. Methodological development and validation (21.3%) and climate change impact analysis (21.3%) form the second most important group of research focuses, indicating that a substantial part of the literature is concerned with improving index applicability and assessing future changes in tourism comfort, seasonality, and demand. A similar share of studies (20.2%) connects TCIs with economic, planning, or management applications, while literature reviews and knowledge gap studies remain marginal (1.1%). This distribution suggests that TCI research is still strongly grounded in climatic suitability assessment but is increasingly linked to methodological refinement and applications in the context of climate change.

Methodologically, TCIs research can be grouped into five categories: (A) classical index calculation/application, (B) adapted/modified or comparative indices, (C) statistical and econometric modelling, (D) forecasting and projections, and (E) conceptual, bibliometric, or tool development studies. The largest share of studies applies classical indices, most often the TCI, to assess the climatic suitability of destinations or seasons (37.4%). Adapted, modified or comparative approaches account for 23.4% of studies, while forecasting and projection-based

studies represent 16.8%. Statistical and econometric modelling is used in 15.9% of studies, mainly to connect climate indices with tourism demand, behaviour or seasonality. Conceptual, bibliometric and tool-oriented studies are less common (6.5%). This distribution indicates that descriptive index application remains the dominant methodological pattern, while comparative, model-based and projection-oriented approaches represent smaller but increasingly relevant directions within the reviewed literature.

To summarize these patterns over time, Table 4 presents the dominant research focuses and methodological approaches across five publication periods. The table is intended as a synthesis of the temporal development of TCI research, rather than as a separate chronological description.

Tablica 4. Razvoj istraživačkih fokusa i metodologija u istraživanjima TKI-ja u turističkoj geografiji (1985.–2025.)

Table 4 *Evolution of Motivations and Methodologies in Tourism Geography Research of TCIs (1985–2025)*

Razdoblje / *Period*	**Fokus istraživanja / *Research focus***	**Metodološki pristup / *Methodological approach***
1985.–2010.	Temeljni ciljevi: razvoj sustavnih indeksa (TCI), kvantificiranje klime u odnosu na druge pokretače turizma, procjena učinaka klimatskih promjena / *Foundational goals: developing systematic indices (TCI), quantifying climate vs. other tourism drivers, assessing impacts of climate change*	Razvoj i primjena TCI-ja; osnovni izračun indeksa; kartiranje klime / *Development and application of TCI; basic index calculation; climate mapping*
2011.–2015.	Regionalne i sektorske primjene: procjena klimatske pogodnosti za pojedine destinacije, promicanje održivog turizma, razumijevanje ekonomskih učinaka klime na turističke tokove / *Regional and sectoral applications: assessing climate suitability for specific destinations, promoting sustainable tourism, understanding economic impacts of climate on tourism flows*	Regionalne prilagodbe; modificirani indeksi; rana primjena regionalnih klimatskih modela / *Regional adaptations; modified indices; early use of regional climate models*
2016.–2019.	Povezivanje klimatskih indeksa s turističkom potražnjom i sezonalnošću; primjena modificiranih/složenih indeksa; rješavanje nedostataka u podacima / *Linking climate indices with tourism demand and seasonality; using modified/composite indices; addressing data gaps*	Statističko/ekonometrijsko modeliranje; modificirani/složeni indeksi; usporedne studije / *Statistical/econometric modelling; modified/composite indices; Comparative studies*

2020.–2023.	Višedimenzionalni i prediktivni ciljevi: modeliranje odgovora turizma na klimu, procjena klimatske ugode za različite vrste turizma, uključivanje socioekonomskih varijabli, potpora prilagodbi / *Multi-dimensional and predictive aims: modelling tourism responses to climate, assessing climate comfort for diverse tourism types, integrating socio-economic variables, supporting adaptation*	Složeniji indeksi (CCI, CIT, varijante HCI-ja); veliki podaci, strojno učenje, GIS; hibridni pristupi / *Complex indices (CCI, CIT, HCI variants); big data, machine learning, GIS; hybrid approaches*
2024.–2025.	Cjeloviti, integrirani i primijenjeni ciljevi: usporedbe više indeksa, prognoziranje prema scenarijima klimatskih promjena, potpora politikama i planiranju / *Holistic, integrative, and applied objectives: multi-index comparisons, forecasting under climate change scenarios, supporting policy and planning*	Usporedbe više indeksa; uključivanje socioekonomskih čimbenika; projekcije prema klimatskim scenarijima / *Multi-index comparisons; socio-economic integration; projections under climate scenarios*

Izvor / Source: Izradila autorica / Author's own work

Table 4 shows that the temporal development of TCI research is marked by a gradual expansion from descriptive suitability assessment toward more comparative, model-based, and future-oriented applications. However, classical index application remains an important methodological reference throughout the reviewed period.

DISCUSSION

The findings of this review indicate that tourism climate indices within tourism geography have evolved from relatively simple composite measures toward more diversified and context-sensitive tools. However, this development did not occur as a complete replacement of older approaches. Instead, the results suggest a simultaneous continuity and diversification of the field: the TCI remains the main reference index, while newer and modified indices are increasingly used in specific tourism environments, climatic contexts, and research designs.

The continued dominance and popularity of the TCI are largely attributable to its methodological simplicity, its reliance on widely available climate data, and its suitability to broad spatial and temporal comparison (Amelung et al., 2007; Mieczkowski, 1985; Perch-Nielsen et al., 2010). From a geographical perspective, this explains why the TCI remains attractive for studies that compare destinations, regions, seasons, or long-term climate suitability patterns. However, its persistence also reflects certain structural limitations of the field, particularly data availability, path dependency, and the lack of equally established

alternatives across different tourism environments. Newer indices, although methodologically more refined, often require higher-resolution data, additional validation, or adaptation to specific tourism contexts, which can limit their wider application. As a result, the TCI is often applied not necessarily because it is conceptually optimal, but because it remains the most transferable and widely recognized tool in tourism-climate research.

Critics of the TCI focus on its subjective weighting scheme, monthly temporal resolution, and limited empirical validation against actual tourist preferences and behaviour (de Freitas et al., 2008; Scott et al., 2016). At the same time, the increasing use of HCI, modified TCI versions, CCI, and other specialized indices shows that researchers are responding to the limitations of general indices. The reviewed literature indicates that the main methodological pressure on TCI research comes from the need to better capture tourist perception, activity-specific climatic requirements, shorter temporal variability, and regional climatic differences. This is particularly visible in studies dealing with beach tourism, camping, urban tourism, outdoor recreation, and climate change scenarios, where general monthly assessments are often insufficient to represent actual tourism-climate interactions (Ma et al., 2020; Morgan et al., 2000; Scott et al., 2016; Yu et al., 2009).

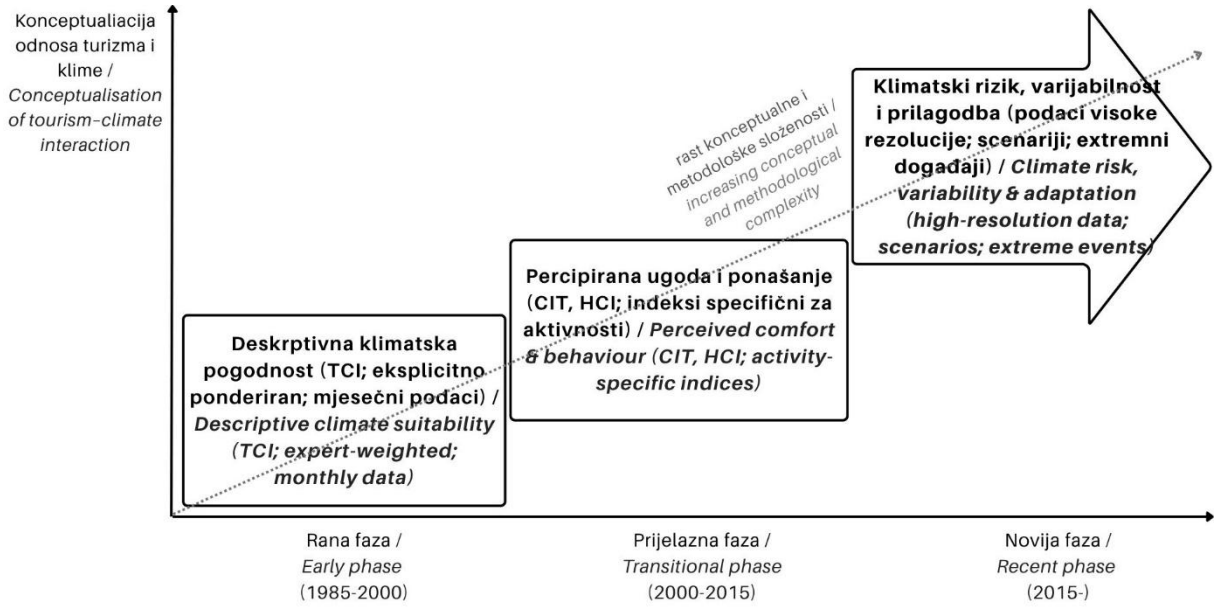
The spatial distribution of studies has important implications for tourism geography. The concentration of research in temperate and continental climates, particularly in European and Asian contexts, indicates that the empirical basis of TCIs research remains geographically uneven. This matters because several climate-sensitive contexts, including tropical, island, arid, mountain, camping, and nature-based tourism environments, are less represented in the reviewed literature. Consequently, many existing indices were tested primarily in settings with relatively clear seasonality, while their transferability to areas with high humidity, limited thermal seasonality, frequent extreme weather events, or different tourism functions remains less certain. Research is often concentrated in regions with a longer tradition of tourism-climate studies, better access to long-term meteorological data, and stronger research capacity. Temperate destinations also have clearer seasonal differences, which makes changes in climatic suitability easier to identify using established indices. In contrast, tropical and island destinations may have more limited weather-station coverage, greater spatial variability, high humidity, and more frequent extreme weather events, which are not always well captured by conventional indices. These factors may partly explain both the lower number of studies and the more limited applicability of indices originally developed for temperate regions.

Several studies in the reviewed dataset examine the same or overlapping geographical contexts, including South Africa, the Caribbean, China, Turkey, Spain, and Argentina, with more specific overlaps in Madrid, Granada, and Tibet/the Tibetan Plateau. In Madrid, the Interior Climate-Tourism Index (ICTI) was applied in both López & García (2018) and López (2019), with the studies showing a consistent seasonal pattern, while the latter additionally demonstrated shifts in climatic suitability under future climate scenarios. A similar longitudinal perspective is evident in Tibet, where Zhong et al. (2019) found an overall increase in tourism-climate suitability, although with contrasting regional trends, while Li et al. (2023) likewise reported increasing annual and monthly TCI trends across the broader Tibetan Plateau. Although these studies are not strict replications due to differences in spatial extent, datasets, and index formulations, they show that TCIs can capture both consistent spatial-seasonal patterns and changes in tourism-climate suitability over time.

The analysis of tourism environments further shows that climatic suitability cannot be interpreted uniformly across all forms of tourism. Coastal and urban destinations are among the most frequently analysed environments, reflecting both their high tourism intensity and their sensitivity to thermal comfort, heat stress, and seasonal demand patterns. However, suitable climatic conditions differ between urban sightseeing, beach tourism, camping, winter tourism, and nature-based recreation. This suggests that the choice of index should be more explicitly linked to the functional characteristics of the analysed tourism environment, which is consistent with earlier arguments that tourism climate assessment should account for different dimensions of weather conditions and activity-specific requirements (Becken & Wilson, 2013; de Freitas et al., 2008; Rutty & Scott, 2014; Scott & Lemieux, 2010).

The methodological results show that descriptive index application remains the dominant approach, while comparative, modified, model-based, and projection-oriented studies represent smaller but increasingly relevant directions. This pattern suggests that TCIs are still most used to classify present climatic suitability, but their role is gradually expanding toward the analysis of tourism demand, seasonality, and projected climate-related changes. This is particularly visible in post-2020 research, where TCIs are increasingly used in relation to climate change impacts, adaptation, and tourism resilience (Gössling & Scott, 2025; IPCC, 2021). In this context, they are applied not only to describe present climatic suitability, but also to assess possible future shifts in seasonality, destination attractiveness, and the vulnerability of climate-sensitive destinations (Amelung et al., 2007; Moreno & Amelung, 2009). This methodological development is summarized in Figure 4, which presents the evolution of TCI research as a

timeline rather than as a conceptual model. The figure illustrates the gradual expansion from general index application toward modified, comparative, model-based, and climate-responsive approaches.



Slika 4. Vremenska crta metodološkog razvoja istraživanja turističkih klimatskih indeksa

Figure 4 *Timeline of methodological development in tourism climate index research*

Izvor: izradila autorica / *Source: author's own work*

Despite methodological progress, several limitations remain. Many TCIs still rely primarily on climatic variables and assumed thresholds, while empirical validation with observed tourist behaviour, visitation patterns, expenditure, or tourist preferences remains limited. Since TCIs are often not tested against real tourist behaviour, they are less reliable for explaining destination attractiveness, visitor flows, or tourism adaptation. Previous research showed that the influence of weather and climate on tourism demand varies by activity type, market segment, and destination context, which confirms the need for stronger behavioural validation of TCIs (Baños-Pino et al., 2023; Becken & Wilson, 2013; Rutty & Scott, 2014; Zhou et al., 2024). In addition, socio-economic and destination-specific factors are still insufficiently integrated into many index applications, although they strongly influence how climatic conditions are experienced and managed in tourism destinations.

For future research in tourism geography, the main challenge is not simply to develop more indices, but to improve the connection between climatic suitability, spatial context, and tourism

behaviour. Future studies should pay greater attention to underrepresented climatic regions and tourism environments, particularly those where existing indices may not be directly transferable. They should also strengthen the empirical validation of TCIs by linking index values with visitor numbers, tourist preferences, activity patterns, and destination characteristics. Such an approach would make TCIs more useful for analysing spatial differences in tourism climate resources, seasonality, and climate change impacts, while also reducing reliance on a single universal index. Therefore, the future relevance of TCIs will depend on their ability to become more empirically grounded, spatially sensitive, and adaptable to different tourism contexts.

CONCLUSION

This review systematically synthesized the development and application of tourism climate indices within tourism-geographical research between 1985 and 2025. Based on 94 peer-reviewed studies, the analysis showed that TCI research remains strongly centred in the original Tourism Climate Index, while also becoming more methodologically diverse through modified, perception-based, activity-specific, and scenario-oriented approaches. The findings indicate that TCIs are still primarily used to assess climatic suitability for tourism, but their application has expanded toward the analysis of seasonality, climate change impacts, and destination-specific climatic conditions. From a geographical perspective, the review also revealed uneven spatial, climatic, and tourism-environment coverage, with stronger attention given to temperate climates, coastal destinations, and urban areas, while tropical, island, nature-based, and other climate-sensitive contexts remain less represented. Overall, the study confirms that TCIs remain important tools for analysing tourism-climate relations, but their value depends on how well they reflect spatial context, tourism activity, and actual tourist behaviour.

The review has several limitations. The analysis was restricted to publications indexed in Web of Science and Scopus, which may have excluded relevant studies available through other databases, non-indexed books or chapters, conference proceedings, and grey literature. In addition, using ‘tourism climate index’ as the primary search term may have excluded tourism-climate studies that applied relevant composite, activity-specific, or perception-based indices without explicitly using this term in their title, abstract, or keywords. The classification of research focus, methodological approach, tourism environment, and climatic context also involved interpretative decisions, particularly in studies with overlapping aims or mixed

methodological designs. Finally, the review focused on TCIs used within tourism-geographical research and therefore did not include broader bioclimatic or thermal comfort indices unless they were directly applied in a tourism-specific framework.

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Appendix A

Abbreviations

BCI - Beach Climate Index
CCI - Camping Climate Index
CI - Climate Comfort Index
CIT - Climate Index for Tourism
CTCI - Coastal Tourism Climate Index
FAI–NMCI - Fresh Air–Natural Microclimate Comfort Index
HCI - Holiday Climate Index
ICTI - Índice Climático-Turístico de Interior
MCIT - Modified Climate Index for Tourism
RCI - Relative Climate Index
SCI - Summer Tourism Comfort Index
TCCI - Tourist Climate Comfort Index
TCI - Tourism Climate Index
TCIs - tourism climate indices
TCSI - Tourism Climate Suitability Index
WTI - Winter Tourism Mildness Index

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