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Spatial Analysis of Tourism Climate Comfort in the Belitung Geopark Based on Historical and Projected Climate Data

Aflah Yuliarti[1 2*], Budhi Setiawan[3], Mokhamad Yusup Nur Khakim[4], Presli Panusunan Simanjuntak[2]

[1]Environmental Management Study Program, Graduate Program, Universitas of Sriwijaya, Palembang 30139, South Sumatra, Indonesia

[2]Bangka Belitung Climatology Station, BMKG, Koba 33681, Central Bangka, Bangka Belitung, Indonesia

[3]Geological Engineering Study Program, Faculty of Engineering, University of Sriwijaya, Palembang 20139, South Sumatra, Indonesia

[4]Physics Department, Faculty of Mathematics and Natural Sciences, University of Sriwijaya, Palembang 20139, South Sumatra, Indonesia

aflah.yuliarti@bmkg.go.id

Abstract

Climate-based tourism is closely linked to atmospheric comfort, while ongoing global climate change has intensified uncertainty in climatic conditions across many tourism destinations, including tropical geoparks. This study evaluates the spatial and temporal patterns of tourism climate comfort in the Belitung Geopark by integrating historical climate data (1991–2024) and future climate projections (2026–2050) under the Representative Concentration Pathway (RCP) 4.5 scenario. Tourism climate comfort was assessed using the Tourism Climate Index (TCI), which incorporates key meteorological variables, namely air temperature, relative humidity, precipitation, wind speed, and solar radiation. A spatial–temporal analysis supported by Geographic Information Systems (GIS) and heatmap visualization was applied to examine variations across 17 geosites. The results reveal a pronounced seasonal pattern characteristic of tropical climates, with the highest TCI values occurring during the dry season, particularly in August and September. Coastal geosites consistently exhibit higher and more stable comfort levels than inland, hilly, and forested areas, which experience noticeable declines in comfort during the wet season due to increased rainfall and humidity. Climate projections indicate a general reduction in TCI values, especially during transitional and wet months; however, most coastal geosites remain within acceptable to good comfort categories for tourism activities. These findings highlight the role of geographical factors, such as proximity to the coast and local atmospheric dynamics, in shaping spatial variations in tourism climate comfort. The study provides a scientific basis for adaptive tourism management, seasonal tourism planning, and climate change adaptation strategies in tropical geopark destinations, it offers potential applications in geography education and spatial climate analysis.

Keywords: Adaptation, Climate Change, Geosite, Spatial, Temporal

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**Corresponding Author*

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1. Introduction

Global climate change has significantly affected environmental conditions, particularly meteorological parameters such as air temperature, precipitation, humidity, solar radiation, and wind speed, which collectively shape of region's climatic characteristics. The variability of these meteorological parameters is a central concern in physical geography, as it is closely linked to interactions between atmospheric dynamics, the Earth's surface, and human activities (Trenberth et al., 2015); (Legg, 2021).

Indonesia, as a tropical archipelagic country, experiences considerable climatic variability influenced not only by the monsoon system but also by ocean–atmosphere interactions and large-scale climate drivers such as ENSO and the Indian Ocean Dipole. These interacting processes produce marked spatial and temporal differences in climate conditions across regions, highlighting the importance of long-term climate analysis in environmental and physical geography studies (Hidayat et al., 2016) ; (Supari et al., 2017)

Belitung Geopark is a region with distinctive geological characteristics, consisting of granite coastal landscapes, plutonic rock hills, and tropical forests, and has been designated as a UNESCO Global Geopark since 2021 (Zukhri et al., 2021). The area encompasses 17 geosites distributed across coastal and hilly environments, creating diverse natural conditions that make it highly relevant to studies in physical and environmental geography, particularly for spatial climate analysis in tropical regions. Furthermore, ongoing climate change dynamics have the potential to influence local atmospheric conditions in this area (Meinshausen et al., 2020). Previous studies have reported an increase in average air temperature of approximately 0.2–0.3 °C per decade, accompanied by a decrease in dry-season rainfall in the coastal areas of Bangka Belitung (Putri et al., 2022). These changes affect levels of climatic comfort, especially at open geosites such as Tanjung Tinggi Beach and hilly areas such as Bukit Peramun. Therefore, a study based on long-term meteorological parameters is required to analyze the spatial and temporal patterns of climate comfort and to identify climate vulnerability levels in the Belitung Geopark area (Yuliarti et al., 2024)

Quantitative assessment of climate comfort in geographical and tourism studies can be conducted using several indices. In addition to the Tourism Climate Index (TCI) developed by Mieczkowski, several alternative indices have been proposed, such as the Holiday Climate Index (HCI) which emphasizes tourism-specific climate preferences (Hasanah et al., 2020) (Jong et al., 2023) and indices based on thermal comfort models such as the Physiologically Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI) (Chen & Matzarakis, 2017) ; (Zare et al., 2018). These indices reflect the evolution of climate comfort assessment methods by incorporating human biometeorological responses and tourism activity preferences. However, the Tourism Climate Index (TCI) remains widely applied in regional and spatial tourism studies due to its integrative structure, which combines key meteorological variables—air temperature, relative humidity, precipitation, solar radiation, and wind speed—into a single composite index that enables both spatial and temporal comparison (Mieczkowski, 1985) ; (Atasoy & Guneysu Atasoy, 2020) ; (Yu et al., 2021). Its relatively simple data requirements also make it particularly suitable for long-term historical analysis and climate projection studies at the regional scale.

In addition to historical climate analysis, the use of climate projection data based on the Representative Concentration Pathway (RCP) 4.5 scenario provides insights into future climate changes at the regional scale (Neill et al., 2018). The integration of historical and projected climate data using a Geographic Information System (GIS) approach offers a comprehensive spatial depiction of climate dynamics and climate comfort over time.

Although numerous studies have examined climate variability and climate comfort in tropical regions of Indonesia, research that integrates long-term historical climate data with future climate projections through spatial–temporal climate comfort analysis at the geosite scale remains limited, particularly within geopark areas. Moreover, the utilization of spatial climate analysis results as learning resources in geography education and environmental geography studies has not been systematically explored. Accordingly, the novelty of this study lies in integrating spatial–temporal climate comfort analysis using the Tourism Climate Index (TCI) based on long-term historical data and RCP 4.5 climate projections within the Belitung Geopark. This study aims to analyze the spatial and temporal patterns of climate comfort in Belitung Geopark using historical and projected climate data, and to examine their implications as references for physical geography studies and spatial- and environment-based geography education.

2. Method

A. Type and Research Approach

This research adopts a quantitative approach with spatial–temporal analysis in the field of physical geography. Historical climate data and climate projection datasets are utilized to analyze regional-scale patterns of tourism climate comfort based on key meteorological parameters.

B. Study Area

The study area is Belitung Geopark, situated in the Bangka Belitung Islands Province, Indonesia, between approximately 2°30′–3°30′ S and 107°30′–108°30′ E. Administratively, the geopark covers Belitung Regency and East Belitung Regency. It consists of 17 geosites representing diverse physical landscapes, including granite coastal zones, tropical forest ecosystems, and hilly plutonic formations. Since its designation as a UNESCO Global Geopark in 2021, Belitung Geopark has become an important area for studying environmental and climatic dynamics in tropical island settings. The spatial distribution and geographical diversity of geosites provide a robust basis for spatial climate analysis within the context of physical and earth geography. The locations of the geosites are illustrated in Figure 1.

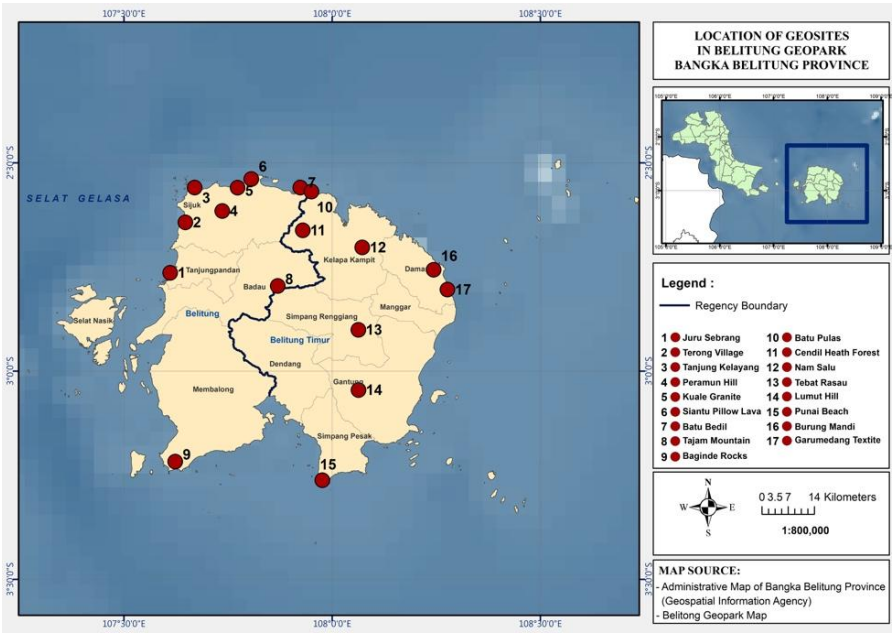

Figure 1. Location of Geosites in Belitung Geopark

C. Data Collection

The data used in this study consist of historical climate data (1991–2024) and climate projection data (2026–2050). The main meteorological variables analyzed include air temperature, maximum air temperature, minimum air temperature, relative humidity, wind speed, solar radiation, and precipitation. The historical baseline period was defined as 1991–2024, excluding the year 2025 because this study was conducted during the ongoing year, for which a complete annual dataset was not yet available. Including incomplete data could introduce temporal inconsistencies in long-term climate analysis; therefore, only fully completed years were used to ensure data reliability and consistency.

This study employs secondary data in the form of historical and projected climate datasets to represent the spatial atmospheric conditions of the study area. The historical data (1991–2024) were obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) through the ERA5 reanalysis product, which has an hourly temporal resolution and a spatial resolution of 0.25° × 0.25°. These data were downloaded from the Copernicus Climate Data Store (CDS) and extracted using Python in a Google Colab environment.

Climate projection data for the period 2026–2050 were derived from the Representative Concentration Pathway (RCP) 4.5 scenario of the Coupled Model Intercomparison Project Phase 5 (CMIP5). The projection data have a spatial resolution of 0.5° × 0.5° and a daily temporal resolution and were regridded to match the latitude–longitude grid of the study area. The projection datasets were also obtained from the Copernicus Climate Data Store (CDS) and processed using Python on the Google Colab platform for climate change analysis and the assessment of tourism climate comfort in the Belitung Geopark area.

D. Calculation and Analysis

In this study, tourism climate comfort was assessed using the Tourism Climate Index (TCI). TCI is an index developed to evaluate the suitability of climatic conditions for tourism activities. The TCI formulation proposed by Mieczkowski (1985) is expressed in Equation (1) as follows:

$$TCI = 2[(4CID) + CIA + (2R) + (2S) + W] \quad (1)$$

where TCI is the Tourism Climate Index; CID represents the Daytime Comfort Index; CIA denotes the Daily Comfort Index; R refers to monthly precipitation (mm); S indicates sunshine duration (hours); and W represents wind speed (km h^{-1}).

Each TCI component is calculated based on meteorological variables that are converted into comfort index scales according to climatic conditions considered optimal for tourism activities. The TCI rating scheme for each parameter follows the classification developed by Mieczkowski, as presented in Table 1 (Scott et al., 2016); (Hasanah et al., 2020).

Table 1. Rating Scheme in TCI

Rating	Effective Temperature (°C)	Monthly rainfall (mm)	Sun hour (hour)	Wind Speed (km/hour) Normal	Wind Speed (km/hour) Trade
5.0	20 - 26	0 – 14,9	>10	<2,88	12,24 – 19,79
4.5	19 - 20 27 - 28	15 – 29,9	9	2,88 – 5,75	
4.0	18 - 19 28 - 29	30 – 44,9	8	5,76 – 9,03	9,04 – 12,23 19,80 – 24,29
3.5	17 - 18 29 - 30	45 – 59,9	7	9,04 – 12,23	

3.0	15 - 17 30 - 31	60 – 74,9	6	12,24 – 19,79	5,76 – 9,03 24,30 – 28,79
2.5	10 - 15 31 - 32	75 – 89,9	5	19,8 – 24,29	2,88 – 5,75
2.0	5 - 10 32 - 33	90 – 104,9	4	24,30 – 28,79	<2,88 28,80 – 38,52
1.5	0 - (-5) 33 - 34	105,0 – 119,9	3	28,8 – 38,52	
1.0	(-5) - 0 34 - 35	120 – 134,9	2	-	
0.5	35 - 36	135 – 149,9	1	-	
0.25	-	-	-	-	
0	(-10) – (-5)	>150	< -2	>38,52	>38,52
-1.0	(-15) – (-10)				
-2.0	(-20) – (-15)				
-3.0	<-20				

The effective temperature in this study was calculated using the Normal Effective Temperature (NET) index. Although newer thermal indices such as PET and UTCI incorporate more complex physiological responses, NET remains widely used in tourism climate studies due to its simplicity and compatibility with long-term meteorological datasets (Blazejczyk et al., 2012), as formulated in Equation (2).

$$\mathrm{NET} = 37 - \frac{37 - T}{0{,}68 - 0{,}0014\,RH + \frac{1}{1{,}76 + 1{,}4\,\upsilon^{0{,}75}}} - 0{,}29T\,(1 - 0{,}01RH). \quad (2)$$

In Equation (2), NET represents the *Normal Effective Temperature* (°C), T denotes air temperature (°C), RH is relative humidity (%), and υ refers to wind speed (m/s). The TCI values that have been obtained show the level of tourist comfort based on the values in Table 2. (Scott et al., 2016)

Table 2. TCI Climate Comfort Levels for Tourism

Indeks Value	Descriptions of climate comfort levels
90 – 100	Ideal
80 – 89	excellent
70 – 79	very good
60 – 69	good
50 – 59	acceptable
40 – 49	marginal
30 – 39	unfavorable
20 – 29	very unfavorable
10 - 19	extremely unfavorable
< 9	impossible

3. Result and Discussion

Monthly climate variables for the period 1991–2024 (34 years) were obtained from reanalysis data for 17 geosite locations in Geopark Belitung. Normal climate values were then calculated by averaging the monthly data over the 34-year period. Monthly reanalysis data at each geosite were used to calculate the Tourism Climate Index (TCI) for the entire baseline period using the same temporal coverage. Subsequently, TCI values were computed for each geosite using the Mieczkowski formula to produce monthly normal (baseline) TCI values for the period 1991–

2024. These baseline TCI values represent long-term tourism climate comfort conditions for each month and each geosite.
Projected TCI values for the period 2026–2050 were derived using climate projection data based on the Representative Concentration Pathway (RCP) 4.5 scenario from global climate models. The projected climate variables were translated into future TCI values for each month and each geosite. A comparative analysis was then conducted between baseline TCI values (1991–2024) and projected TCI values (2026–2050) to identify trends in tourism climate comfort changes. This analysis was performed for each geosite and presented in the form of graphs, tables, and spatial visualizations to illustrate changes in seasonal patterns, identify optimal tourism periods, and anticipate the potential impacts of climate change on the tourism sector in the Geopark Belitung area.

A. Monthly TCI Analysis for The Period 1991-2024

The heatmap pattern in Figure 2 indicates that tourism climate comfort in Geopark Belitung is strongly influenced by seasonal variability. The highest TCI values occur from June to September, with peak comfort conditions observed between August and September. During this period, almost all geosites particularly those located in coastal areas experience climatic conditions that are highly favorable for tourism activities.

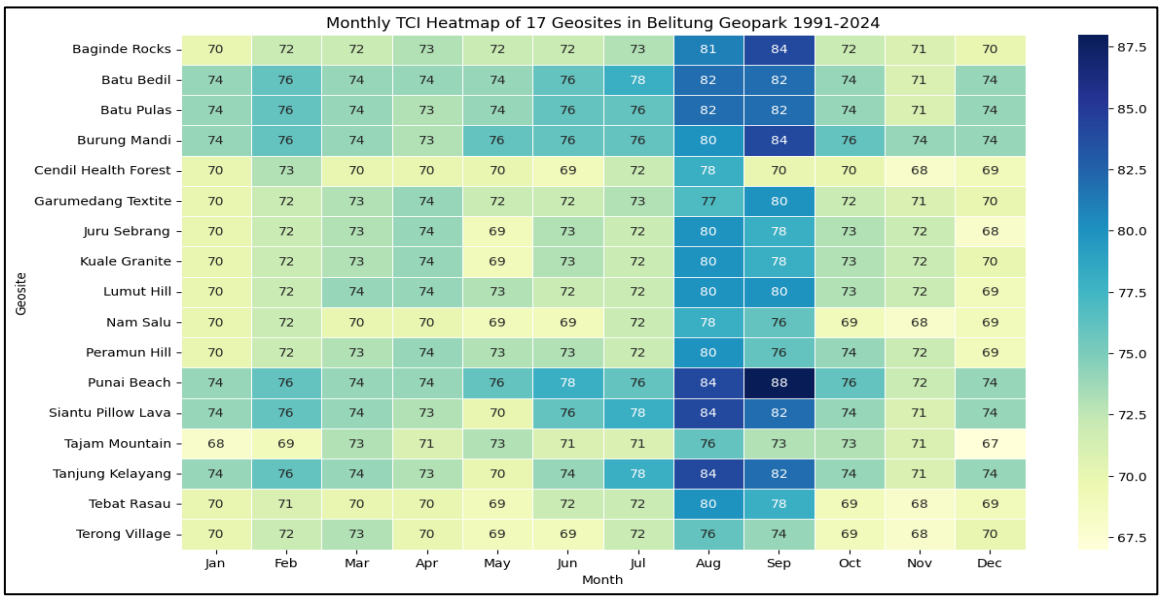

Figure 2. Monthly TCI Heatmap for the Baseline Period 1991-2024

Differences among geosites are evident in both stability and variability of TCI values. Coastal locations such as Punai Beach, Tanjung Kelayang, Siantu Pillow Lava, Batu Bedil, Batu Pulas, and Burung Mandi consistently display higher and more stable comfort levels throughout the year. In contrast, mountainous and forested areas such as Tajam Mountain and Cendil Health Forest show noticeable declines in TCI during the wet season.

This spatial contrast is closely related to geographical characteristics. Coastal geosites benefit from open landscapes and marine influences, which contribute to more stable atmospheric conditions. The presence of sea breezes plays an important role in regulating air temperature and local microclimate variability in coastal environments, as highlighted in previous studies (Huang et al., 2025). Conversely, inland geosites located in hilly and forested areas are more susceptible to increased humidity and localized rainfall during the wet season, resulting in lower tourism climate comfort.

Overall, the dry season represents the most optimal period for tourism comfort across the majority of geosites in Geopark Belitung. These findings highlight the importance of adaptive tourism

management, particularly through adjustments to tourism calendars and the improvement of supporting facilities during wetter months, when the potential for reduced climate comfort is greater.

B. Monthly TCI Projections for the Period 2026-2050

The projected heatmap in Figure 3 indicates that several geosites are expected to experience a decline in climatic comfort, particularly during the wet season. Although this decrease is not spatially uniform, most inland and non-coastal geosites show lower TCI values compared to the baseline period. Coastal geosites, however, continue to exhibit relatively higher TCI values than inland locations throughout the year. The contrast is especially visible during wetter months, when non-coastal sites experience more pronounced reductions in comfort levels.

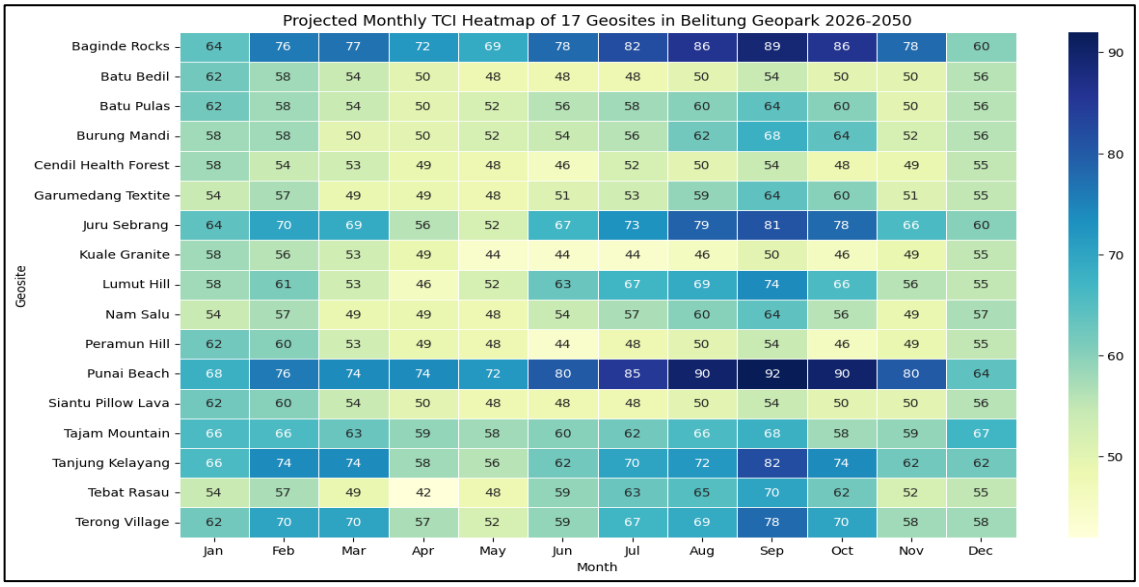

Figure 3. Monthly TCI Heatmap fo the 2026-2050 Projection Period

Overall, the heatmap suggests that wet-season conditions are likely to intensify variability in climatic comfort across geosites, while coastal areas maintain more stable TCI patterns. This projected decline in tourism climate comfort is closely associated with increasing humidity and rainfall intensity under future climate conditions. Inland and forested geosites are more sensitive to these changes due to localized precipitation and higher moisture retention, which contribute to reduced comfort levels.

In contrast, coastal geosites appear more resilient, likely due to the continued influence of marine air circulation such as sea-breeze systems, which help moderate temperature and humidity even under changing climatic conditions. This spatial resilience highlights the role of geographic factors, including topography, proximity to the coastline, and land cover, in shaping local climate responses.

From a tourism management perspective, these findings emphasize the need to adjust medium-term planning, particularly during months projected to become increasingly humid. Such adaptive strategies align with recommendations for nature-based tourism destinations facing climate variability (Neill et al., 2018).

C. Comparison of TCI Values for the 1991–2024 Baseline Period and the 2026–2050 Projection Period

Based on Table 3, monthly TCI values across all geosites in the Belitung Geopark exhibit pronounced seasonal variability. Peak climatic comfort occurs during the dry season, particularly from August to September, when most locations fall within the "good" to "excellent" comfort categories. Coastal destinations consistently demonstrate more stable and higher comfort levels compared to hilly and forested areas. During the rainy season, several geosites remain within the "good" to "very good" categories in the dry-season months, especially from July to September. Coastal geosites show higher and more stable TCI values than hilly and forested areas, with an average difference of 4–8 points between location groups. The range of TCI variation among geosites in September reaches up to 18 points, highlighting the strong influence of geographic setting on tourism climate comfort.

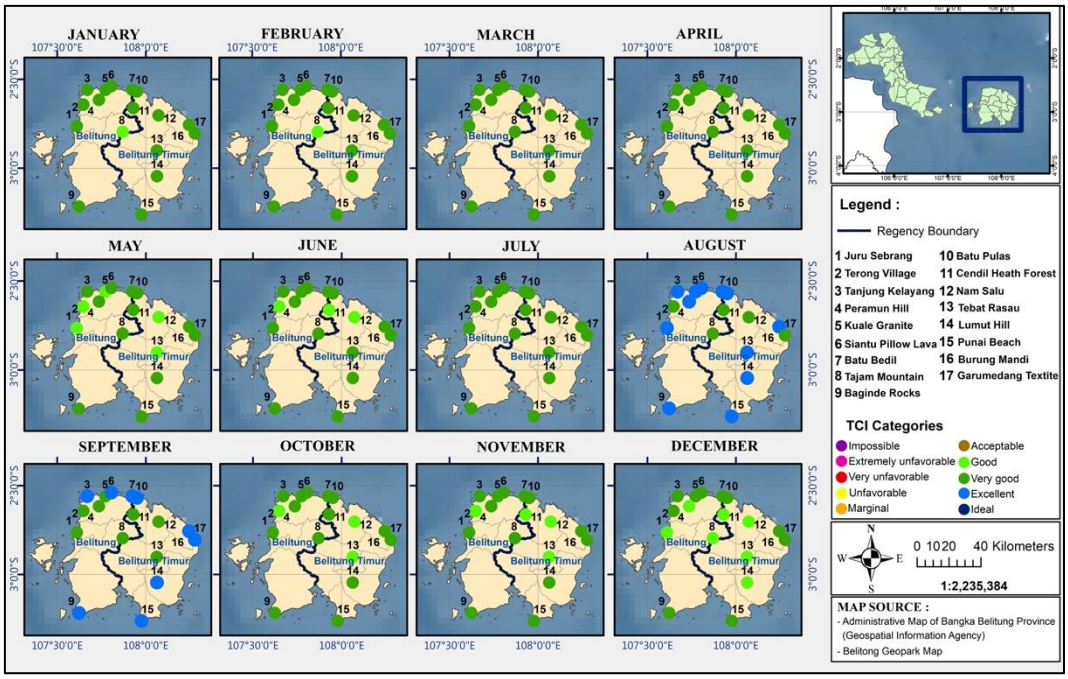

Figure 4. Monthly Spatial Distribution of the TCI During the Baseline Periode 1991-2024

Table 3. TCI Summary for the 1991-2024 Baseline Period

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Category
Baginde Rocks	70	72	72	73	72	72	73	81	84	72	71	70	very good - excellent
Batu Bedil	74	76	74	74	74	76	78	82	82	74	71	74	very good - excellent
Batu Pulas	74	76	74	73	74	76	76	82	82	74	71	74	very good - excellent
Burung Mandi	74	76	74	73	76	76	76	80	84	76	74	74	very good - excellent
Cendil Health Forest	70	73	70	70	70	69	72	78	70	70	68	69	good - very good
Garumeda ng Textite	70	72	73	74	72	72	73	77	80	72	71	70	very good - excellent
Juru Sebrang	70	72	73	74	69	73	72	80	78	73	72	68	good - excellent
Kuale Granite	70	72	73	74	69	73	72	80	78	73	72	70	good - excellent
Lumut Hill	70	72	74	74	73	72	72	80	80	73	72	69	good - excellent

Nam Salu	70	72	70	70	69	69	72	78	76	69	68	69	good - very good
Peramun Hill	70	72	73	74	73	73	72	80	76	74	72	69	good - excellent
Punai Beach	74	76	74	74	76	78	76	84	88	76	72	74	very good - excellent
Siantu Pillow Lava	74	76	74	73	70	76	78	84	82	74	71	74	very good - excellent
Tajam Mountain	68	69	73	71	73	71	71	76	73	73	71	67	good - very good
Tanjung Kelayang	74	76	74	73	70	74	78	84	82	74	71	74	very good - excellent
Tebat Rasau	70	71	70	70	69	72	72	80	78	69	68	69	good - excellent
Terong Village	70	72	73	70	69	69	72	76	74	69	68	70	good - very good
Category	good - very good	good - very good	very good	very good	good - very good	good - very good	very good	very good - excellent	very good - excellent	good - very good	good - very good	good - very good	

Based on Figure 4, the spatial–temporal TCI analysis for 17 geosites in Belitung Geopark during the baseline period 1991–2024 indicates that TCI values are predominantly classified within the "good" to "very good" categories throughout most of the year. During the peak of the dry season (August–September), the majority of geosites—particularly those located along the northern and eastern coastal areas—experience an increase in TCI from the "very good" to the "excellent" category. From October to December, climatic comfort remains relatively stable, with most geosites maintaining TCI values within the "good" to "very good" categories. The highest TCI values are consistently observed during the dry-season months.

These findings are consistent with previous research conducted in Bukittinggi (Rahmadhani & Sudiar, 2024), which reported that the highest TCI values tend to occur during the dry season, particularly in June–July, with low rainfall and reduced atmospheric humidity as the primary controlling indicators. Similar results have also been reported for East Nusa Tenggara (Hidayat, 2022), where TCI values ≥ 70 generally increase during the peak dry season (June–August), providing optimal climatic conditions for both coastal and nature-based tourism destinations. Similar findings were identified in Bali (Rose et al., 2017), where favorable tourism conditions were associated with reduced precipitation and increased solar radiation during the dry season.

Overall, the tendency for optimal TCI values to occur during the peak dry season, driven by low rainfall and extended sunshine duration, reinforces the role of the dry season as the most climatologically suitable period for nature-based tourism. Accordingly, the consistently high TCI values observed between July and September provide a robust scientific basis for the development of season-based tourism strategies and destination promotion. Beyond strengthening the international positioning of Belitung Geopark, these findings also align with sustainability-oriented tourism practices that emphasize risk mitigation in response to climate variability (Yulianti, 2022).

Table 4. TCI Summary for the 2026-2050 Projection Period

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Category
Baginde Rocks	64	76	77	72	69	78	82	86	89	86	78	60	good - excellent
Batu Bedil	62	58	54	50	48	48	48	50	54	50	50	56	marginal - good
Batu Pulas	62	58	54	50	52	56	58	60	64	60	50	56	acceptable - good
Burung Mandi	58	58	50	50	52	54	56	62	68	64	52	56	acceptable - good
Cendil Health Forest	58	54	53	49	48	46	52	50	54	48	49	55	marginal - acceptable
Garumedang Textite	54	57	49	49	48	51	53	59	64	60	51	55	marginal - good

Juru Sebrang	64	70	69	56	52	67	73	79	81	78	66	60	acceptable - excellent
Kuale Granite	58	56	53	49	44	44	44	46	50	46	49	55	marginal - acceptable
Lumut Hill	58	61	53	46	52	63	67	69	74	66	56	55	marginal - very good
Nam Salu	54	57	49	49	48	54	57	60	64	56	49	57	marginal - good
Peramun Hill	62	60	53	49	48	44	48	50	54	46	49	55	marginal - good
Punai Beach	68	76	74	74	72	80	85	90	92	90	80	64	good - ideal
Siantu Pillow Lava	62	60	54	50	48	48	48	50	54	50	50	56	marginal - good
Tajam Mountain	66	66	63	59	58	60	62	66	68	58	59	67	acceptable - good
Tanjung Kelayang	66	74	74	58	56	62	70	72	82	74	62	62	acceptable - excellent
Tebat Rasau	54	57	49	42	48	59	63	65	70	62	52	55	marginal - very good
Terong Village	62	70	70	57	52	59	67	69	78	70	58	58	acceptable - very good
Category	acceptable - good	acceptable - very good	marginal - very good	marginal - very good	marginal - very good	marginal - excellent	marginal - excellent	marginal - ideal	acceptable - ideal	marginal - ideal	marginal - excellent	acceptable - good	

During the projected period presented in table 4, monthly TCI values across all geosites generally show a decline compared to the baseline period, particularly during the transitional months and the rainy season. Several locations that were previously classified within the “good” category shift toward the “acceptable” category, while some upland geosites approach the “marginal” category during the rainy season. Overall, the monthly TCI categories remain predominantly within the “acceptable” to “good” range, especially during the dry-season months such as August and September. Coastal areas continue to exhibit relatively better conditions than non-coastal regions, although a declining trend is evident across nearly all locations.

For the projection period, TCI values tend to decrease at almost all geosites, particularly during the dry and transitional seasons, with an average reduction of approximately 10–30 points compared to the baseline. Although most coastal geosites still maintain “good” comfort levels, non-coastal and forested areas more frequently fall into the “acceptable” or even “marginal” categories.

The spatial variation of TCI values in Belitung Geopark is strongly influenced by geographical factors and local climatic conditions. Coastal geosites generally exhibit higher and more stable TCI values, particularly during the dry season. This pattern is closely associated with the influence of sea breezes, which help maintain lower air temperatures and relatively reduced humidity, thereby creating more favorable climatic conditions for tourism activities. Conversely, geosites located in hilly and forested environments show greater declines in TCI during the rainy season due to increased local precipitation and higher atmospheric humidity. Based on the TCI components, maximum air temperature, solar radiation, and wind speed contribute more strongly to higher comfort levels during the dry season, whereas rainfall and humidity become dominant limiting factors during wetter periods.

Furthermore, the OECD report on Southeast Asian tourism highlights that coastal destinations in tropical regions tend to be more resilient to seasonal variability compared to inland areas (Post-pandemic, 2023). Tourism comfort in coastal zones remains relatively stable due to more consistent temperatures, balanced humidity levels, and the moderating effect of sea breezes, which help reduce the likelihood of extreme climatic conditions.

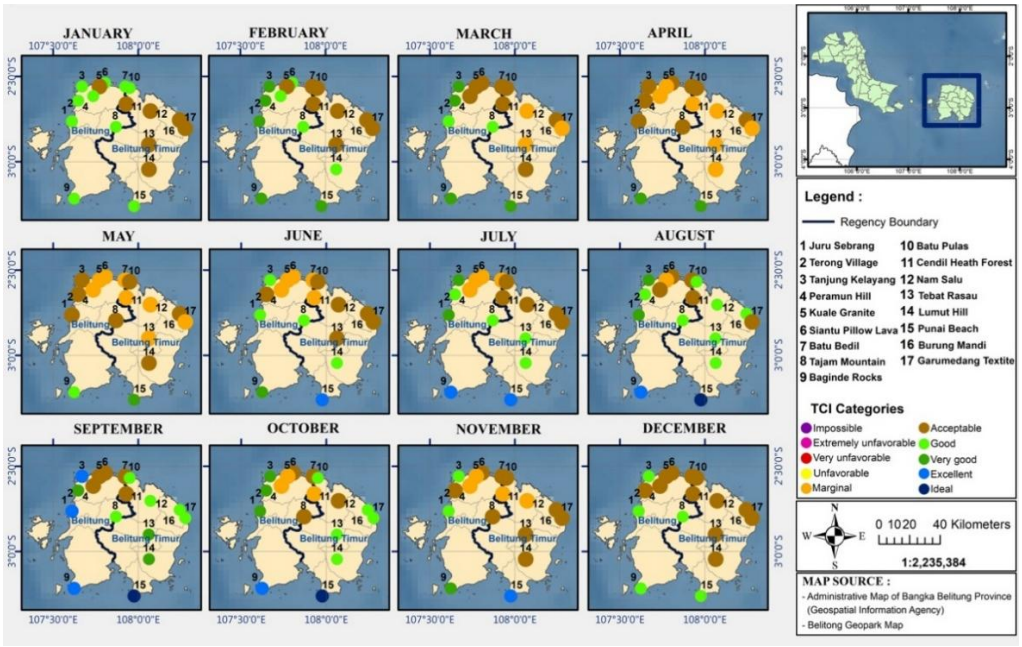

Figure 5. Monthly Spatial Distribution of the TCI During the Projection Periode 2026-2050

Based on Figure 6, the spatial–temporal projection map of TCI for 17 geosites in Belitung Geopark during the 2026–2050 period indicates a variable distribution of tourism climate comfort that generally remains within categories suitable for tourism activities throughout the year. During January–June, most tourism locations in the northern and eastern parts of the island fall within the "acceptable" or "marginal" categories, while southern sites such as Baginde Rocks and Punai Beach consistently maintain "good" to "very good" comfort levels.

A noticeable shift in TCI patterns is evident when compared to the 1991–2024 baseline period. In the projection period, the distribution of TCI categories tends to move toward more moderate levels. Geosites that were previously stable within the "very good" and "good" categories increasingly exhibit dominance of the "acceptable" and "marginal" categories during certain months, particularly from January to June. However, no locations fall into the "unfavorable" or "very unfavorable" categories. From July to December, several sites again reach "good" to "excellent" comfort levels, especially along the southern coast, which is likely influenced by strong maritime effects on daily temperature regulation. In contrast, central and northern regions appear more sensitive to variations in rainfall and increases in maximum temperature.

The projected decline in TCI values is consistent with patterns reported in previous studies, such as the TCI projection analysis in the Toba Caldera Geopark (Siregar et al., 2023), which indicates that climate variability alters temperature and precipitation regimes, thereby affecting tourism climate comfort in the future. These changes are also associated with atmospheric processes and shifts in large-scale circulation patterns driven by global warming.

Overall, the findings confirm that tourism climate comfort is not spatially uniform across Belitung Geopark, despite its location within a single island system. Variations in TCI values among geosites reflect the influence of physical environmental factors, including landform characteristics, proximity to the sea, and local atmospheric dynamics, which collectively shape distinct local climate conditions.

4. Conclusion

This study integrates baseline climate data (1991–2024) and future climate projections (2026–2050) to assess tourism climate comfort across 17 geosites in Belitung Geopark using a spatial–temporal approach. The historical analysis reveals a consistent seasonal pattern, with the highest

TCI values occurring during the dry season (August–September), ranging from 75 to 85 at coastal geosites. In contrast, during the rainy season, TCI values decline to approximately 68–74 in hilly and forested areas due to increased rainfall and higher humidity. The inter-geosite variation in TCI reaches up to 18 points during the peak dry season and about 6–7 points during wetter months.

Under the projection scenario, average monthly TCI values across all locations decrease by approximately 10–30 points compared to the baseline period, particularly during the dry season. Nevertheless, coastal geosites generally remain within categories suitable for tourism activities. These findings indicate the relative climatic resilience of coastal areas to seasonal variability and projected future climate change.

Overall, the results demonstrate that climatic conditions and atmospheric comfort levels within Belitung Geopark are not spatially uniform, despite the sites being located on the same island. Variations in tourism climate comfort among geosites reflect the influence of physical geographic factors, including topography, proximity to the sea, and local atmospheric characteristics. From a practical perspective, these findings highlight the importance of adaptive tourism management strategies, particularly through adjustments to tourism calendars and improvements in supporting facilities during periods when climate comfort is projected to decline.

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