

Assessment of Spatio-temporal Climate Suitability for Outdoor Tourism Using the Enhanced Tourism Climate Index in the Black Sea Coastal Region

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Abstract: The connection between tourism and weather conditions is undeniable; however, a comprehensive assessment of the tourism climate along the Black Sea coast is still limited. This article aims to address the research gap concerning the accurate assessment of how weather conditions influence the suitability of outdoor tourism within the Black Sea region. In this regard, the Enhanced Tourism Climate Index, a dynamic adaptation of the original index proposed by Mieczkowski, was used as a foundational tool. This index was calculated by using daily and sub-daily weather data collected in nine coastal meteorological stations across four riparian countries. The main findings are: i. the climate conditions in the Black Sea region are generally suitable for outdoor tourism for about 61% days per year; ii. Suitable conditions are dominant from the first decade of April to the first decade of November; iii. Locations with a higher frequency of heavy-precipitation days lead to lower Enhanced Tourism Climate Index scores and fewer excellent/ideal conditions. These results could serve as a useful tool for tour operators and decision-makers in the tourism sector to diversify their services and increase tourist arrivals and overnight stays in the non-peak season.

1. Introduction

Tourism climatology studies offer an opportunity to enhance information dissemination on the most suitable periods for holidays and travel, benefiting both policymakers and tourism operators (Alonso-Pérez et al., 2021). The relevance of such research was underlined by the suggestive results of a survey carried out by the Caribbean Tourism Organization. It indicated that 96% of tourism planners in that region were highly interested in obtaining accurate information that could provide insights into how tourists are influenced by climate (Rutty et al., 2020). Understanding bioclimatic resources becomes crucial for stakeholders within the tourist destination. They are considered essential for informing tourists, efficient resort planning and construction, expanding the location, developing infrastructure, marketing and branding the destination, and mitigating adverse weather-related effects on tourism (Scott et al., 2007; Tzenkova et al., 2007; Katerusha and Matzarakis, 2015).

Tourism is one of the industries that experienced spectacular growth in recent decades, before the onset of the SARS-CoV-2 pandemic, and has rapidly recovered since then (UNWTO, 2023). With the increasing importance of the tourism sector in national economies, international tourism is often promoted by governments and development organisations as a key contributor to achieving the Sustainable Development Goals, particularly in poverty eradication, gender equality, and environmental sustainability (UNWTO and UNDP, 2017). It is, at the same time, a sector highly dependent on the natural environment, with a high sensitivity to the influence of climate change, especially in the context of global warming (Gössling and Hall, 2006; Amelung et al., 2007; Liana et al., 2022; Wang et al., 2022). Climate change significantly impacts the tourism sector, particularly in coastal areas, as these regions are highly vulnerable to its effects, including extreme weather events and sea-level rise. It is essential for destination managers to understand this vulnerability and develop effective responses (Farid et al., 2016; Croitoru et al., 2024). Despite the well-known risks of climate change to tourism and its vulnerability, the sector still needs to prepare. Addressing weather conditions in the context of climate change is crucial for achieving sustainable development and advancing sustainable tourism research. Many studies focus excessively on destination-specific issues and overlook the broader environmental and social framework (Scott, 2011).

Given the growth of the tourism sector, on the one hand, and the consequences of climate change, on the other, the need for accurate information on favourable weather conditions at a particular destination becomes increasingly evident. Success and sustainability in the tourism industry largely depend on weather conditions. Scientific studies state that these conditions influence tourist demand, tourism spending, and tourist satisfaction by determining the suitability of the location, duration, and quality of tourist seasons (De Freitas, 2003; Scott et al., 2007; Tzenkova et al., 2007; Deniz, 2011; Jong et al., 2023; Ma et al., 2024).

Tourists require truthful, accurate, and up-to-date information about the weather at their chosen destinations. They take this knowledge into account when choosing a holiday destination, deciding on the length of their stay and the attractiveness of outdoor activities (Becken, 2005; Amelung et al., 2007; Tzenkova et al., 2007; Gössling et al., 2012). Weather conditions play a significant role in tourism destination selection, and regions experiencing unsuitable conditions will have limited possibilities for tourism development. Tourism develops in a region only to the extent that tourists perceive it as adequate, and the potential considerably reduces with the increase in climatic discomfort estimated at the destination (De Freitas, 2003; Katerusha and Matzarakis, 2015). To sum up, climate is an essential resource in the outdoor tourism industry, and, like other resources, it must be measured and evaluated (De Freitas, 2003). Studies regarding the relationship between climate and tourism have gained momentum in recent decades, both globally and regionally (Wang et al., 2022).

More than 200 climate indices are available to assess the suitability of weather/climate conditions for outdoor tourism (Matzarakis, 2007). Since tourists perceive the combined effect of all-weather variables, not each one separately, the importance of indices combining more variables to assess the perception of the combined effect is crucial. Tourists are also interested in climate suitability during their stay rather than for the entire season or year, which considerably increases the difficulty in assessing the influence of climate on tourism (De Freitas, 2003). Climate-tourism indices were designed to quantify the climate suitability of a destination for outdoor tourism activities (Rutty et al., 2020). Consequently, the designed indices must include thermal comfort, as well as physical and aesthetic features (De Freitas et al., 2008; Moreno and Amelung, 2009; Perch-Nielsen et al., 2010). One of the first such indices is the Tourism Climate Index (TCI), proposed by Mieczkowski in 1985. It was developed based on a series of parameters that directly influence tourists' satisfaction at the destination: air temperature, humidity (and the resulting thermal conditions), precipitation, wind speed, and duration of sunshine. Although the TCI is widely used globally and scientifically

validated (De Freitas, 2003; De Freitas et al., 2008; Moreno and Amelung, 2009; Perch-Nielsen et al., 2010; Rutty et al., 2020; Alonso-Pérez et al., 2021; Efe et al., 2022), several authors pointed out some of its limitations (Becken, 2005; Gössling et al., 2012; Mihăilă and Bistricean, 2018; Demiroglu et al., 2020; Adiguzel et al., 2022; Croitoru et al., 2022; Gao et al., 2022; Wang et al., 2022; Jong et al., 2023; Ma et al., 2024; Prinsloo and Fitchett, 2024; Petrou and Kassomenos, 2025). One notable problem is the insufficient temporal resolution, which limits the accuracy of the results. The monthly TCI has limited relevance for tourists, as their stay at the destination typically does not exceed ten days in most instances. Therefore, tourists are more concerned with the weather conditions during their stay than the monthly average, since they can experience notable fluctuations within the same month. Additionally, by using monthly data, the distribution of precipitation within the month is not considered, an issue that is also valid for the other parameters. Daily or weekly changes in weather conditions, whether minor or severe, gradual or sudden, can alter the predetermined schedule of activities and negatively impact the tourist experience. Moreover, there is a lack of consideration for extreme weather events, such as heavy rainfall, violent winds and heat, that not only affect the satisfaction of tourists but can put them at risk in some instances.

Some of the identified limitations have been addressed through the creation of new indices which, while solving certain problems, also have their own deficiencies. Among those specific to coastal areas, the Beach Climate Index (BCI) cannot be applied at a daily resolution because one of its indicators is the number of foggy days (Lashaki, 2021). The Climate Index for Tourism (CIT) is mainly designed for beach activities, making it less applicable to other forms of tourism, particularly in large urban centres near the coast (De Freitas et al., 2008). The Coastal Tourism Climate Index (CTCI) includes air pollution, making it suitable for coastal urban destinations, but with limited applicability in rural or non-polluted coastal areas (Gao et al., 2022). The Holiday Climate Index (HCI) for beach tourism is based on studies of tourist preferences (Scott et al., 2016; Rutty et al., 2020), but it excludes nocturnal thermal comfort, limiting its applicability in regions where air conditioning is unavailable or where its use is impacted by rising energy costs (Mushawemhuka et al., 2020; Noome and Fitchett, 2022; Petrou 2024). Moreover, HCI uses cloud cover (Jong, 2023; Petrou, 2024; Prinsloo, 2024), a parameter not available in historical data at certain meteorological stations.

However, despite these limitations identified and the development of new indices, both the TCI and its various enhanced versions are widely used as a research tool to study climate-tourism interactions at global and regional levels, including Europe, Canada, USA, China, Turkey, Iran, Australia, Russia, South Africa, and others (Amiranashvili et al., 2017; Cenk et al., 2020; Demiroglu et al., 2020; Alonso-Pérez et al., 2021; Prinsloo and Fitchett, 2024; Petrou and Kassomenos, 2025).

Despite that beach tourism is among the most sensitive to weather conditions (Matzarakis et al., 2007), the scientific literature did not thoroughly address this subject until the last decade (Cenk et al., 2020). The approach to this subject has only recently been carried out in certain coastal regions of the globe, especially the Mediterranean coast (Morgan et al., 2000; Cenk et al., 2020; Demiroglu et al., 2020; Petrou and Kassomenos, 2025), the Chinese coast (Gao et al., 2022), and the Caribbean coast (Rutty et al., 2020). Limited exploration of the Black Sea coastal destinations has been done so far. Several papers have referred to the influence of climate on tourism along the Black Sea coast (Tzenkova et al., 2007; Katerusha and Matzarakis, 2015; Erginal, 2017). They were developed based on the original or an enhanced version of the TCI but focused on the coastline of a single country or location (Deniz, 2011; Amiranashvili et al., 2017, 2018; Efe et al., 2022; Croitoru et al., 2022). Previously conducted studies revealed that suitable climatic conditions for outdoor tourism could also occur outside the period, which is generally considered the “tourist season” for some sectors of the seaside (Croitoru et al., 2022). Assessing the climate suitability season can help address other problems and implement sustainable solutions, thereby reducing extreme

seasonality, extending the length of stay at the destination, increasing tourist spending, and improving the tourism sector in the region.

This paper aims to assess the climate suitability for outdoor tourism in the Black Sea region and explore extending the tourist season using the enhanced version of the TCI (ETCI), recently developed by Croitoru et al., (2022, 2024). A comprehensive comparative analysis of the coastal areas of several riparian countries (Ukraine, Romania, Bulgaria, and Turkey) was performed. The enhancement mainly considers extreme weather events and improves the temporal resolution. Thus, the ETCI was used to ascertain optimal periods for outdoor activities daily, followed by aggregation into 10-day periods, addressing tourists' need for more precise weather information during their stay and support a sustainable approach of the tourism sector in the region.

2. Dataset and Method

2.1. Data Used

To quantify climate suitability for outdoor tourism activities in the study area using the ETCI, daily and hourly data for 11 years (2010–2020) from nine weather stations in four countries surrounding the Black Sea (Ukraine, Romania, Bulgaria, and Turkey) were used. The geographic coordinates are presented in Table 1, and their locations are shown in Fig. 1. The weather stations cover most of the Black Sea coast. No weather station with complete data for the analysed period has been identified for the northeastern coastal region and eastern coastal regions, representing the Russian Federation and Georgian territories, except for Kerch, located in Crimea, a region under disputed control.

It should be noted that results for the southeastern Black Sea coast (Hopa) may not fully reflect the climatic conditions of the entire eastern and northeastern part of the basin due to the lack of long-term data series from multiple locations. Thus, findings for the eastern Black Sea should be interpreted with caution until more complete datasets become available for this sector.

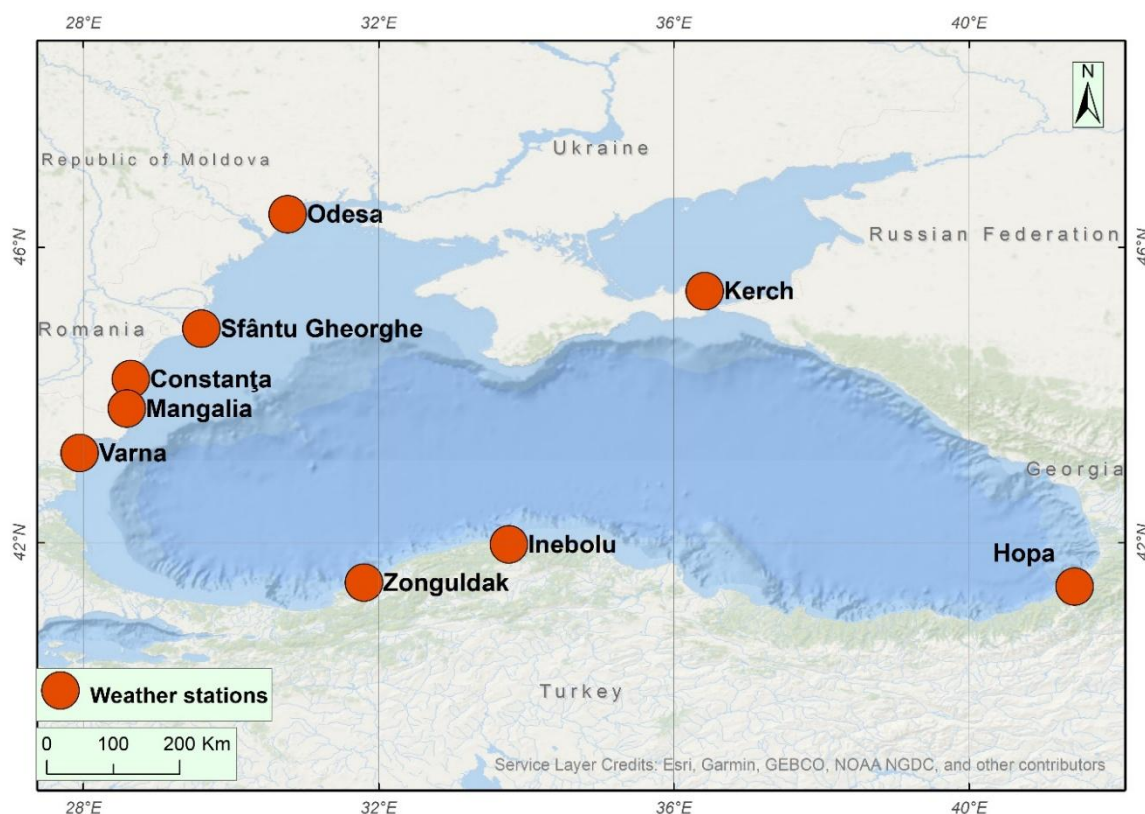


Figure 1. Location of the weather stations used in the Black Sea coastal area

However, comparison of the main variables among some other important tourism locations in the eastern half of the region (e.g. Sochi and Batumi) revealed that the differences compared to the Hopa climatic conditions are quite small (<https://weatherspark.com/compare/y/101302~102069~102084/Comparison-of-the-Average-Weather-in-Sochi-Hopa-and-Batumi>). The insignificant differences between Batumi and Hopa are also explained by the short distance, which is about 33 km in a straight line, whereas the driving distance is about 38 km (<https://www.rome2rio.com/map/Batumi/Hopa>).

Freely available data sets have been extracted from online databases: Meteomanz (www.meteomanz.com), Ogimet (www.ogimet.com), ROCADA (Dumitrescu and Bîrsan, 2015), and Reliable Prognosis 5 (<http://rp5.ru>). Except for ROCADA, the other three databases derive data from raw SYNOP messages issued by the respective weather stations. The ROCADA database was developed and made available by the Romanian National Meteorological Service (National Meteorological Administration).

Table 1. Geographical coordinates of the meteorological stations used (Source: www.ogimet.com, 2023)

No.	Weather station	Latitude (N)	Longitude (E)	Altitude (m)	Country
1	KERCH	45.24	36.25	46.0	Ukraine/Russia
2	ODESA	46.26	30.46	42.0	Ukraine
3	SFÂNTU GHEORGHE-DELTA	44.89	29.59	2.0	Romania
4	CONSTANȚA	44.21	28.64	14.0	Romania
5	MANGALIA	43.81	28.58	7.2	Romania
6	VARNA	43.12	27.57	43.0	Bulgaria
7	ZONGULDAK	41.27	31.48	136.0	Turkey
8	INEBOLU	41.59	33.47	64.0	Turkey
9	HOPA	41.23	41.25	33.0	Turkey

The ETCI was derived from daily average and maximum air temperatures, average and minimum relative humidity, mean and maximum wind speed, sunshine hours, and precipitation amount.

2.2. Method

2.2.1. ETCI calculation

The TCI proposed by Mieczkowski comprises five sub-indices, each with a specific weight in the final index score. The two thermal comfort sub-indices account for 50 % of the score: the daytime comfort index brings 40 %, and the daily comfort index (24h) contributes 10 %. Daily rainfall and sunshine duration add 20 % each to the final value, and the remaining 10 % is attributed to wind speed at an altitude of 1.2 m.

The limitations of the index original version generated by using monthly values are addressed in this research in terms of data used (daily and hourly, where applicable), aggregated then for 10-day periods (decades) to improve the temporal resolution, and by adapting the reclassification algorithm for precipitation to also consider heavy

precipitation events. Thus, new scores were given for heavy precipitation days (10–20 mm/day) and very heavy precipitation days (more than 20 mm/day): -1 and -2, respectively. The index was further enhanced by using Effective Temperature (TE)-based sub-indices instead of simple comfort indices (CI) employed in the original version of the TCI. The TE-based sub-indices (TEd and TEa) considered the wind speed at 1.2 m above the ground level, along with air temperature and relative humidity (Banc et al., 2020; Croitoru et al., 2024), to calculate thermal comfort, considering both daytime and 24-hour average/extreme values. Previous studies also used this ETCI version, replacing CId and CIa with TEd and TEa (Scott et al., 2004; Amelung and Viner, 2006; Perch-Nielsen et al., 2010; Kovacs and Unger, 2014), whilst some others included the thermal indices replacement mentioned and the heavy precipitation events (Croitoru et al., 2022, 2024).

Based on recorded or calculated values, a daily score between 0 and 5 is assigned to each sub-index or variable considered, following the reclassification algorithms proposed by Mieczkowski (Table 2), except for precipitation, for which values between (-2) and 5 are assigned, as we enhanced the algorithm. The reclassification of wind speed was performed by considering its correlation with maximum air temperature, following the original version of the index proposed by Mieczkowski (1985).

The ETCI final score ranges between -8 and 100, where 90–100 implies ideal conditions and -8 to 10 values are used for impossible conditions.

The weights of all sub-indices in the original formula were kept to calculate the ETCI score.

$$ETCI = 2 \times (4 \times TEd + TEa + 2 \times R + 2 \times S + W) \quad (1)$$

where:

- TEd - maximum daytime effective temperature (°C);
- TEa - average daily effective temperature (°C);
- R - daily amount of precipitation (mm);
- S - daily sunshine hours (h);
- W - wind speed at 1.2 m (km/h).

Wind speed (W) was converted from 10 m to 1.2 m using the Wind Speed Interpolation formula, available online (<https://websites.pmc.ucsc.edu/jnoble/wind/extrap>) and previously used in similar studies (Banc et al., 2020; Croitoru et al., 2024).

After calculating daily values for the entire period, they are aggregated into shorter periods (decades). Three decades are defined for each month, resulting in 36 annual decades: in each month, two 10-day periods were established (from day 1 to day 10, and respectively from day 11 to day 20 of each month), while the third decade is considered from day 21 to the last day of the month. Furthermore, the average ETCI score is calculated for each decade of the year, and each decade is subsequently assigned to a corresponding suitability class (Table 2).

Thus, all calculations were performed daily, and the ETCI score was calculated each day and then averaged over 10-day periods. Three reasons determined the choice for the length of the period:

The first is the high variability from one day to the next, particularly for short-term extreme events associated with convective cells (Cumulonimbus clouds), such as heavy rainfall/rain showers, hail, and squalls, which are characteristic of the warm season. In climate studies, 10- to 15-day windows are typically used for averaging and under these circumstances, shortening the period would become unreliable.

The second reason is that, despite the general trend toward shorter vacations of just three to four days, this study aims to encourage extending stays beyond seven days, or even 10 days, as this can make tourism more sustainable and more profitable. Longer visits not only reduce the environmental impact per day of travel but also create economic efficiencies for both tourists and destinations. Extended stays typically offer

lower nightly rates, making trips more affordable while allowing tourists' spending to be more evenly distributed across local businesses.

The third is that vacations lasting more than a week provide the body and mind with sufficient time to fully relax, offering a level of comfort and rejuvenation that shorter trips cannot achieve.

By encouraging longer, more meaningful stays, destinations can ease the pressure of high-turnover tourism, improve visitor well-being, and strengthen the long-term sustainability of the local economy.

Table 2. Suitability classes for outdoor tourism (Source: after Mieczkowski, 1985; Perch-Nielsen et al., 2010, modified.)

ETCI score	Suitability class	Suitability
90-100	Ideal	Suitable for outdoor activities
80-89	Excellent	
70-79	Very good	
60-69	Good	
50-59	Acceptable	
40-49	Marginal	Unsuitable for outdoor activities
30-39	Unsuitable	
20-29	Very unsuitable	
10-19	Extremely unsuitable	
<10	Impossible	

The original thresholds for suitability classes proposed by Mieczkowski (1985) were maintained in this study. For a more explicit graphical representation, we grouped the detailed classes into two broader categories: "suitable" ($ETCI \geq 50$) and "unsuitable" ($ETCI < 50$) for outdoor tourism. This simplified classification was used only for visualisation, while all calculations and interpretations relied on the original threshold values with 10 classes of favourability. A colour palette was applied to support intuitive visual interpretation. Since only decades with a multiannual average score of at least 50 are considered suitable for outdoor tourism activities, only those decades were retained for further analysis.

2.2.2. Graphical representation

The maps were generated using ArcGIS 10.6.1, combined with Google Earth Pro and Google Maps to position the weather stations. Subsequently, the acquired data was imported into ArcMap in .kml format. To better visualise the weather stations in a territorial context, the World Ocean Base, including the marine bathymetry and inland waters, was added as a base map (ESRI, 2024). The ETCI database was stored, processed, and presented in charts using Microsoft Excel.

2.3. Study Area

The Black Sea is the world's largest inland sea, located between Europe and Asia (Bakan and Büyükgüngör, 2000), and is recognised as the most important beach destination in Europe after the Mediterranean Sea. It is bordered by the coastlines of Romania, Bulgaria, Turkey, Georgia, the Russian Federation, and Ukraine, encompassing an approximate area of 422,000 square kilometres and reaching a maximum depth of more than 2,210 meters (Bakan and Büyükgüngör, 2000). The Black Sea coastlines extend for more than 4,340 kilometres, with Ukraine and Turkey having the longest stretches (Stanchev et al., 2011).

Key waterways connecting the Black Sea to neighbouring bodies of water include the Kerch Strait to the Sea of Azov and the Bosphorus Strait to the Sea of Marmara. Coastal cities and resorts, including famous ones, such as Varna, Constanța, Odesa, Sochi, and Istanbul, contribute to the region's economic and touristic significance. By contrast, existing islands (Snake Island, Pirezin and Kefken) lack consistent tourism facilities and infrastructure. Crimea Peninsula, the largest peninsula, is in an unclear and critical geopolitical situation due to ongoing conflicts and tensions, which limit international tourism.

3. Results and discussions

3.1. Spatio-temporal analysis by suitability classes

Based on the obtained ETCI values, the suitable period for outdoor tourism begins, on average, in the last decade of March or during the first decade of April and ends, on average, in the first decade of November (Table 3). For locations along the Turkish Black Sea coast (Inebolu and Zonguldak), the end of the season was identified to be in the second decade of November. In contrast, the suitable conditions for Odesa seem to end earlier in the autumn, during the final decade of October (Table 3). The southern coast, mainly belonging to Turkey, showed a smoother increase across the transition between decades, with acceptable and good conditions compared with very good and excellent climate conditions in May and June. By contrast to the other coastal areas, a marginal prolongation of the season was detected towards October and November.

The ideal weather conditions were detected in the analysed region during the peak of the tourist season, extending across the end of July and the beginning of August. Typically, these conditions do not persist for more than two to three decades. A longer extension of the ideal conditions (three decades) is specific to the central part of the western coastline and on the northern coastline (Kerch and Varna), whereas, on the southeastern coast (Hopa) such conditions were not identified (Table 3).

Excellent conditions prevail from mid-June to mid-September at most locations analysed (Table 3), when various outdoor tourism activities, including bathing and spa-related pursuits, can be undertaken. The exception is the southeastern region, where the frequency of excellent conditions is very low (e.g., one decade at Hopa). The lack or low frequency of ideal and, respectively, excellent conditions in the southeastern region may be attributed to the higher precipitation recorded there compared with other areas (Table 3). Very good conditions are specific in late May and early June, as well as in early and mid-September. On the southeastern Black Sea coast (Hopa), the very good class is dominant, occurring with the highest frequency, from June to mid-September (10 decades) (Table 3).

Good climatic conditions dominate during the last ten days of April and the first two decades of May. Furthermore, there is a gradual advancement from acceptable conditions to very good ones during this period. Conversely, a progressive shift is not mirrored at the end of the season, when the transition from very good to acceptable conditions is more rapid, lasting no more than two consecutive decades, at the end of September and/or the beginning of October (Table 3).

Table 3. Climatic suitability for outdoor tourism activities along the Black Sea coast using ETCI

	Kerch	Odesa	Sf. Gheorghe Delta	Constanța	Mangalia	Varna	Inebol u	Zonguldak	Hopa
Jan_1	24.7	25.2	26.3	28.9	30.9	35.3	34.1	33.3	37.6
Jan_2	26.3	25.9	28.9	33.2	33.6	36.7	37.5	38.5	39.0
Jan_3	19.9	18.2	26.5	22.8	31.1	31.0	31.0	34.6	35.0
Feb_1	26.6	26.5	29.1	31.5	34.7	37.5	41.3	42.8	40.1
Feb_2	28.3	31.1	31.4	36.2	33.0	40.2	37.5	40.0	37.8
Feb_3	30.5	30.9	31.9	36.1	33.9	38.3	37.1	39.7	46.8
Mar_1	39.5	43.0	40.0	39.4	38.7	45.3	42.0	45.2	42.6
Mar_2	40.5	46.6	43.5	47.9	43.9	49.6	41.3	44.8	43.8
Mar_3	47.3	48.6	46.4	50.4	45.0	50.9	49.6	50.6	52.8
Apr_1	52.2	55.5	52.7	54.8	50.1	54.7	50.2	51.4	53.6
Apr_2	56.0	53.6	53.8	54.2	51.3	56.0	55.8	56.4	55.4
Apr_3	65.5	66.7	65.0	63.9	61.8	66.4	62.3	62.5	57.1
May_1	66.2	67.9	64.8	62.6	60.2	62.9	57.6	56.7	59.2
May_2	69.6	70.6	68.0	68.8	65.9	70.7	66.8	68.5	62.6
May_3	75.1	74.3	71.5	70.8	65.6	71.9	65.0	66.7	67.5
Jun_1	80.2	79.3	78.7	77.4	73.0	77.9	73.1	73.5	72.0
Jun_2	87.2	82.9	85.9	82.2	80.4	82.8	79.4	78.6	74.7
Jun_3	83.7	82.5	84.9	80.5	79.1	83.3	82.8	79.9	75.4
Jul_1	88.8	83.0	83.3	82.4	80.5	86.7	86.0	85.7	73.3
Jul_2	89.6	86.0	86.8	88.1	87.1	89.2	86.3	85.0	80.4
Jul_3	92.0	89.6	91.3	88.5	90.0	90.3	91.1	90.4	78.4
Aug_1	91.0	90.0	91.8	91.5	91.6	92.2	90.9	89.0	76.7
Aug_2	90.3	87.9	87.1	88.2	87.1	89.6	88.5	87.9	78.4
Aug_3	89.7	85.9	88.4	88.7	85.7	90.4	87.7	85.4	75.4
Sep_1	80.8	79.9	81.5	84.2	78.7	85.7	80.6	80.3	73.6
Sep_2	79.8	77.1	79.3	79.7	71.6	82.8	76.8	80.0	77.4
Sep_3	68.6	68.4	66.5	67.7	61.1	71.2	64.6	67.0	63.3
Oct_1	63.3	58.7	55.0	59.5	53.2	62.3	60.2	60.5	58.2
Oct_2	58.0	56.7	55.5	59.3	52.0	60.0	57.3	58.6	55.9
Oct_3	52.2	50.0	52.7	54.2	50.3	56.2	53.5	56.3	53.4
Nov_1	52.4	49.3	52.3	58.1	52.4	58.8	54.9	55.0	52.4
Nov_2	39.9	38.7	45.8	48.7	47.3	48.7	50.6	54.1	49.0
Nov_3	34.0	32.1	38.0	38.4	38.1	39.3	43.8	46.6	44.5
Dec_1	31.7	31.7	39.6	38.6	43.0	42.0	40.0	42.5	40.3
Dec_2	30.2	27.7	36.0	34.6	34.3	39.3	40.9	41.4	39.9
Dec_3	30.0	31.8	33.8	35.2	35.8	39.5	36.8	39.3	40.4

Note: the colours of cells signify the suitability class identified with the same colour in Table 2.

The acceptable conditions for outdoor tourism are specific to April and to the period from the end of October till early November over the entire region. A limited series of outdoor activities can be performed during this period. Notably, the period is shorter at the beginning of the season (in spring) than at the end (in autumn) (Table 3).

However, under climate change conditions, it is estimated that all classes of climatic suitability around the Black Sea will extend in time, primarily due to increasing thermal comfort conditions, which have a significant weight in the index value.

3.2. Frequency analysis

Considering all decades spanning 2010–2020 across the nine weather stations, 203 decades (63%) fall into the suitable period for outdoor tourism. By contrast, the remaining 121 decades correspond to classes of unsuitable weather conditions (Fig. 2a).

Among the decades characterised by suitable conditions, 29% is covered by acceptable conditions. Remarkably, this class is closely followed by excellent conditions (26%), which cover mainly the peak of the season. The very good and good weather conditions accounts for more than 18% and 19% of the total number of decades considered (Fig. 2b).

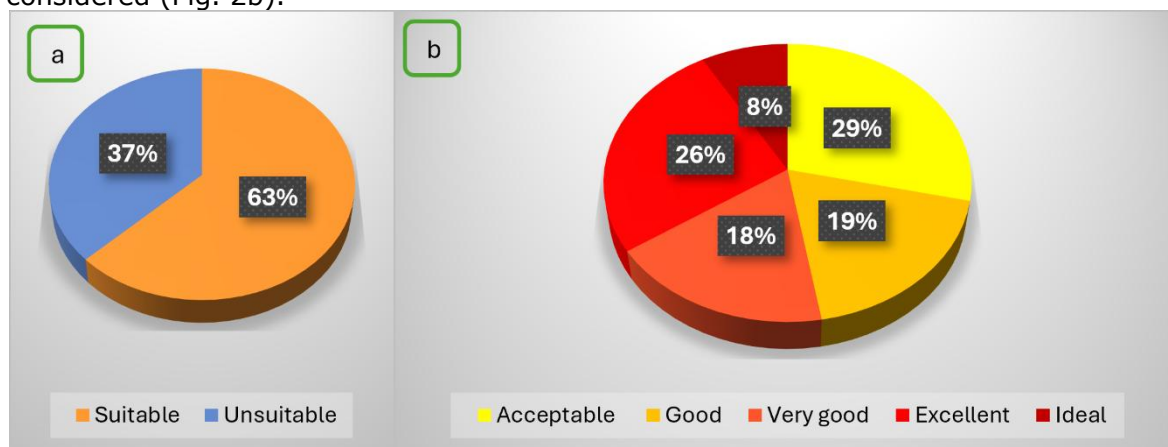


Figure 2. The frequency of decades with suitable and unsuitable weather conditions (a) and by classes of suitability (b) over the period 2010–2020

Only 8% of the decades with suitable conditions fall into the ideal conditions class, with ETCI scores closely aligned with the upper limit of the excellent conditions class (90.0 – 92.2) (Fig. 2b, Table 3).

In general, the duration of the tourist season, from the perspective of suitable weather conditions, indicated a length of 21–24 decades, with slightly higher values in the western and southern coastal areas. The maximum value was observed in Zonguldak (24 decades) and the minimum at Odesa (21 decades). Consequently, it can be inferred that the southeastern region boasts the longest tourist season, whereas the shortest is in the northwestern one (Fig. 3).

A greater degree of heterogeneity is observed in the distribution of the number of decades across each suitability class. Thus, the acceptable climatic conditions cover a maximum length in the southeastern area (nine decades at Hopa) and a minimum of five decades in the northern and partly in the western areas (Kerch, Odesa, and Varna) (Fig. 4a). The good weather conditions have the most well-balanced temporal and spatial distribution, with all regions experiencing 3–5 decades with such conditions (Fig. 4b). The very good conditions have a duration of 2–5 decades on the western half of the coastal region as well. By contrast, the most extended duration was detected in the southeastern area (Hopa) (10 decades) (Fig. 4c). However, it should be noted that these are the best conditions identified at this weather station since excellent and ideal conditions were not detected but accidentally (one decade in Hopa) (Fig. 4d).

The excellent and ideal conditions classes were jointly examined because the duration of the ideal conditions was relatively limited (8%). Both suitability classes cover

7–10 decades in all locations except Hopa. The short duration of excellent conditions at Hopa is offset by the most extended period of very good conditions (Fig. 4).

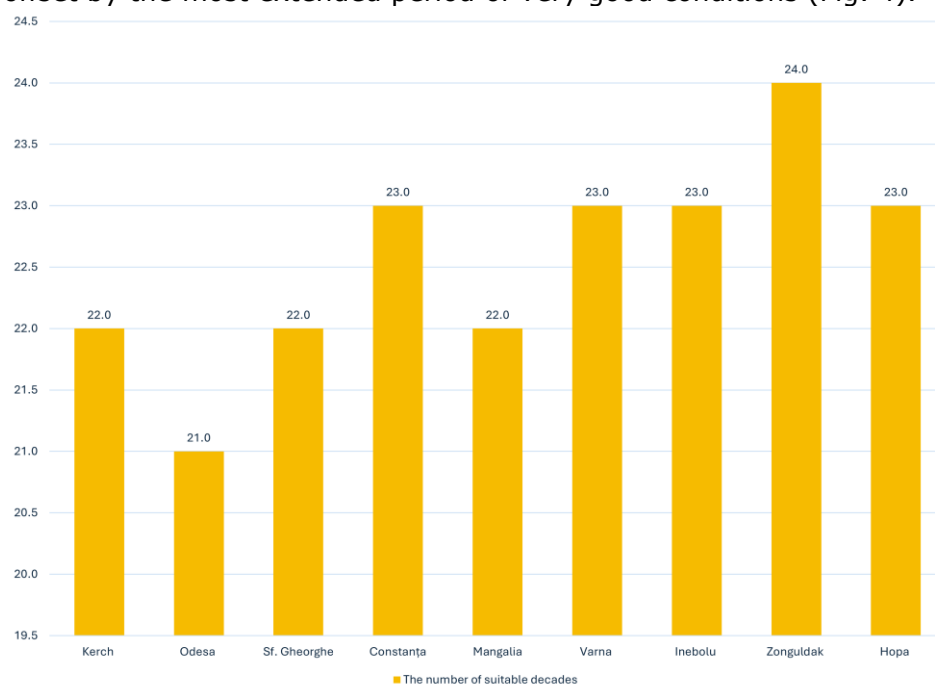


Figure 3. The number of suitable decades calculated for each meteorological station

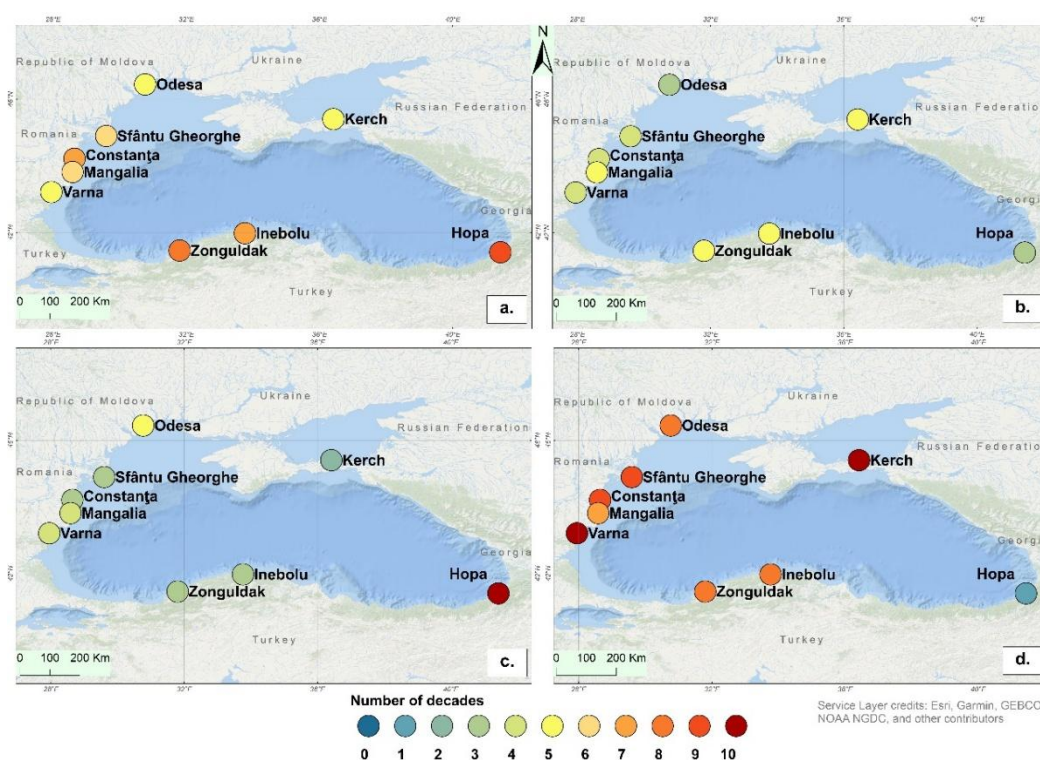


Figure 4. Duration of climatic suitability in the Black Sea region: a – acceptable, b – good, c – very good, d – excellent and ideal (number of decades).

3.3. Impact of extreme precipitation on the general score of ETCI

We analysed the impact of extreme precipitation events on suitability classes, mainly in the superior classes (e.g. lack of excellent and ideal conditions in the southeastern region). Thus, a careful examination of the ETCI sub-indices revealed that, during the suitable period, the parameter with the highest variability is precipitation. The

southeastern region (Hopa) recorded a much higher amount of precipitation than the other locations. Additionally, there is a notable difference in the number of heavy rainfall days recorded in other locations and Hopa (Table 4).

Table 4. Frequency of precipitation days by reclassification score from 10 June to 10 September (%)

Score	Kerch	Odesa	Sf. Gheorghe Delta	Constanța	Mangalia	Varna	Inebolu	Zonguldak	Hopa
5.0	79.9	75.9	76.7	74.4	76.2	77.8	75.1	76.0	54.9
4.5	3.1	3.0	2.9	3.1	2.0	1.6	2.2	1.3	3.6
4.0	0.2	0.6	1.3	0.8	0.7	1.5	1.3	0.9	2.4
3.5	1.5	0.9	1.5	1.8	0.6	0.6	0.9	1.3	2.4
3.0	0.2	0.5	0.4	0.5	0.4	0.6	0.5	0.9	1.2
2.5	0.7	0.6	0.6	0.5	0.6	1.3	1.5	0.9	1.4
2.0	0.0	0.0	0.3	0.4	0.5	0.5	1.0	0.6	1.0
1.5	0.2	0.5	0.6	0.9	0.5	0.5	0.4	0.4	1.0
1.0	0.1	0.0	0.2	0.1	0.3	0.3	0.5	0.4	1.2
0.5	1.3	0.5	0.4	0.5	0.1	0.2	0.3	0.4	1.1
0.0	1.1	2.5	2.4	2.6	2.3	1.9	3.2	2.7	5.4
-1.0	2.1	4.2	1.3	3.9	2.1	2.5	3.2	3.1	6.6
-2.0	0.8	1.6	1.4	2.5	2.0	1.3	1.8	3.1	7.1

To determine whether extreme precipitation is responsible for the nearby absence of ideal and excellent classes along the southeastern coast, we analysed the precipitation frequency by scores in the reclassification table. The period considered is June 10 - September 10, during which the other stations recorded the most decades with excellent and ideal conditions (Table 4).

The findings revealed that, across all scores, the frequency of days with precipitation is notably higher at the Hopa station, except for the highest score of 5 points (0 - 0.5 mm). Hopa recorded a reduction of approximately 20 percentage points in the number of days, achieving a score of 5 points compared to the other stations, notably decreasing their ETCI score (Table 4).

For scores ranging from 0.5 to 4.5, Hopa had a higher frequency (1.0 - 3.6%) than the other locations (0.0%–3.1%). An even more pronounced disparity was revealed for days with scores ranging from 0 to -2. This station recorded values much higher (5.4-7.1%) than the other locations (0.8-4.2%) (Table 4).

This high frequency of scores lower than 5 significantly contributed to the overall reduction in final ETCI scores, which attained a maximum value of 80 on days characterised by a precipitation score of 0, 76 on days with a score of -1, and 72 on days

with a score of -2. A thorough examination was conducted across all stations on days featuring these specified precipitation scores. It was noted that for a precipitation score of -2, the highest attained ETCI score value was 70 (Table 5).

Table 5. Maximum ETCI score on days with negative or 0 precipitation scores

Score	Kerch	Odesa	Sf. Gheorghe Delta	Const anța	Mangalia	Varna	Inebolu	Zongul dak	Hopa	Average
0.0	68	75	76	75	72	76	76	75	75	74.22
-1.0	72	71	70	71	68	68	72	71	72	70.56
-2.0	70	65	63	67	68	66	69	66	69	67.00

Heavy precipitation also influences other parameters, especially sunshine duration. Consequently, the lower ETCI scores in the southeastern region (Hopa), including the absence of excellent/ideal conditions relative to other locations, may be explained by the higher frequency of days with heavy and very heavy precipitation in that region.

This may be due to the over-weighting of precipitation by assigning negative scores to days with heavy and very heavy precipitation, which is one of the changes we propose to enhance the TCI. Heavy rainfall is a significant disadvantage, as it can disrupt tourists' activities by causing flooding and affecting tourists' safety. Employing the initial classification approach, these discrepancies would not have been so evident, and the accuracy of the findings could have been compromised.

4. Conclusions

This research addresses the impact of climate and weather on the possibility of practising outdoor tourism activities. The ETCI is used on the Black Sea region as a whole for the first time, addressing a gap in the scientific literature.

As expected, the most suitable months for visiting destinations in the region to practise most forms of outdoor tourism, including sun and sea bathing, are during summer and early autumn (from June to September), with scores ranging from 72.0 to 92.2, indicating very good, excellent, and ideal conditions. However, other outdoor activities, such as sports and cultural endeavours, can be pursued from April until the first part of November since acceptable, good or very good weather conditions are present. The analysis revealed that, on average, 223 days (61.02% of the year) are suitable for outdoor tourism, which is significantly longer than the current season in the region. Approximately 63 % of the decades during 2010-2020 were found to be suitable for outdoor tourism activities. Most analysed locations showed similar ETCI scores, except for Hopa, which indicated a lower frequency of suitable conditions, particularly for superior classes, due to more frequent extreme precipitation days. This highlights the importance of accounting for negative scores for days with heavy and very heavy precipitation to enhance the accuracy and relevance of the original TCI. Thus, it is demonstrated that favourable climatic conditions for outdoor tourism in the region persist much longer than the "classic" tourist season (mid-June to mid-September), extending from April to November. Identifying these suitable periods may serve as a starting point for extending the tourist season in the region, resulting in a more evenly spread distribution of visitors/tourists over seven months and reduced anthropogenic pressure at the peak of the season. Therefore, the ETCI proved to be a valuable tool for

sustainable tourism planning and assessing climate suitability in the Black Sea coastal destinations.

This study can support policy- and decision-makers and stakeholders to diversify the tourist programs in the region, extend the season and increase the number of arrivals and overnight stays, particularly in the spring and autumn months, which were identified as suitable for some outdoor tourist activities. Tour operators can further enhance their services by extending the season and offering alternative entertainment, such as sun and sea bathing. At the same time, accommodation and treatment establishments can flexibly align their schedules and infrastructure with weather conditions (climatic patterns) throughout the year. The sustainable development of tourism is encouraged by understanding and adapting to local climatic conditions. Strategic tourism planning must adapt to constantly evolving weather conditions, and the ETCI can be a very useful tool for achieving this goal, enabling destinations to promote tourism over longer period of optimal weather conditions (Croitoru et al., 2024).

The present approach can also form the basis for adaptation strategies that minimise the negative impacts of adverse weather and climate change. Integrating these data into tourism development strategies can contribute to the diversification of services, the optimisation of resources, and the reduction of the negative impact on the environment, which are fundamental pillars of sustainable tourism. By adopting informed policies, grounded in detailed knowledge of how climate affects tourism flows, adaptive and resilient solutions can be created that support sustainable economic growth and long-term conservation of natural and cultural heritage.

Further research should focus on (i) expanding the database to enable more detailed spatial and temporal analysis, with particular attention to the currently underrepresented coastal areas of Georgia and Russia; (ii) comparing this study's objective results with tourists' perceptions of weather conditions' suitability for various regions, and (iii) adjusting the index accordingly, if needed.

In the current climate change context, if longer datasets become available, a trend analysis should be performed using historical and projection data, as it is expected to detect an increase in the frequency of superior weather conditions and a significant shift of the Black Sea coastline towards optimal climatic conditions. Since Mediterranean coastal regions are expected to experience a decline in favourability due to heat stress, especially in the summer months, the Black Sea coastal region could become one of the most important seaside summer destinations in the Eastern half of Europe in the upcoming decades.

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Appendix: The appendix is an optional section that can contain details and data supplemental to the main text.

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