GEOGRAPHY AND TOURISM, Vol. 8, No. 2 (2020), 107-119, Semi-Annual Journal
eISSN 2449-9706, ISSN 2353-4524, DOI: 10.36122/GAT20200820

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Anemometric conditions in the area of Bydgoszcz in the years 1971–2010 using the example of the Bydgoszcz-Airport weather station

Abstract: This paper refers to the characteristics of anemometric conditions in the area of Bydgoszcz based on data sourced from the Bydgoszcz-Airport weather station in 1971–2010. Annual mean wind speed measured in a multi-annual period was higher in the winter half-year and lower in the summer half-year, which is typical of the climate of central Poland. In the analysed multi-annual period, the annual mean wind speed was 3.3 m·s-1. The annual curve of average wind directions in the multi-annual period was characterised by a prevailing share of west wind, followed by that of south, east and north winds. The prevailing average wind direction in the analysed multi-annual period was west wind (W), followed by southwest (SW), northwest (NW), southeast (SE), east (E), south (S), north (N) and northeast (NE) wind.
Keywords: Bydgoszcz, airport, wind, speed, direction

1. Introduction

Interest in the information on meteorological resources and risks has been continuously increasing. The most spectacular manifestation of the changes is a regular, statistically significant increase in air temperature observed in many regions and localities (Łaszyca and Kuśmierek-Tomaszewska, 2013), accompanied by intensified severe weather phenomena. The intensification involves increased frequency and dynamics of such phenomena, the area of their impact, and their increasingly adverse effect on the natural environment and human life (Łaszyca, 2018).

Wind, being one of the most significant elements of the climate, determines the horizontal and vertical transport of heat, water vapour and air pollutants. According to Parczewski (1960), when the limit values are exceeded, a correspondence occurs between small increases or decreases in wind speed and rapid changes in the intensity of many important weather processes having a significant effect on climatic and bioclimatic conditions (ventilation processes curve, elimination of stuffiness, daily temperature amplitudes). Pawlak (2014) claims that the direction and speed of wind may lead to the purification of air or result in an influx of new environmentally harmful emissions from industrial, municipal and transportation sources. In addition, according to Dubicka (1994), when analysing wind speed, the distribution of frequency of wind direction changes is a significant indicator of weather variability and air masses advection variability. On the other hand, the structure of wind direction is a valuable indicator of the thermodynamic status of air.

This paper aims to describe the characteristics of anemometric conditions in the area of Bydgoszcz in the years 1971-2010 using nineteen intervals such as months, year, summer and winter half-years, and seasons of the year.

2. Weather measurements in Bydgoszcz

The regular weather measurements and monitoring in Bydgoszcz commenced in 1848. Therefore, knowledge in this respect is quite extensive, but often fragmentary and scattered through different publications, e.g. Wójcik and Marciniak, 1989; Bąk, 2003; Żmudzka, 2009; Kasperska-Wołowicz and Bolewski, 2015; Łaszyca, 2018. It is based on data from different multi-annual periods and measuring stations. In particular, measurement data from the weather station set up within the premises of the airport in 1924 is not used in full. The station, located in open space, meets the condition of the results being representative, which means they can refer to both the city of Bydgoszcz and a wider area within the radius of several dozen kilometres.

According to the study by Peszek and Żarski (1990), regular weather measurements and monitoring in Bydgoszcz started at the beginning of 1848 (air temperature) and in 1861 (atmospheric precipitation). Until 1906 they were carried out in different locations in the city and since the beginning of 1907 in the premises of agricultural institutes located in the city centre. The local establishment of the Institute for Land Reclamation and Grassland Farming (also known as Bydgoszcz-IMUZ) operated continuously until 2005 playing different roles – from a weather station operating in a national network (until 1970) to a measuring station working for the needs of agricultural scientific institutes, mainly the Institute for Land Reclamation and Grassland Farming (Kasperska-Wołowicz and Bolewski, 2015). In the opinion of Żarski (2012), it is impossible to include the results of measurements from the 19th century in the studies of changes in regional and local climate as they are not comparable to measurements carried out later.

Another measuring station in the city of Bydgoszcz with a long history and series of meteorological data is the station set up in 1924 on an upland in the area of the airport. This station (most often called Bydgoszcz-Airport) operated in the national network continuously until August 1982 and was closed down as a station of the National Hydrological and Meteorological Institute (PIHM-IMGW) due to economic difficulties (Peszek and Żarski, 1990). Data from that station were used in numerous studies and publications, primarily in the Climatic Atlas of Poland (Atlas Klimatyczny Polski, 1977-79) containing data from 1931 to 1960 and for some indicators from 1951 to 1960. Despite meteorological measurements being carried out in Bydgoszcz such as: atmospheric pressure, air temperature, dew point, degree and type of clouds, cloud base height, relative air humidity, wind direction and speed, visibility, weather phenomena, the data were not processed for many years. Only recently, thanks to the collaboration between the author and employees of the local University of Science and Technology (UTP), works were published describing thermal conditions in the area of Bydgoszcz in 1951–2010 (Łaszyca and Kuśmierek-Tomaszewska, 2013) and relative humidity in vegetation periods in 1985–2010 (Kuśmierek-Tomaszewska et al., 2015). The first publication was based on the results of measurements carried out both within a national network and by military weather stations.

The third measuring station providing data on climatic conditions in the area of Bydgoszcz described in many publications is a measuring station in Mochle, attached to the Research Station of the University of Science and Technology in Bydgoszcz. As reported by Żarski et al. (2017), the measuring station has operated continuously since 1949. It is situated on the south-eastern edge of the Krajenskie Lake District, about 20 km away from the city centre, in a poorly urbanised and industrialised area. According to the above-mentioned authors, the measuring station is free from urban anthropogenic impacts and can be representative of the area of Bydgoszcz.

Due to closing of the measuring stations Bydgoszcz-Airport and Bydgoszcz-IMUZ operating in a national measuring network of the Institute of Meteorology and Water Management, data from Bydgoszcz were not included in the latest edition of the Climatic Atlas of Poland by Lorenc (2005). A widely interpreted Kuyavian-Pomeranian region is represented by the weather station of the Institute of Meteorology and Water Management (IMGW) in Toruń and a more distant station in Chojnice.

3. Source material

The work uses meteorological data collected in 1971–2010 (40 years of continuous weather measurements and monitoring) by the Bydgoszcz-Airport Weather Stations operating in the years 1951–1982 (SZS code: 353170240) under the auspices of the Institute of Meteorology and Water Management – EPBY reference according to ICAO (International Civil Aviation Organization). In 1951–1965 the station was used for basic measurement of meteorological parameters such as: air temperature, dew point, degree and type of clouds, relative air humidity, wind direction and speed, and visibility. In 1983–2010 the measurements of meteorological parameters were continued by military observers trained in Dęblin and army civilians in the Military Aviation Meteorological Station – EPBW reference according to ICAO (International Civil Aviation Organization), providing meteorological services for military and civil aviation and standard climate measurements and observations.

In February 2007, at the airport in Bydgoszcz-Szwederowo, the station of the Institute of Meteorology and Water Management – National Research Institute was reactivated (SZS code: 253180220) and remained in operation until 31 December 2019. The measuring stations were situated in a reserved, fenced section of the airport, about 800 m from one another, so data used for the analyses were considered homogeneous and meeting the condition of comparability of measurements. The stations were located on an upland within the premises of Bydgoszcz-Szwederowo Airport (Fig. 1) φ=53˚05'N, λ=17˚58'E, h=72.0 m a.s.l., about 3.5 km away from the city centre, free of any anthropogenic impact, which guarantees that they are representative of the area of Bydgoszcz. At the same time, both stations met the standards according to the World Meteorological Organization No 8 2010.

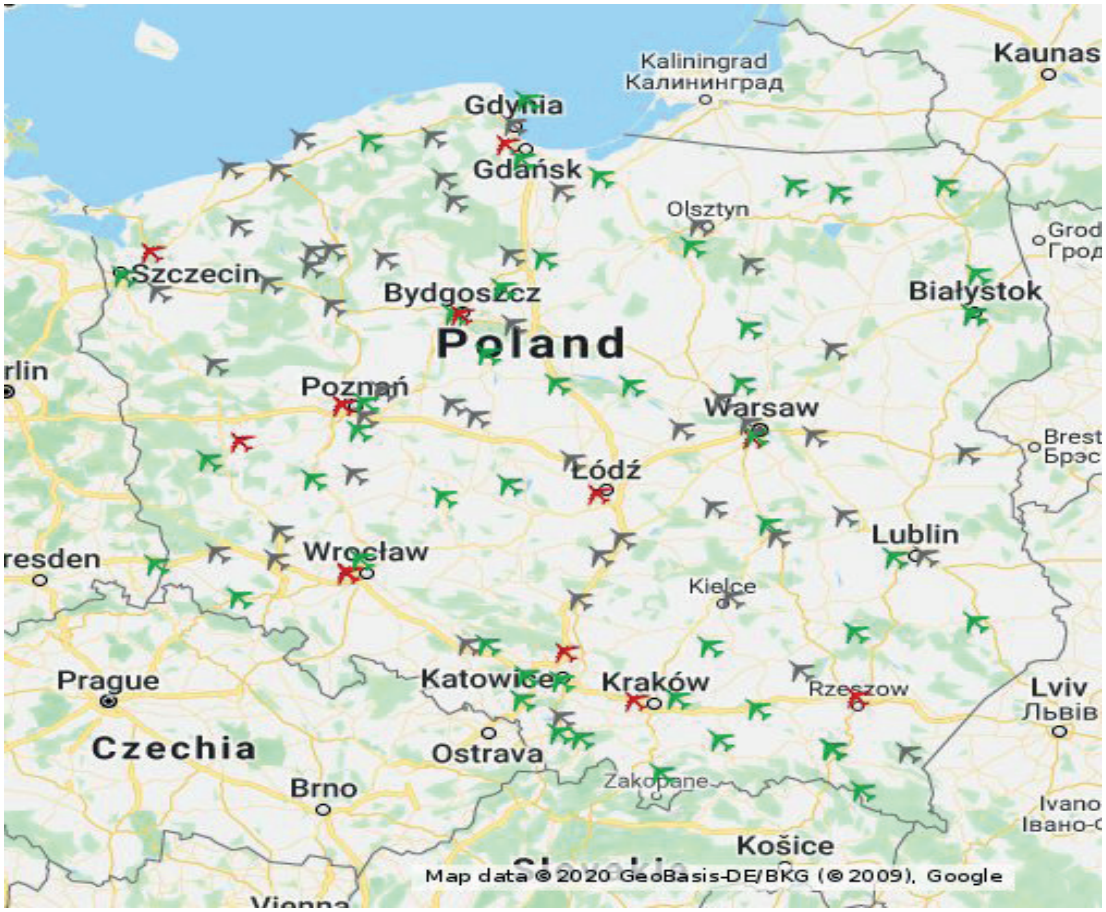

Figure 1. Location of the Bydgoszcz-Airport station (Source: https://www.google.com/maps)

3.1. Research methods

Data was verified using Standard Normal Homogeneity Test (SNHT) developed by Alexandersson (1986), as modified by Stepanek (2006), which revealed relative series homogeneity. Homogeneous data were obtained through a comparative analysis of results with those provided by the nearest representative weather station of the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB) Toruń-Wrzosy, situated about 50 km to the east from Bydgoszcz. The second reference point was an agrometeorological measuring point in Mochełek situated about 18 km towards northwest from Bydgoszcz. It is run by employees of the Department of Land Reclamation and Agrometeorology at the University of Science and Technology in Bydgoszcz and satisfies the general guidelines of the Institute of Meteorology and Water Management for weather stations and measuring points operating in Poland.

After revisions, the research covered homogeneous series of daily mean values of continuous meteorological elements, i.e. wind direction measured according to the eight-pointed wind rose and wind speed measured in $m \cdot s^{-1}$.

Based on the data, the variability of monthly, periodic and annual mean values of meteorological elements was analysed in the multi-annual period of 1971–2010, and selected elements of descriptive statistics were calculated. Regression analysis was carried out and, based on the linear function, the direction and trends of changes of the analysed elements in time were determined. The study period was divided into two twenty-year periods, that is, 1971–1990 and 1991–2010, and it was examined whether the extremity of respective meteorological parameters increased or decreased over time. Two indicators used in that case were standard deviation and value range.

4. Wind speed

Mean wind speed, being a fundamental meteorological element describing the wind conditions in the area of Bydgoszcz, was analysed using nineteen intervals such as months, year, summer and winter half-years and seasons of the year.

The annual mean wind speed in a multi-annual period in the area of Bydgoszcz was higher in the winter half-year and lower in the summer half-year, which is typical of the climate of central Poland. The highest mean multi-annual wind speed was noted in December, and the lowest in August. The largest variability of wind speed over time, considering value range and standard deviation, was recorded in October and March, and the smallest in May (Fig. 2).

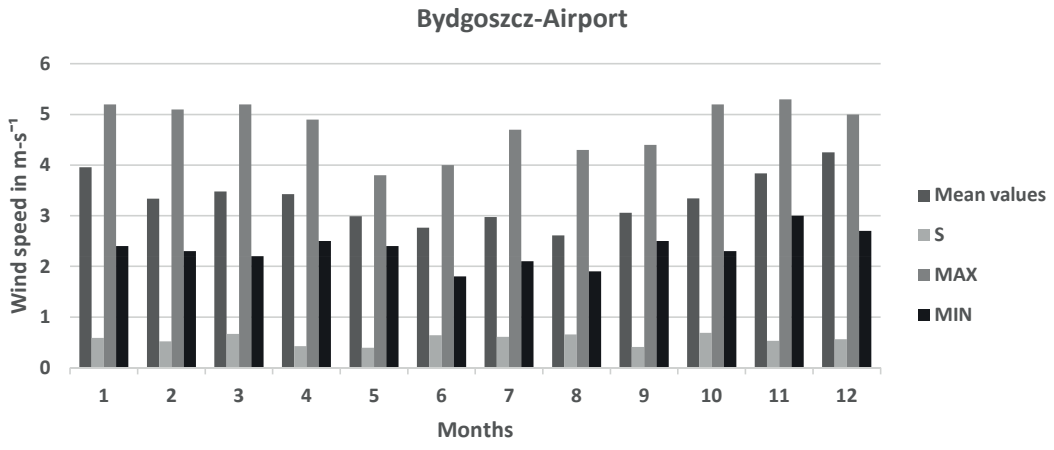

Figure 2. Annual curves of monthly mean wind speed in a multi-annual period, including maximum (MAX) and minimum (MIN) value and standard deviation (S) in the area of Bydgoszcz in the years 1971–2010

The annual mean wind speed in the area of Bydgoszcz based on measurements carried out in the Bydgoszcz-Airport station in the multi-annual period 1971–2010 was 3.3 $m \cdot s^{-1}$, ranging from 3.0 in 1993, 1994, 2001, 2002, 2005 to 4.0 $m \cdot s^{-1}$ in 1972 and 1979 (Table 1). Comparing half-years, higher wind speed values were recorded in the winter half-year in comparison to the summer half-year. Analysing mean wind speed in respective seasons of the year, a decreasing order was observed: winter – the highest speed, autumn, spring, summer – the lowest speed.

Wind speed in the area of Bydgoszcz was characterised by high variability over time in analogous periods of successive years of the analysed multi-annual period of 1971–2010. The proof is the values of standard deviation and extreme mean wind speed in the analysed multi-annual period of 1971–2010 as presented in Table 1.

Table 1. Multi-annual (1971–2010) mean wind speed in the area of Bydgoszcz [$m \cdot s^{-1}$] including temporal variability characteristics

Month Period	Mean	MAX Year	MIN Year	Value range MAX-MIN	S
I	4.0	5.2 1995	2.4 2009	2.8	0.59
II	3.3	5.1 1973	2.3 1978	2.8	0.52
III	3.5	5.2 1972, 1981	2.2 1993	3.0	0.67
IV	3.4	4.9 1972	2.5 2001	2.4	0.42
V	3.0	3.8 1972	2.4 1978, 2005	1.4	0.39
VI	2.8	4.0 2008, 2009	1.8 1999	2.2	0.64
VII	3.0	4.7 1974	2.1 2003	2.6	0.61
VIII	2.6	4.3 1980	1.9 1984, 1987, 1997, 2002	2.4	0.65
IX	3.1	4.4 1979	2.5 1989, 2001	1.9	0.41
X	3.3	5.2 1978	2.3 1977	2.9	0.69
XI	3.8	5.3 1980	3.0 1983	2.3	0.53
XII	4.3	5.0 1973, 1974, 1978, 1981	2.7 2007, 2008	2.3	0.56
I-XII	**3.3**	**4.0** **1972, 1979**	**3.0** **1993, 1994, 2001, 2002, 2005**	**1.0**	**0.30**
IV-IX	3.0	3.9 1972	2.5 1994, 2001, 2002	1.4	0.39
X-III	3.7	4.6 1979	3.0 2009	1.6	0.34
III-V	3.3	4.6 1972	2.6 1993	2.0	0.40
VI-VIII	2.8	3.8 1972, 1979	2.1 1984, 1999	1.7	0.55
IX-XI	3.4	4.5 1978, 1980	2.9 1984, 2005	1.6	0.42
XII-II	3.9	4.5 1979	2.8 2009	1.7	0.33

MAX – the highest mean value in the multi-annual period, MIN – the lowest mean value in the multi-annual period, S – standard deviation

Out of the analysed 480 monthly mean values (40 years x 12 months) the highest wind speed was recorded in November 1980 (5.3 $m \cdot s^{-1}$), and the lowest in June 1999 (1.8 $m \cdot s^{-1}$). A higher number of extremes (33) occurred in the previous twenty-year period, that is, 1971–1990, in comparison to 1991–2010 (27).

In the analysed period, that is 1971–2010, mean wind speed showed a positive trend in February only, and for other analysed time intervals negative trends and tendency for change over time were observed. Linear regression equations were significant in 12 out of 19 analysed cases and referred to: the whole year and both half-years, spring, summer, autumn and the months: April, July, September, October, November and December (Table 2). Figures 3–5, illustrating change trends, indicate that the annual mean wind speed in the area of Bydgoszcz decreased by 0.15 $m \cdot s^{-1}$ over 10 years, in autumn by 0.19 $m \cdot s^{-1}$, and in December by 0.26 $m \cdot s^{-1}$ over every 10 years in the analysed multi-annual period, that is 1971–2010.

Table 2. Changes in wind speed [$m \cdot s^{-1}$] in the area of Bydgoszcz in the period from 1971 to 2010, including the coefficient of correlation and determination characterising the linear relationship

Month Period	Change over 10 years	Coefficient of determination R^2	Coefficient of correlation r
I	-0.03	0.0036	-0.0604
II	-0.03	0.0073	0.0855
III	-0.16	0.0802	-0.2832
IV	-0.15	0.1686	-0.4106**
V	-0.09	0.0755	-0.2749
VI	-0.12	0.0517	-0.2273
VII	-0.23	0.1867	-0.4321**
VIII	-0.17	0.0913	-0.3022
IX	-0.14	0.1519	-0.3897*
X	-0.26	0.1991	-0.4463**
XI	-0.18	0.1566	-0.3958*
XII	-0.26	0.2956	-0.5437**
I-XII	**-0.15**	**0.3311**	**-0.5754****
IV-IX	-0.15	0.1977	-0.4447**
X-III	-0.14	0.2518	-0.5005**
III-V	-0.13	0.1532	-0.3914*
VI-VIII	-0.17	0.1369	-0.3699*
IX-XI	-0.19	0.2868	-0.5355**
XII-II	-0.09	0.0929	-0.3084

critical value of the coefficient of correlation 0.3120 (α=0.05), 0.4026 (α=0.01); * statistical significance

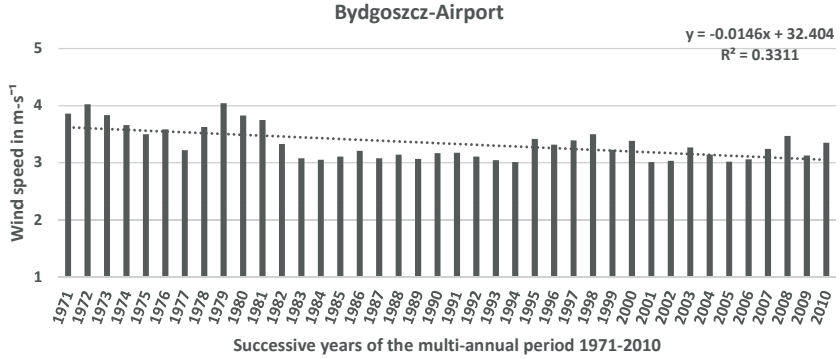

Figure. 3. Downward trend in annual mean wind speed in the area of Bydgoszcz in 1971–2010

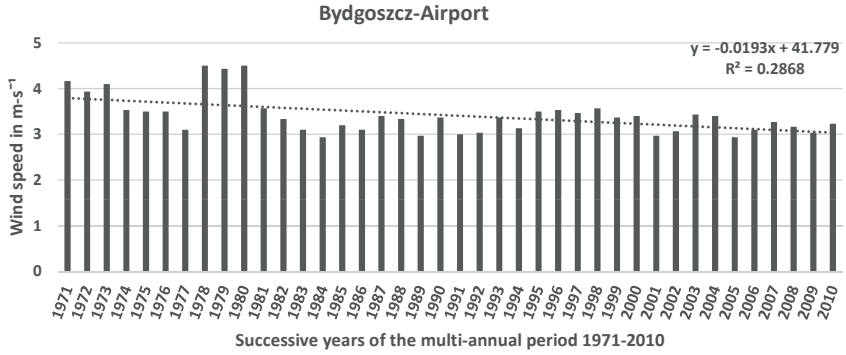

Figure 4. Downward trend in the mean wind speed in autumn (IX-X) in the area of Bydgoszcz in 1971-2010

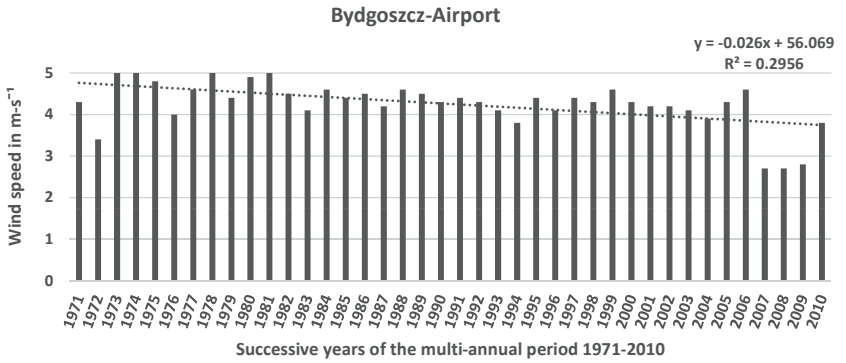

Figure 5. Downward trend in the mean wind speed in December in the area of Bydgoszcz in 1971-2010

Based on the comparison of the results of temporal variability of mean wind speed measured in the period 1991–2010 (second 20-year-period) with those in the period 1971–1990 (first 20-year-period), it can be stated that increased temporal variability was identified in 3 out of 19 analysed cases (Table 3). It referred to months such as January and December, and the winter season. With reference to other time intervals either a decrease was identified in temporal variability (February, March, April, May, July, August, September, October, November, year, warm and cold half-year, spring and autumn) or no clear changes in the extreme values of mean wind speed were observed in the compared 20-year periods (June, summer).

Table 3. Comparison of indicators of temporal variability of wind speed in 1971–1990 and 1991–2010 in the area of Bydgoszcz

Month / Period	Standard deviation		Value range (MAX-MIN)		**Temporal variability**
	1971–1990	1991–2010	1971–1990	1991–2010	
I	0.59	0.60	1.9	2.8	+
II	0.64	0.35	2.8	1.3	-
III	0.80	0.50	2.7	1.9	-
IV	0.46	0.36	2.0	1.4	-
V	0.43	0.34	1.4	1.1	-
VI	0.64	0.62	1.9	2.2	
VII	0.62	0.50	2.4	1.7	-
VIII	0.80	0.42	2.4	1.5	-
IX	0.47	0.28	1.9	1.0	-
X	0.83	0.44	2.9	1.5	-

XI	0.60	0.41	2.3	1.8	-
XII	0.40	0.59	1.6	1.9	+
I-XII	0.35	0.16	1.0	0.5	-
IV-IX	0.42	0.31	1.3	1.0	-
X-III	0.37	0.27	1.2	1.0	-
III-V	0.48	0.29	1.9	0.9	-
VI-VIII	0.57	0.46	1.7	1.7	
IX-XI	0.51	0.21	1.6	0.6	-
XII-II	0.30	0.37	1.3	1.5	+

+ increased temporal variability; - decreased temporal variability

5. Wind direction

Wind direction, being a fundamental meteorological element describing anemometric conditions in the area of Bydgoszcz, was analysed for nineteen intervals including mean values for months, year, summer and winter half-years, and seasons of the year.

The frequency of multi-annual wind directions in the area of Bydgoszcz was characterised by the prevailing share of the west wind sector (SW-W-NW) – 43.8%, followed by south wind sector (SE-S-SW) – 33.2%, east wind sector (NE-E-SE) – 26.7% and north wind sector (NW-N-NE) – 25.9% (Fig. 6, Table 4). Variable wind and windstill accounted for 5.6% and 7.2% of occurrence frequency, respectively (Table 4).

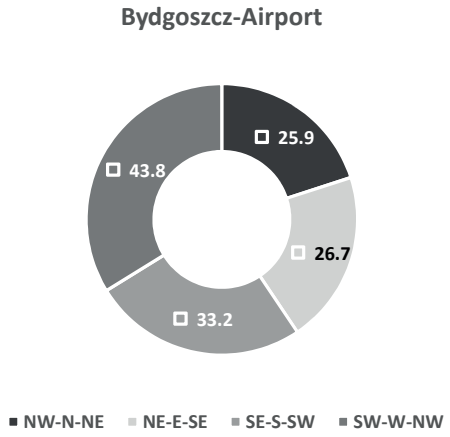

Figure 6. Annual distribution of average wind directions by sectors in the multi-annual period 1971–2010 in Bydgoszcz

Table 4. Frequency of monthly and seasonal average wind directions according to "sectors" in the multi-annual period 1971–2010 in the area of Bydgoszcz

Month	Sector NW-NNE	Sector NE-ESE	Sector SE-SSW	Sector SW-WNW	Windstill ST	Variable wind VW
I	18.1	26.7	42.2	46.5	5.6	5.4
II	29.6	19.4	34.0	51.9	5.4	7.5
III	26.7	29.3	33.0	41.8	5.5	7.7
IV	34.1	28.5	29.2	39.7	5.8	5.8
V	32.2	32.0	25.9	36.4	6.5	8.3
VI	34.1	16.7	24.4	44.5	9.1	9.3
VII	32.9	25.4	21.0	44.2	9.3	5.6
VIII	24.9	32.1	31.1	37.3	12.3	4.2
IX	30.3	36.4	31.9	35.7	5.7	2.8
X	18.8	18.1	40.3	56.0	8.1	2.5
XI	15.7	31.0	40.3	41.7	7.5	4.3
XII	13.8	24.9	45.0	50.1	5.2	3.2

IX-II	**25.9**	**26.7**	**33.2**	**43.8**	**7.2**	**5.6**
IV-IX	31.4	28.5	27.3	39.6	8.1	6.0
X-III	20.5	24.9	39.1	48.0	6.2	5.1
III-V	31.0	29.9	29.4	39.3	5.9	7.3
VI-VIII	30.6	24.7	25.5	42.0	10.2	6.4
IX-XI	21.6	28.5	37.5	44.5	7.1	3.2
XII-II	20.5	23.7	40.4	49.5	5.4	5.4

NW-W-NE – north sector, NE-E-SE – east sector, SE-S-SW – south sector, SW-W-NW – west sector, ST – windstill, VW – variable wind.

In the analysed multi-annual period, that is 1971–2010, the most frequently observed average wind direction was west wind (W) – 18.3%, followed by southwest (SW) – 13.7%, northwest (NW) – 11.8%, southeast (SE) – 10.7%, east (E) – 9.8%, south – 8.9%, north (N) – 7.9% and northeast wind (NE) – 6.2% as well as variable wind (VW) – 5.6% of occurrence frequency; windstill on average accounted for 7.2% (Fig. 7).

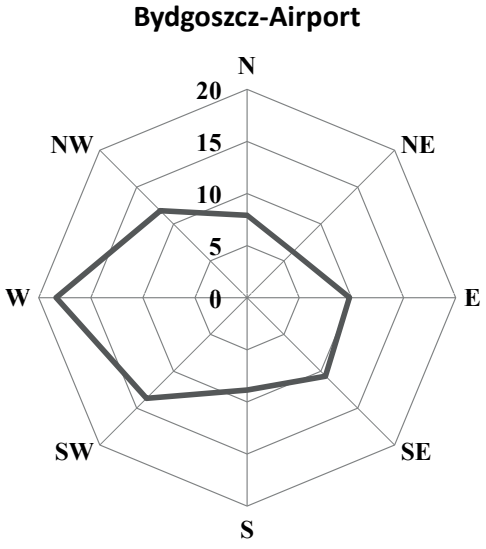

Figure 7. Frequency of average wind directions in the multi-annual period 1971–2010 in the area of Bydgoszcz

The prevailing wind direction in both half-years was west wind (W), which accounted for 20.1% and 16.6% of occurrence frequency, respectively, in the winter half-year and the warm half-year (Fig. 8). Wind direction with the lowest occurrence frequency share in the winter half-year was northeast wind (NE) – 3.7%, and in the warm half-year it was south wind (S) – 7.6% (Fig. 8). In respective seasons of the year, the most frequently occurring wind was also west wind (W) which accounted for 15.5% of occurrence frequency in spring, 18.3% in summer, 19.5% in autumn and up to 20.0% in winter. The least frequently occurring wind directions in respective seasons of the year were: northeast wind (NE) – in winter (3.9%) and autumn (4.7%) and south wind (S) – in summer (7.3%) and in spring (7.9%) (Fig. 9-12). In respective months of the multi-annual period the prevailing wind direction, except in February (NW – 17.9%), was west wind (W) which occurred with a frequency ranging from 23.7% in October to 14.3% in May (Fig. 12). The lowest share in particular months of the year was that of NE wind which occurred with a frequency ranging from 5.4% in February to 1.4 % in October. The month with the most even distribution of wind directions was September, when the share of west wind (W) was 14.8% and that of east wind (E) – 14.5% (Fig. 13).

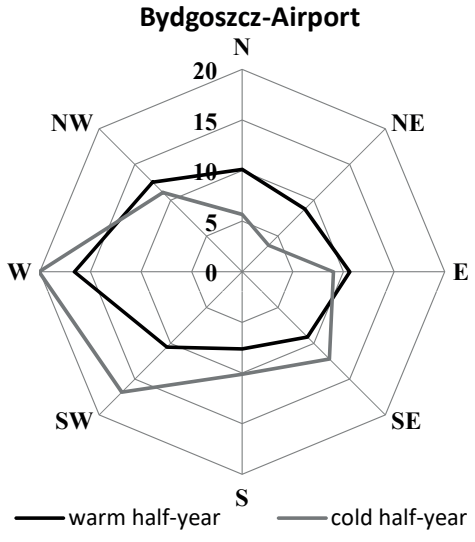

Figure 8. Frequency distribution of average wind directions in the warm and cold half-year in the multi-annual period 1971–2010 in the area of Bydgoszcz

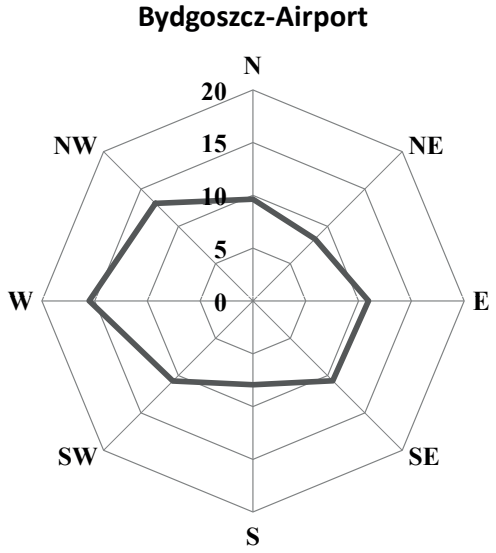

Figure 9. Frequency of average wind directions in spring in the multi-annual period 1971–2010 in the area of Bydgoszcz

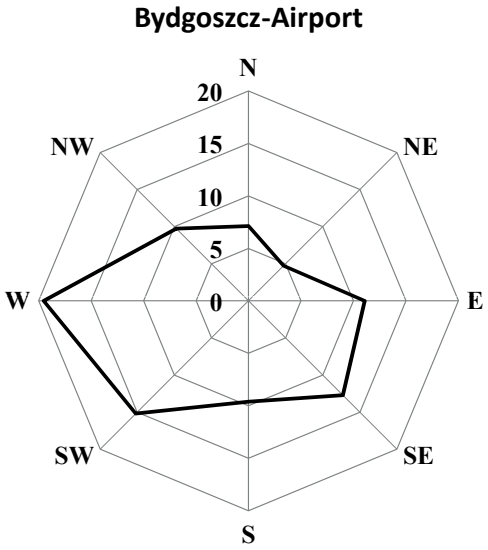

Figure 11. Frequency of average wind directions in autumn in the multi-annual period 1971–2010 in the area of Bydgoszcz

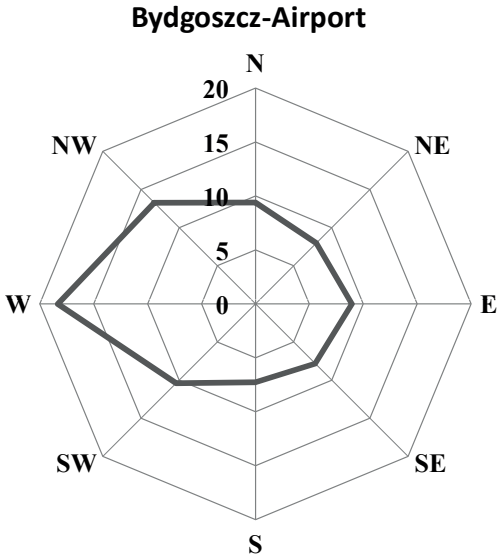

Figure 10. Frequency of average wind directions in summer in the multi-annual period 1971–2010 in the area of Bydgoszcz

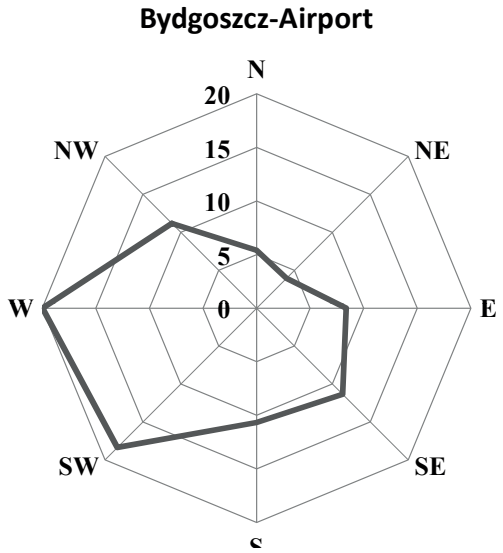

Figure 12. Frequency of average wind directions in winter in the multi-annual period 1971–2010 in the area of Bydgoszcz

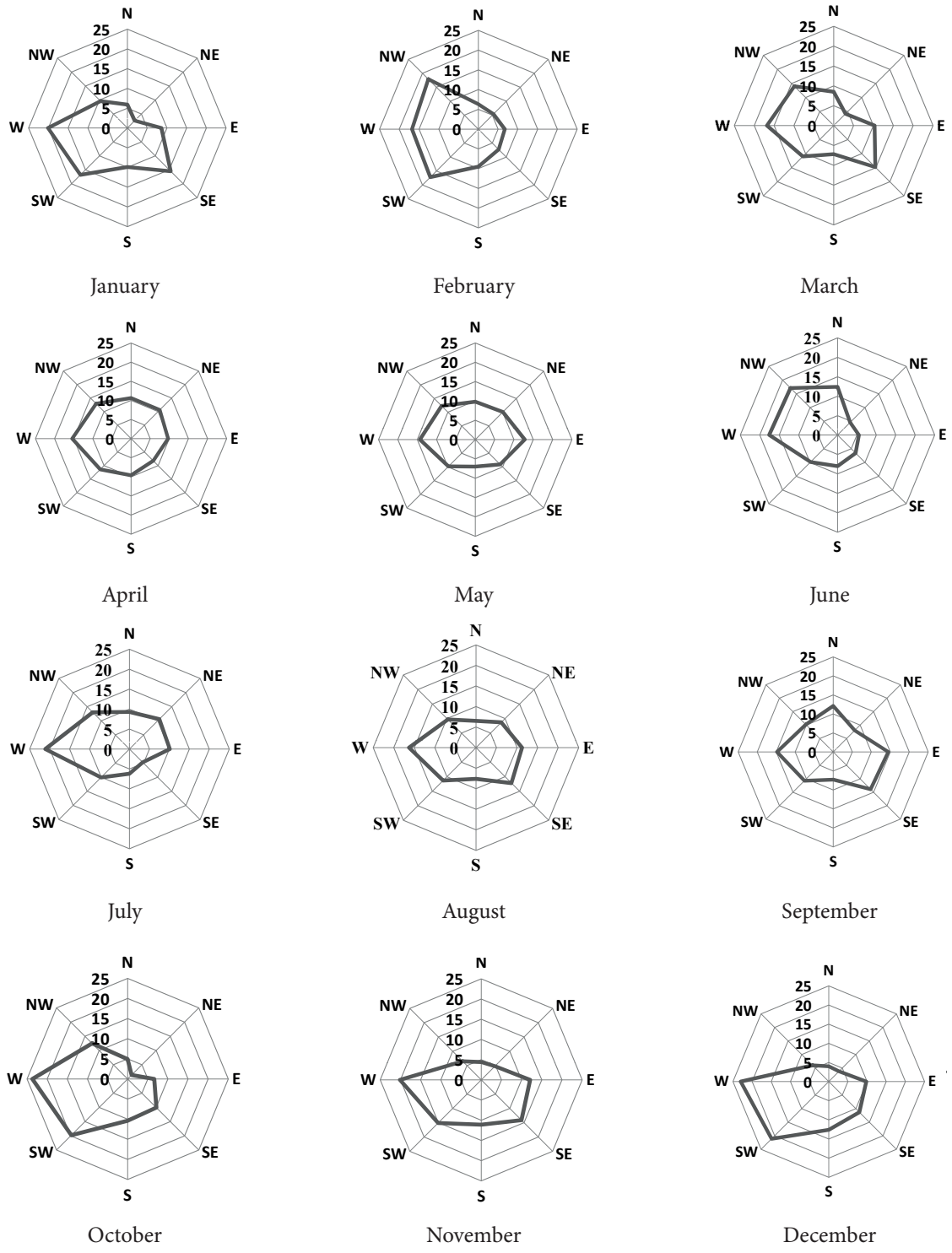

Figure 13. Distribution of frequency of average wind directions in respective months of the multi-annual period 1971–2010 in the area of Bydgoszcz

6. Discussion and conclusions

Studies carried out by Hohendorf (1969) within the area of the airport in Bydgoszcz in 1931–1960 showed mean wind speed of 3.2 $m \cdot s^{-1}$, which was higher than in the city centre. According to Woś (1994), weak winds with speeds ranging from 2.5 to 3.5 $m \cdot s^{-1}$ prevail throughout the region of Kuyavia. On the other hand, studies carried out by Lorenc (2005) revealed that in 1971–2000 the mean wind speed in the area of Bydgoszcz was approximately 4 $m \cdot s^{-1}$, and the prevailing wind directions were west sector winds (SW-W-NW). Similar results were obtained in own studies by the present author for the multi-annual period of 1971–2010, where the mean wind speed was 3.3 $m \cdot s^{-1}$, and the average wind direction (43.8%) for all analysed measurements was west wind sector (SW-W-NW).

Based on the comparison of the results of temporal variability of mean wind speed measured in the period 1991-2010 (second 20-year-period) with those in the period 1971–1990 (first 20-year-period), it can be stated that increased temporal variability was identified in 3 out of 19 analysed cases (Table 3).

The annual values and curves of cloud formation conditions in the area of Bydgoszcz were characteristic of the climate of central Poland and generally did not deviate from those found in publications on national, regional or local climatic conditions.

Cloud formation and wind conditions in the area of Bydgoszcz in 1971–2010 featured very high temporal variability manifested in different values of the analysed meteorological parameters in the analogous calendar periods in respective years.

The results of the study can be used in order to develop a climatological guide for the Bydgoszcz-Szwederowo Airport and help in operations carried out for the needs of meteorological services for civil aviation, such as planning and insurance of the flights of airplanes, helicopters, gliders, as well as military drills and operations, and safe parachute jumping.

In addition, this paper contributes new knowledge and addresses the gaps in literature on wind speed and directions in the area of Bydgoszcz.

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