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# Bioclimatic features of Toruń according to the tourism climate index

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**Abstract.**The paper characterises the annual pattern and the long-term variability of the Tourism Climate Index (TCI) in Toruń in the years 1966–2020. In the annual variation, conditions for tourism and recreation were best from May to August. For the summer period (from June to August), the climatic conditions according to TCI were excellent, while for May they were assessed as very good. Meanwhile, the least favourable conditions for recreational and tourist activity occur in the winter months of January and December. In Toruń, there was a statistically significant increase of 0.9 pt/10yr in the annual average TCI value. An improvement in climatic conditions for humans was demonstrated for all seasons but was greatest in spring and autumn (respectively 1.6 and 1.0 TCI pt/10yr). Atmospheric circulation was also found to affect TCI. This was determined using a calendar of circulation types over central Poland, based on which indices of zonal, meridional and cyclonic circulation were used. The study has shown that anticyclonic circulation has the greatest impact on improving conditions for tourism.

**Key words:**
human bioclimate,
climate change,
tourism climate index,
atmospheric circulation,
Toruń,
Poland

## Introduction

Tourism and recreation are a very important part of life for individuals and various social groups alike, as they satisfy three essential human needs: getting to know the world around us, rest and relaxation, and health prophylaxis (Błażejczyk and Kunet 2011; McCabe and Diekmann 2015). The assessment of climate in terms of tourism needs is based mainly on the following climate characteristics: air temperature and humidity, wind speed, sunshine duration and precipitation (Mieczkowski 1985; Błażejczyk 2004).

In terms of bioclimatic regions in Poland (Kozłowska-Szczesna et al. 1997), Toruń is encompassed by a weakly stimulating bioclimate. This means that a visit there requires, at most, only slight physiological adaptation upon arrival and re-adaptation upon return. In another regionalisation, A. Woś (1999) divided Poland according to the frequency of occurrence of various weather types. Toruń lies near the western edge of the Chełmno–Toruń region (Woś 2000).

General information on bioclimatic conditions in the Toruń region can be found in studies on the bioclimate of Poland (e.g. Kuchcik et al. 2013). The more detailed knowledge of Toruń's bioclimate consists of only two studies by Araźny et al. (2015, 2016). The first study assesses the spatial diversity of biometeorological conditions in Toruń and its suburbs. It used data from ten measuring stations to present the Universal Thermal Climate Index (UTCI), Physiological Subjective Temperature

(PST), Insulation Predicted (Iclp) and Physiological Strain (PhS). The second study compares predicted clothing insulation in Toruń and its suburban zone.

The paper presents circulation conditions using indices that contain key information on changes in the intensity of zonal and meridional circulation over the study area (Kożuchowski 1993; Kutiel et al. 1996; Jacobeit et al. 2001; Tomingas 2002; Nowosad 2011; Bartoszek 2017; Araźny et al. 2021). This study employs atmospheric circulation indices denoting zonal, east–west circulation (W), meridional, north–south circulation (S) and cyclonicity (C) (Araźny et al. 2021). These circulation indices (W, S and C) were used to study the long-term variability in atmospheric circulation and to assess the impact of atmospheric circulation on selected meteorological, biometeorological and hydrological elements/indexes in Poland (e.g. Niedźwiedź 2000; Błażejczyk et al. 2003; Falarz 2007; Niedźwiedź et al. 2009; Bartoszek 2017; Araźny et al. 2021; Barczak et al. 2022).

The present study aims to analyse the temporal variability of the main meteorological determinants of tourism-conducive climate in Toruń and to assess the suitability of the climate for tourism on the basis of the TCI index. The article presents the general climate characteristics and TCI values in Toruń for the years 1966–2020. TCI values were analysed for individual months, variability, maximum and minimum values, and frequency of TCI values in ranges that assess climatic conditions for tourism and recreation.

## Research area, materials and methods

This study examines the bioclimatic conditions for tourism and recreation in Toruń (Fig. 1). The meteorological station of the IMGW Toruń-Wrzosy lies at 69 m a.s.l. (53°05'N, 18°35'E) on a flat area in a quite densely built-up, residential district on the outskirts of the city (Araźny and Smukała 2011). Toruń is a medium-sized city in Poland, with about 200,000 residents. It is centred on a Gothic medieval Old Town on the right bank of the Vistula River. The city is the birthplace of Copernicus, and is visited by great numbers of tourists every year (e.g. 2.5 million in 2019, from: www.torun.pl).

This study employed the following meteorological data from the Toruń-Wrzosy IMGW station: average diurnal sunshine duration (h), average and maximum monthly air temperature (°C), average and minimum monthly relative air humidity (%), average monthly sum of atmospheric precipitation (mm), and monthly average wind speed ($m \cdot s^{-1}$). The data were taken from the Institute of Meteorology and Water Management-National Research Institute (Pol. *Instytut Meteorologii i Gospodarki Wodnej – Państwowy Instytut Badawczy*, hereinafter: IMGW-PIB) (https://dane.imgw.pl/).

The above-mentioned data was used to calculate the Tourism Climate Index (TCI). The TCI was proposed by Z. Mieczkowski (1985) and takes into account the main climate characteristics that influence tourism and recreation. The following climate features influence the assessment of the climate in terms of tourism needs: air temperature and humidity, wind speed, sunshine duration, and precipitation. The TCI is a points-based system. The conduciveness of individual climate features to tourism and recreation is assessed on a scale from 0 to 5 (and from -3 to 5 for thermal characteristics), and then the individual ratings are summed according to the following formula (Mieczkowski 1985; Błażejczyk 2004):

$$TCI = 2\cdot(4\cdot CId + CIa + 2\cdot RR' + 2\cdot SD + Wv)$$

where: Cld – thermal comfort assessment index for daylight hours, Cla – thermal comfort assessment index for a full day, RR – precipitation index, SD – sunshine duration assessment index, Wv – wind speed assessment index.

TCI values determine the degree of conduciveness of climatic conditions to tourism: 90≤TCI≤100 – ideal, 80≤TCI<90 – excellent, 70≤TCI<80 – very good, 60≤TCI<70 – good, 50≤TCI<60 – moderate, 40≤TCI<50 – marginal, 30≤TCI<40 – unfavourable, 20≤TCI<30 – very unfavourable, 10≤TCI<20 – extremely unfavourable, TCI<10 – tourist activity impossible.

The influence of atmospheric circulation on TCI was presented by means of three circulation indices: the westerly circulation index (W), the southerly circulation index (S) and the cyclonicity index (C). The study uses monthly atmospheric circulation indices according to Maszewski's calendar of circulation types (Przybylak and


Fig. 1. Location of the meteorological station (WRZ) in Toruń (based on the map in Araźny et al. (2016) and google.com); view of the historic city centre (photo A. Otrębski)

Maszewski 2009). Index values for months were determined by summing weighting points (-2, -1, 0, +1, +2) assigned to specific circulation types. The W index shows the intensity of westerly (positive values) or easterly (negative values) circulation. For each day, depending on the direction of air mass advection, points were assigned: +2 for coming from a westerly direction, +1 for NW and SW, -2 for E, and -1 for NE and SE. The remaining circulation types were assigned a zero score. The S index indicates the intensity of southerly (positive values) or northerly (negative values) circulation. For each day, depending on the direction of air mass advection, points were assigned: +2 for coming from a southerly direction, +1 for SE and SW, -2 for N, and -1 for NE and NW (Araźny et al. 2021). The cyclonicity index C informs about the major activity of atmoshperic lows (positive values) or highs (negative values). The circulation types are scored as follows: +2 for Cc (central cyclonic situation) and Bc (cyclonic trough), +1 for other cyclonic types, and -2 for type Ca (central anticyclonic situation) and Ka (wedge or anticyclonic ridge), -1 for other anticyclonic types (Araźny et al. 2021).

Changes in TCI in the 55-year study period were assessed using linear regression. The significance of the calculated TCI trends was determined using the parametric Student's t-test at a significance level of 0.05. Meanwhile, Spearman's rank-order correlation coefficient between TCI and circulation indices (W, S and C) was set at significance levels 0.01 and 0.05.

## Results

### General characteristic of climatic conditions

The average annual sum of sunshine duration in Toruń in the years 1966–2020 was 1667.6 hours. (4.5 hours/day). The sunshine duration (2,123.3 hours) was highest in 2018, and lowest (1,303.6 hours) in 1980 (Fig. 2). The sunshine duration series for the last 55 years in Toruń shows an upward trend (0.75 h/day), that is statistically significant at 0.05. The number of sunshine hours (>200 h/month) was highest in May–August (7.7–7.4 h/day) and lowest (1.1 h/day) in December. In the analysed period, the highest monthly total sunshine duration (399.0 hours) occurred in July 1994, at 12.9 h/day. Sunshine conditions were also very good in July 2006, at 367.7 hours which equals 11.9 h/day (Wójcik and Marciniak 2006). Conversely, the worst sunshine conditions (12.4 hours) in the analyzed period occurred in December 1970.

The annual average air in Toruń was 8.4 °C. The warmest year (10.5°C) was 2019, and the coldest (6.4°C) was 1987 (Fig. 2). In the last of the analysed years (2018–2020), the highest average annual air temperature values (>10°C) were recorded. Over the full study period of 1966–2020, there was a statistically significant increase of 2.1°C in average annual air temperature in Toruń. The highest average monthly air temperatures occurred in July (18.6°C) and the lowest in January (-1.8°C). The range of variation in average monthly temperature was greatest for in winter, and especially for January, when the temperature ranged from -12.2°C in 1987 to 3.9°C in 2007. The most stable monthly average temperature was for September, ranging from 10.8°C in 1986 and 1996 to from 16.9°C in 1999. The average annual temperature range in Toruń in the analysed 55 years was 22.6 °C. The highest value (31.1°C) was achieved in 2006, and the lowest (17.7°C) in 1989 and 1990. In the period of meteorological research in Toruń beginning in 1871, the absolute values of air temperature varied from -32.4°C (19 January 1963) to 38.2°C (July 11, 1959) (Pospieszyńska and Przybylak 2018). Toruń generates an urban heat island effect. The difference in average air temperatures between the centre of the city (the Old Town) and a reference station is approximately 1°C (Przybylak et al. 2017).

In Toruń, the average annual relative humidity was 79%. The total variability of average annual relative humidity values is 9%. In the 55-year period in Toruń, a statistically significant 4% decrease in humidity was found (Fig. 2). In the annual cycle, the average monthly values (89%) were highest for November and December, and lowest (69%) for May. The variability of monthly averages across the study period ranged from 10% in December and January to 30% in July.

The average annual wind speed in Toruń was 2.7 $ms^{-1}$. In individual years, these values ranged from 2.2 to 3.1 $ms^{-1}$ (Fig. 2). In the examined 55-year period in Toruń, there was a statistically significant 0.5 $ms^{-1}$ decrease in average annual wind speed. The decrease in the average wind speed in Toruń in the 21$^{st}$ century may have been caused by a change in the surroundings of the meteorological station (the surrounding trees grew and the JAR housing estate was built nearby). In the annual cycle, speeds were highest (3.1 $ms^{-1}$) in January and March and lowest (2.2 $ms^{-1}$) in August. The maximum wind speeds in Toruń do not exceed 20 $ms^{-1}$, and the average annual frequency of windless condition is 6% (Wójcik and Marciniak 2006).

In Toruń, the average annual sum of atmospheric precipitation in the period 1966–2020 was 545.0 mm. The range of fluctuations between annual sums of precipitation is significant, amounts to 532.9 mm. The highest sum of 843.3 mm (155% of the average) occurred in 1980, while the lowest was 310.4 mm (57% of the average) in 1989 (Fig. 2). In the study period, no statistical changes were found in the sum of precipitation in Toruń. In the annual cycle, there is a clear maximum of precipitation (84.9 mm) in July, while the minimum (25.0 mm) falls in February. The share of summer rainfall in determining annual sums of precipitation is as much as 39%. October has the highest variability of sums of precipitation, as indicated by the coefficient of variation (75.7%). This is influenced by atmospheric circulation (frequent persistence of high-pressure systems). The absolute monthly sums of precipitation ranged from 0.5 mm (April 2009) to 298.6 mm (June 1980). These values accounted for 1.7% and 440.4% of the long-term average for each of the respective above-mentioned months.

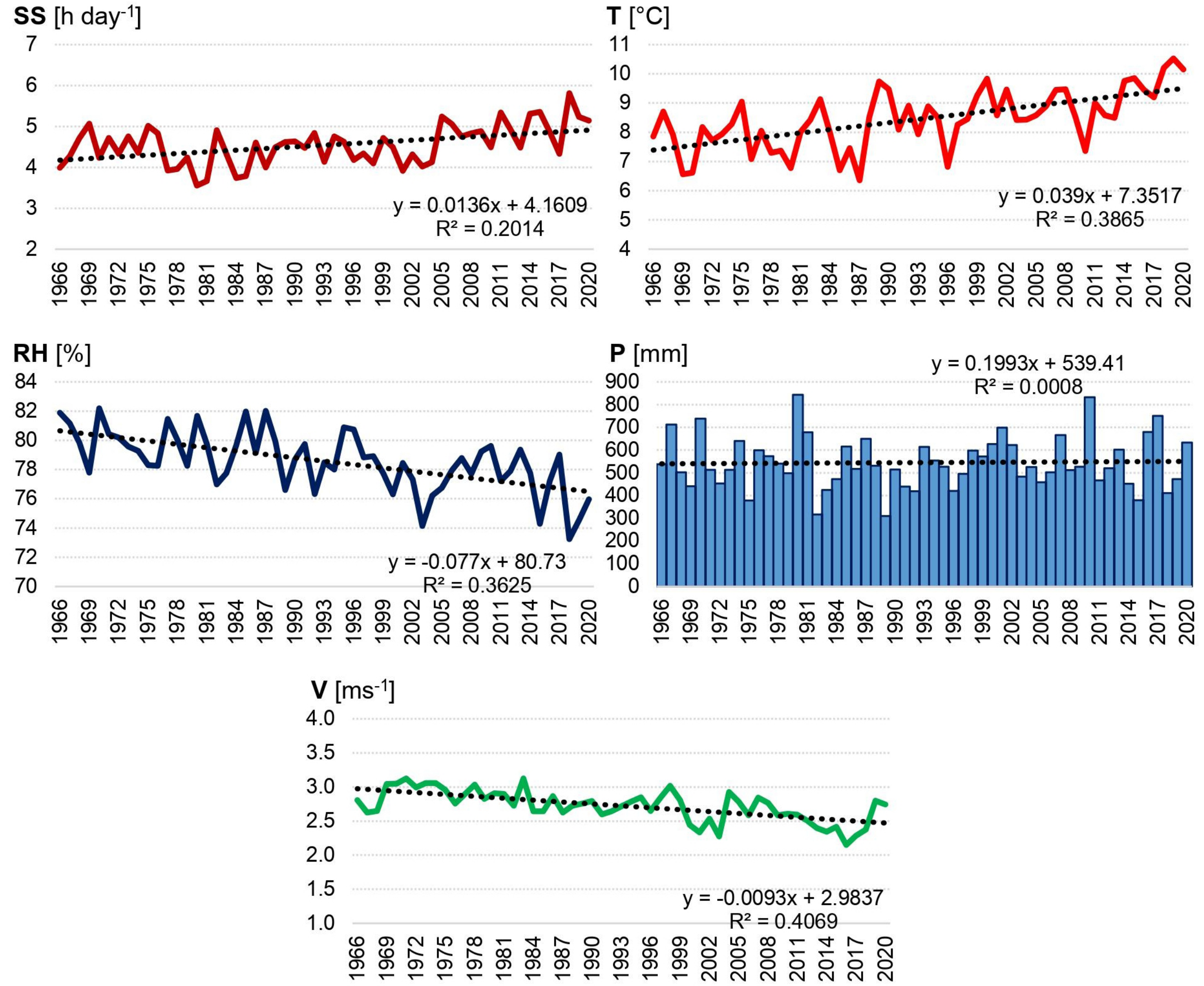


Fig. 2. Climatic conditions in Toruń, 1966–2020 Explanation: T – average annual air temperature, SS – daily sum of sunshine duration, RH – average annual relative humidity, P – annual sum of atmospheric precipitation, V – average annual wind speed

## Tourism Climate Index variability

In Toruń, the best conditions for tourism according to average monthly TCI lasted from May to August (Fig. 3). The climatic conditions were assessed as very good in May, and as excellent in the summer period (Jun–Aug). In annual cycle, two months were assessed as "good" for tourism (Apr and Sept). Conditions were moderate in October and not favourable for tourism in February, March and November. Unfavourable conditions for tourist and recreational activity in Toruń occur in the winter months of January and December.

The extreme monthly TCI values show that TCI is very stable in February and December and very volatile in April and September (Table 1, Fig. 3). TCI values were most variable in the warm half of the year, especially in April, when they ranged from unfavourable to excellent conditions; the volatility reached a maximum of 49 points of difference between the highest and lowest April average TCI. Similarly, in the summer months (June, July, August), the climatic conditions for tourism ranged widely: mostly from moderate to ideal. The absolute variability of monthly TCI values in the analysed period is 73 points (Table 1). The month least favourable for tourism was January 2010 (TCI=25)

Table 1. Range of variation in TCI by month in Toruń, 1966–2020

| Month | Minimum of TCI | Descriptive Category | Maximum of TCI | Descriptive Category | Range of TCI |
|---|---|---|---|---|---|
| Jan | 25 | very unfavourable | 46 | Marginal | 21 |
| Feb | 37 | unfavourable | 52 | Acceptable | 15 |
| Mar | 39 | unfavourable | 62 | Good | 23 |
| Apr | 39 | unfavourable | 88 | Excellent | 49 |
| May | 51 | acceptable | 93 | Ideal | 42 |
| Jun | 59 | acceptable | 93 | Ideal | 34 |
| Jul | 58 | acceptable | 98 | Ideal | 40 |
| Aug | 64 | good | 98 | Ideal | 34 |
| Sep | 43 | marginal | 89 | Excellent | 46 |
| Oct | 33 | unfavourable | 66 | Good | 33 |
| Nov | 30 | unfavourable | 51 | acceptable | 21 |
| Dec | 29 | very unfavourable | 48 | Marginal | 19 |

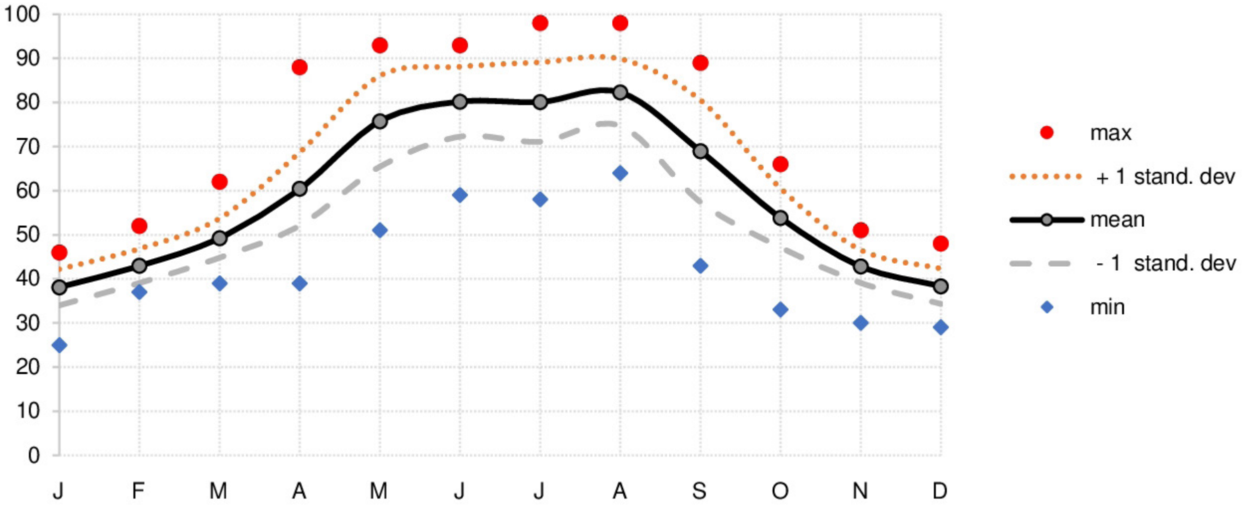

Fig. 3. Annual variation in mean and extreme TCI values in Toruń, 1966–2020

and the most favourable was July 2006 and August 2015 (TCI=98). The climatic conditions of the studied area are therefore very variable in terms of suitability for tourism and outdoor recreation – from very unfavourable to ideal.

Weather conditions affect the TCI value in Toruń. TCI shows very high variations – over the year, from year to year, and from season to season (Figs 3, 4a and 5). The analysis of monthly averages for seasons and for the entire year in the examined 55 years allows trends to be determined in weather conditions favourable for tourism and recreation. In the analysed period, a statistically significant increase (0.9 pt/10yr) in average annual TCI was found (Fig. 5). Also, the TCI for all seasons showed an upward trend. The improvement in climatic conditions for humans is fasted in spring and autumn (1.6 and 1.0 pt/10yr, respectively), and the slowest in winter and summer (0.5 and 0.6 pt/10yr, respectively) (Fig. 5).

From the perspective of the bioclimatological needs of tourism, it is important to determine the frequency of occurrence of certain conditions for individual months over the annual cycle (Fig. 4b). In the analysed 55 years in Toruń, conditions were ideal for tourism from May to August. These conditions were proportionally greatest (18.2%) in July, and slightly less so (16.4%) in August.

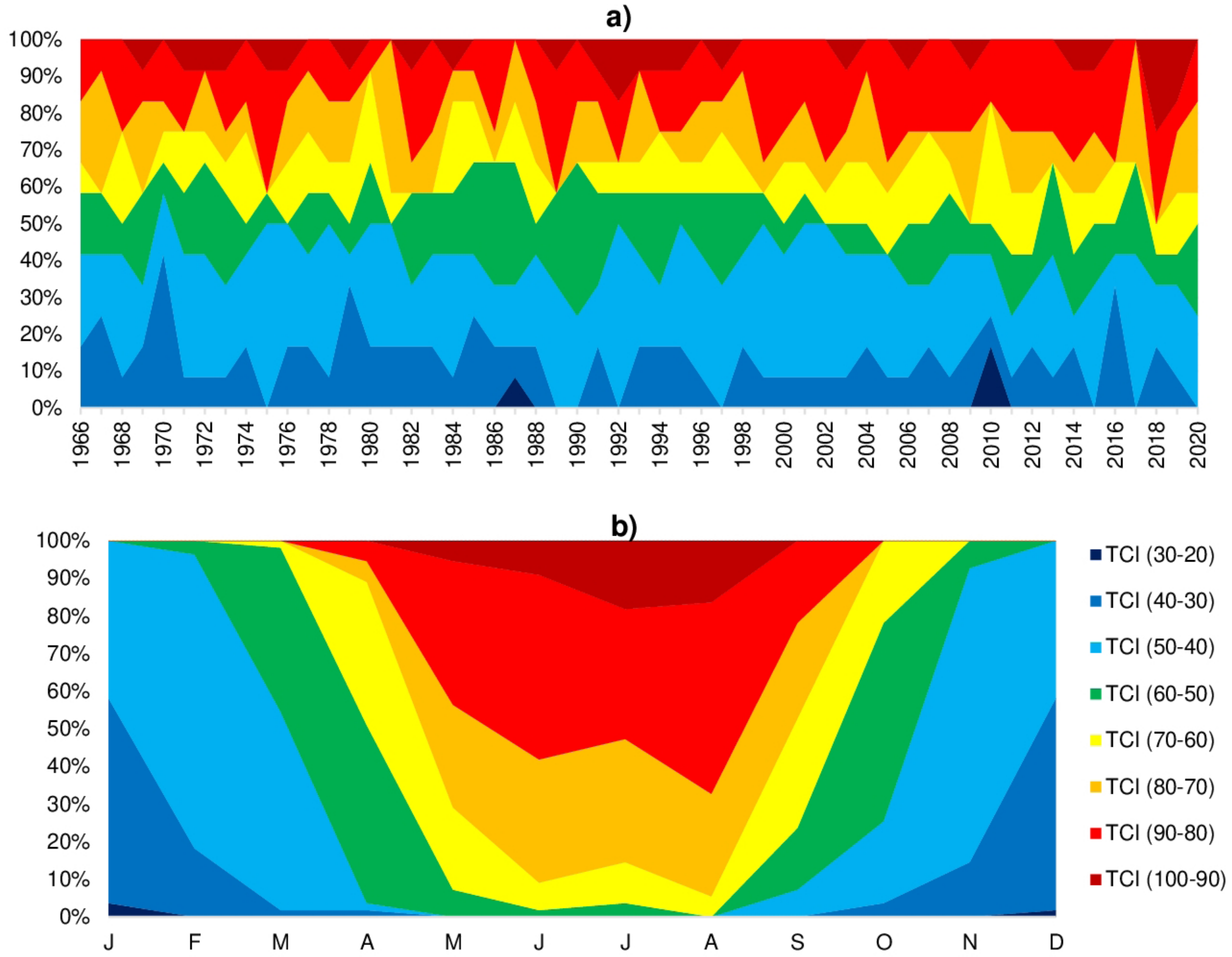


Fig. 4. Relative frequency (%) of climatic conditions according to monthly TCI values: from year to year (a) and in individual months (b) in Toruń, 1966–2020

Toruń had ideal conditions for tourists for 27 months (4% of the entire research period). Excellent conditions were noted from April to September. In May, June, July and August, these accounted for over one third (38.2%, 49.1%, 34.5% and 50.9%, respectively). Climatic conditions that were very good for tourism and recreation occurred from April to September (meanwhile, in August, such conditions were the "worst" that occurred). Very good conditions occurred more frequently (32.7% each) in June and July. Good conditions for tourism appeared from March to October. They had by far their largest share in April (38.2%). Moderate conditions characterised transitional seasons, appearing from February to July and from September to November. They accounted for a significant share in October (52.7%), April (47.3%) and March (43.6%). Conditions in the "marginal" category occurred from September to April, while this was also the best category that the winter months (Dec–Feb) could manage. Their largest share was in February and November (both 78.2%).

The climate was assessed as unfavourable for tourism from October to April. This state dominated the months of December and January (approx. 55–56%). Very unfavourable conditions appeared only in December and January. They occurred only three times: in January of 1987 and 2010, and in December of 2010. In Toruń, in no month of the analysed period did extremely unfavourable conditions (TCI<20) occur, nor conditions preventing tourist activity (TCI<10) (Fig. 4b).

In addition to averages, important information about changes in climatic conditions that affect tourism and outdoor recreation is also provided

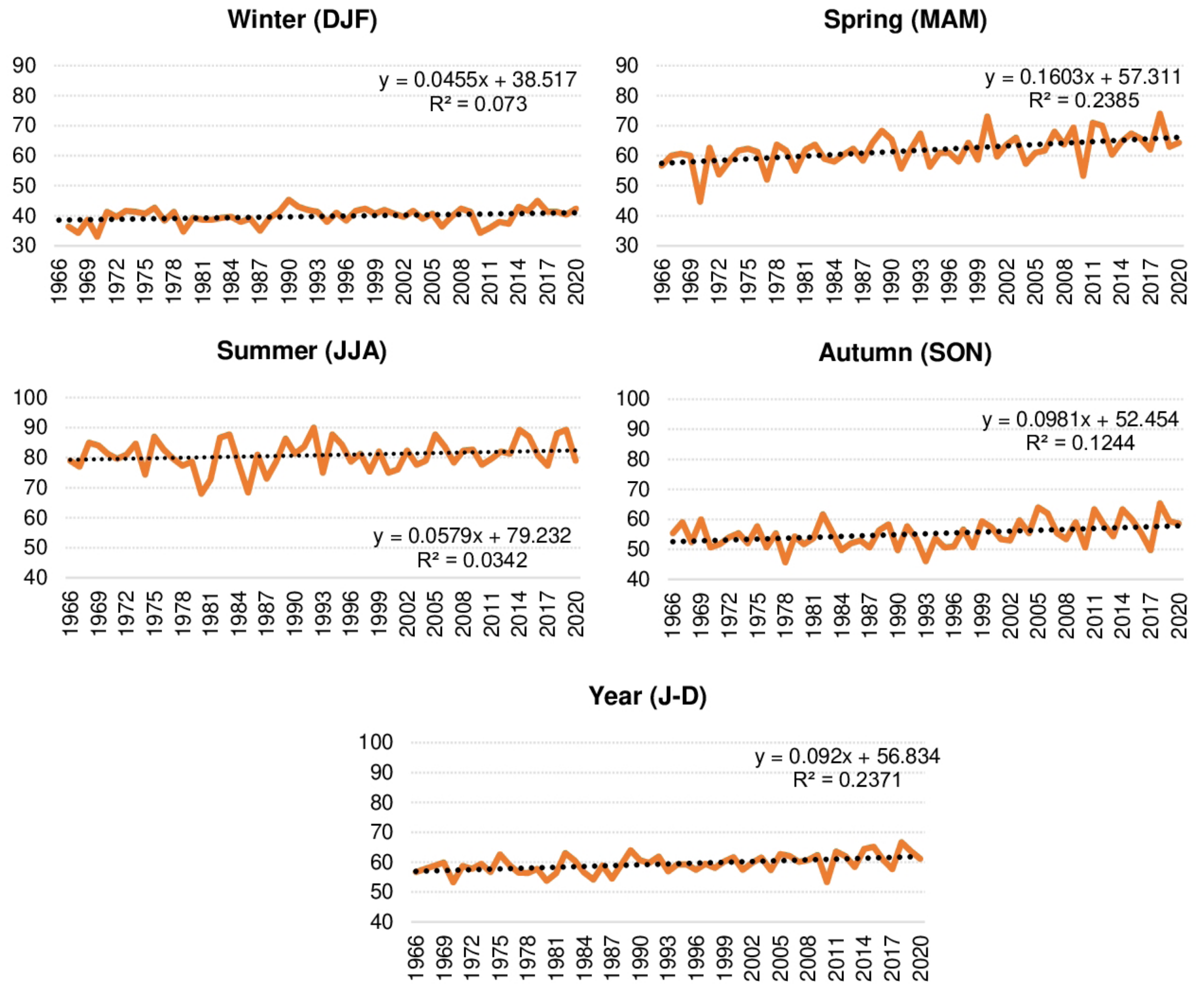

Fig. 5. Variation in monthly mean TCI by season and by whole years in Toruń, 1966–2020

by assessing changes in the frequency of months with specific values of the TCI index (Fig. 6). As shown earlier (Fig. 5), mean TCI values increased steadily in the period 1966–2020. The improvement in conditions for tourism is mainly due to the increased frequency of months with higher TCI values (Fig. 6). The increase was greatest for months with excellent, good and ideal conditions for tourism and recreation (1.6, 0.4 and 0.3 pt/10yr, respectively). Months assessed as unfavourable, moderate and marginal decreased in frequency, with weather conditions in such months also decreasing in conduciveness for tourism and recreation by -1.4, -0.5 and -0.4 pt/10yr, respectively. There were only three months with TCI values of 30–20, i.e. unfavourable conditions for humans, Meanwhile, no months of extremely unfavourable conditions during which tourist activity was impossible in Toruń were found in the analysed period.

## The influence of atmospheric circulation on the Tourism Climate Index

Atmospheric conditions over the Bydgoszcz–Toruń region are shaped by both macroscale and mesoscale circulation processes. During the year, the advection of air from the west prevails over advection from the east over central Poland, and air flows in from the south slightly more frequently than from the north. Anticyclonic situations exceed

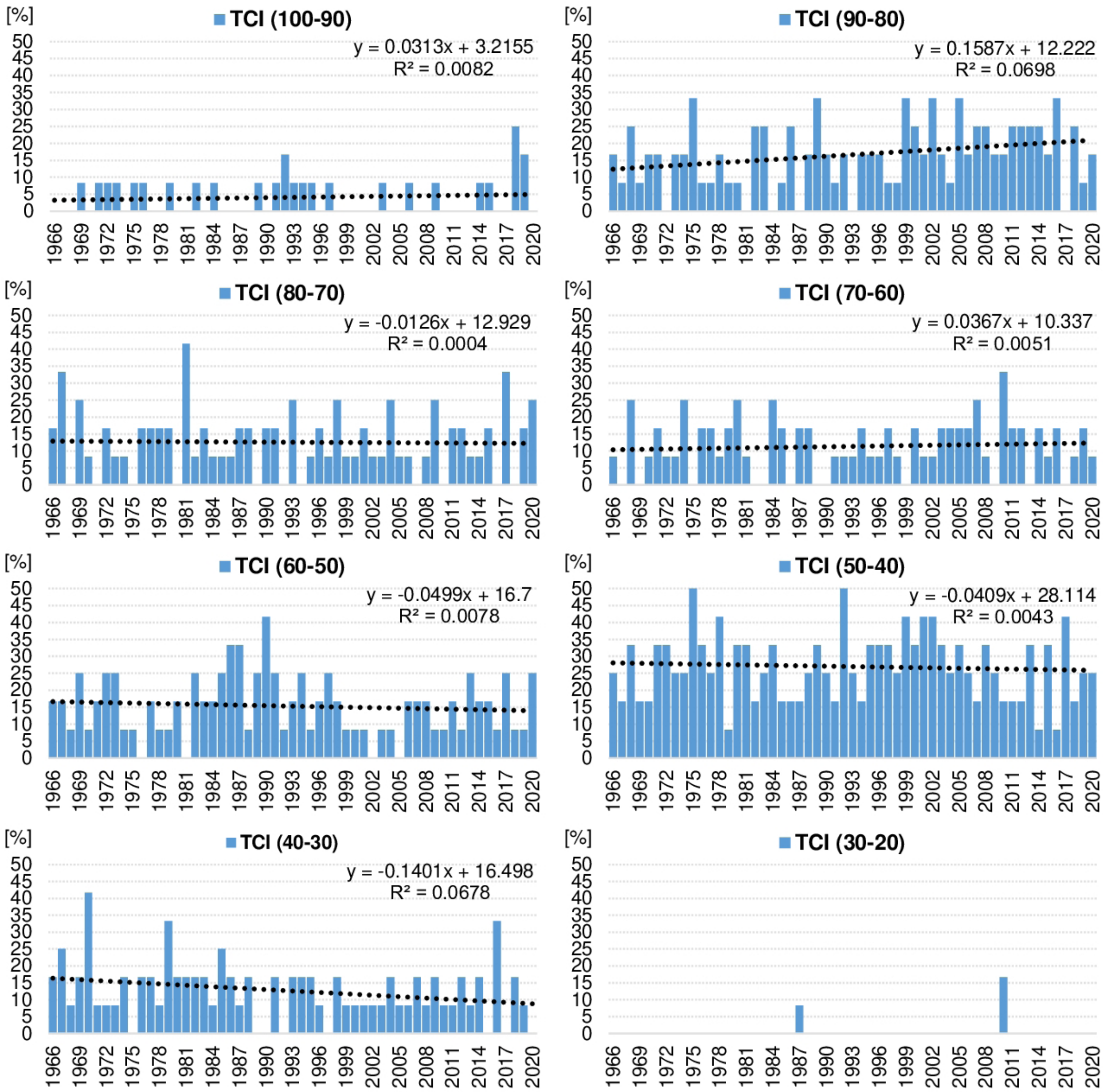


Fig. 6. Relative frequency (%) of climatic conditions according to monthly TCI values: ideal (100–90), excellent (90–80), very good (80–70), good (70–60), moderate (60–50), marginal (50–40), unfavourable (40–30) and very unfavourable (30–20) in Toruń, 1966–2020

cyclonic types in frequency (Araźny et al. 2021; Bartczak et al. 2022).

In Toruń in the years 1966–2020, westerly circulation prevails in the average annual cycle of the zonal W index (Table 2). It predominates from October to January (in December this index rises to 19.3). In the rest of the year, this flow weakens, and only in May does it reach a negative value (W=-0.9). In the annual cycle of the S index for the 55-year study period, in the months from October to March, Toruń was dominated by the southerly component. It reaches its highest intensity in November (S=8.8). From April to September, the opposite is observed, with the minimum in June and July (-9.1 and -9.7, respectively). In the annual cycle of the C index for the 55 years, in the months from November to

Table 2. Mean monthly indices of circulation: W, S and C (A) and Spearman's rank-order correlation coefficients between indices

| Index | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A) Circulation indices | | | | | | | | | | | | |
| W | 16.3 | 10.3 | 10.9 | 2.8 | -0.9 | 6.9 | 11.9 | 8.2 | 11.1 | 14.0 | 15.4 | 19.3 |
| S | 6.1 | 5.6 | 2.4 | -2.5 | -5.8 | -9.1 | -9.7 | -5.4 | -1.7 | 6.6 | 8.8 | 5.1 |
| C | 2.7 | 2.3 | 1.7 | 3.5 | -3.0 | -4.0 | -6.1 | -11.4 | -6.5 | -5.2 | 3.1 | 3.2 |
| B) Correlation coefficients | | | | | | | | | | | | |
| W/TCI | 0.49** | 0.21 | 0.07 | -0.37** | -0.08 | -0.02 | -0.27* | -0.21 | 0.02 | -0.18 | 0.21 | 0.14 |
| S/TCI | 0.04 | 0.05 | -0.19 | -0.05 | 0.30* | -0.07 | -0.16 | 0.10 | 0.44** | 0.34* | 0.09 | 0.31* |
| C/TCI | -0.36** | -0.26 | 0.71** | 0.69** | 0.64** | -0.63** | 0.67** | -0.52** | 0.67** | -0.53** | -0.18 | -0.37** |

Explanations: significant correlation: ** at 0.01; * at 0.05

April, cyclonic forms predominated. Conversely, high-pressure forms predominated over low-pressure forms in the remaining months of the year. In the average annual cycle, the S index drops as low as -11.4 (in August).

The study found a statistically significant correlation between monthly TCI the Bydgoszcz–Toruń region and westerly atmospheric circulation (in January) and easterly circulation (in April and July) (Table 2). The volatility of TCI was well captured by the S index for one third of the year. The highest positive and statistically significant coefficients of correlation between TCI and the frequency of the circulation index S were noted for May, September, October and December. Over Toruń, for most of the year (except February and November), a statistically significant correlation was found between the inflow of anticyclonic air and monthly TCI values (Table 2).

## Summary

The best conditions for outdoor tourism and recreation in Toruń according to the tourism climate index that was adopted for assessing them, occur from May to August. During this period, from June to August, the climatic conditions were described as excellent, and in May as very good. There were good bioclimatic conditions for tourism in April and September. By contrast, the most unfavourable conditions for tourism and recreation were in the winter months of January and December.

The annual cycle of TCI presented in this study is very similar to results for other cities in Poland (e.g. Kalabarczyk and Kalabarczyk 2007; Chabior 2008; Kaszewski and Wawer 2009; Siedlecki 2015) and for cities in Northern and Central Europe such as Helsinki, Stockholm, London, Kraków and Paris (e.g. Błażejczyk and Kunert 2011; Scott et al. 2016). The values of the TCI index reflect the seasonality of the European climate. The most favourable conditions for tourism in the above-mentioned cities are found during the summer months. From November to January, the climatic conditions in northern and central Europe are generally unfavourable. By contrast, in the annual cycle of TCI in Southern Europe, e.g. in Athens, Thessaloniki, Rome, Batumi, Tibilisi, Debrecen and Szeged (according to Amiranashvili et al. 2008, 2010; Błażejczyk and Kunert 2011; Kovacs and Unger 2014; Scott et al. 2016) there is a drop in climatic conduciveness to tourism from June to September. In the summer, there are periods of hot weather (heat waves) that put a significant strain on the human body. This phenomenon is often noted in southern parts of Europe. This is due to the low values of the thermal comfort assessment index for daylight hours (Cld) (Błażejczyk and Kunert 2011).

The evaluation of changes in TCI index values shows a statistically significant positive trend (0.9 pt/10yr) in the average annual index value for Toruń in the years 1966–2020. There is also an increase in the frequency of days with high TCI values, while the number of days with less favourable conditions for tourism and recreation is decreasing. At the turn of the 21st century, the conditions for tourism and recreation in Toruń improved. This is mainly influenced by a marked increase in sunshine duration (e.g. Matuszko et al. 2020, 2021; Bartoszek and Matuszko 2021), air temperature (e.g. Kejna and Rudzki 2021; Climate of Poland 2021; Twardosz et al. 2021; Ustrnul et al. 2021) and intensity of meridional and anticyclonic atmospheric circulation (Araźny et al. 2021; Bartczak et al. 2022) in central Poland.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

## Author contributions

Study design AA; data collection AA, ID; statistical analysis AA, ID; result interpretation AA, ID; manuscript preparation ID, AA; literature review: ID, AA.

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