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Prediction of precipitation deficit and excess in Bydgoszcz Region in view of predicted climate change

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Abstract

The paper presents the prediction of rainfall shortage and excess in Bydgoszcz region in the growing seasons (April–September) in 2011–2050 in the perspective of climate change. Based on the predicted monthly sum of precipitations for the percentile 50%, calculated by the regional climate model RM5.1 for Poland with boundary values taken from global model ARPEGE, a decrease in the amount of rainfall during the growing season by approximately 55 mm is predicted, compared to 1971–2000 taken as a reference period. The qualification of rainfall shortage and excess was made using the standardised precipitation index (*SPI*). According to the predicted values of *SPI*, the occurrence of 38 months of rainfall excess and 40 months of rainfall deficit in the period 2011–2050 is predicted. Dry months will constitute 16% of all months, wet months – 13%, and normal months – 71%. The occurrence of 13 several-month long periods of rainfall excess and 14 such periods of drought are predicted. The longest periods of both wet and dry weather will last 5 months. So long wet periods are expected in 2020, 2022 and 2031, and drought periods in 2017–2018, 2023–2024 and from 2046 to 2049.

Key words: *climate models, drought, precipitation, rainfall excess, standardized precipitation index SPI*

INTRODUCTION

Bydgoszcz region is an area where agriculture is an important country economy sector despite unfavourable natural conditions. In the growing season the Kujawsko-Pomorskie Province, including Bydgoszcz region, faces natural disasters like droughts, floods, inundation and hailstorms. The biggest losses in agriculture of Bydgoszcz region are caused by droughts. The intensity of these phenomena is closely associated with the increase of air temperature which was noted already in the 1980s and prolongs until present with various intensity. Detailed calculations made by BARANOWSKI *et al.* [2012] for the period 1999–2011 showed that losses caused by natural disasters in the province amounted ca. 3.4 billion zlotys (over 800 million €). The biggest losses were noted in agriculture and these were caused by droughts. Particularly severe was the drought in 2006 which covered an area of 750 thousand ha and resulted in 830 million zlotys losses. The region of Bydgoszcz and the neighbouring region of Toruń belong to driest areas in Poland, which was demonstrated in many studies [BĄK *et al.* 2012b; BĄK, ŁABĘDZKI, 2002; BĄK, MASZEWSKI 2012; ŁABĘDZKI 2007; USCKA-KOWALKOWSKA, KEJNA 2009]. ŁABĘDZKI [2008] who analysed standardised precipitation index (*SPI*) in Bydgoszcz for the years 1861–2006 found that the mean period of meteorological drought was 2.4 months and the maximum one was 9 months long. In growing seasons (April–September) of the years 1954–1998 BĄK and ŁABĘDZKI [2002] found 33 months with meteorological droughts in Toruń, 39 in Bydgoszcz, 42 in Polanowice, Poznań and Płock and 48 in Koło. Such distribution of droughts suggests that the greatest threat of droughts is typical of areas south of Bydgoszcz.

The deficit of atmospheric precipitation is the reason of agricultural and hydrological droughts in surface waters (summer–autumn low waters). These phenomena appear 1–2.5 months after a substantial deficit of precipitation combined with high air temperature (and hence increased field evaporation). Bydgoszcz region is an area of less frequent low water periods than e.g. Wielkopolska Lakeland and Wielkopolska Lowland but the periods are longest in Poland [Wachowiak, Kępińska-Kasprzak 2011]. Due to agricultural character of the region, the deficit of surface waters is extremely unfavourable from the economic point of view. Studies by Szymczak [2005] on changes in the river outflow from small lowland catchments in the years 1966–2000 in Masovian region showed decreasing trends of maximum outflow both annually and in the winter half-years. Author showed that observed changes are a result of climate warming (particularly those in the winter half-year) and of decreasing annual sums of atmospheric precipitation.

Spatial differentiation of agricultural droughts in Bydgoszcz region, in Kujawy (Więcławice) and in the upper Noteć River valley (Frydrychowo) was monitored by the Institute of Technology and Life Sciences in the years 2008–2011 based on a network of several automatic meteorological stations [Bąk, Łabędzki 2013]. It was found that meteorological drought exerted most significant effect on agricultural droughts in tuber crops (late potato and sugar beet) on soils of smaller reserve of useful water. The effect was larger in the case of late potato crops. In grasslands, agricultural drought appeared most frequently in dry habitats. Fewer droughts were noted in drying habitats and in moist habitats the droughts did not appear. With the use of remote sensing one may obtain more detailed spatial and temporal distribution of precipitation than from the network of pluviographs. This was shown among others in studies by Somorowska [2012] carried out in the years 2004–2008 in Warsaw agglomeration. Annual sums of precipitation recorded by meteorological radar in November–October and seasonal sums from May till October were on average by 50 mm higher than those measured in the network of pluviographs. Such studies are of particular importance for understanding the effect of precipitation on the functioning of various ecosystems sensitive to water deficits and excesses.

Floods in Bydgoszcz region are most often caused by flood wave originating in the south of Poland as an effect of intensive precipitation. They are of local characters and losses in the Odra River catchment are almost 2.5 times smaller than in the Vistula River catchment. The largest area of inundated lands (almost 7000 ha) was noted during the millennium flood in 1997. Sporadically, the threat is posed by water rising in streams and rivers due to local, short but intensive downpour. Based on measurements from 29 measurement stations in the years 1966–2010, Krężałek *et al*. [2013] demonstrated that the maximum daily precipitations of a probability of p = 1%, 10% and 50% were 95, 57 and 32 mm, respectively. With the use of log-gamma distribution which better describes samples of a high variability, respective values were 109, 63 and 34 mm.

The rate of warming rapidly increased in the last two decades of the 20th century and in the beginning of the 21st century in Poland [Żmudzka 2009]. This phenomenon was observed in both the winter–spring period (January–May) and in the summer. Statistically significant increase in air temperature during the growing season (April–September) was also noted in the years 1971–2010 at the meteorological station Bydgoszcz–ITP (Fig. 1).

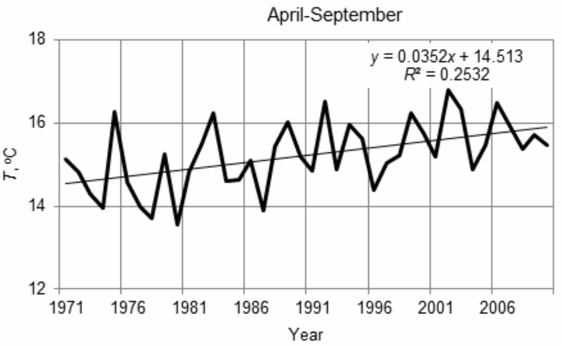

Fig. 1. Mean air temperature T (°C) in the growing season (April–September) in the meteorological station Bydgoszcz–ITP in 1971–2010; source: own study

Most climate change scenarios predict further increase of air temperature in Poland and in Europe in the next decades of the 21st century [ICM 2013; IMGW 2012; Liszewska 2000, 2013; Solomon *et al*. 2007]. Predicted increase of temperature may globally vary between 1.5°C and 4.5°C from 1990 to 2100. In Europe this increase may vary between 2.0°C and 6.3°C. Actions are planned in the EU member countries to prevent temperature increase by more than 2.0°C till the year 2050 [Zebisch *et al.* 2005].

The prediction of monthly mean air temperature in the growing seasons (April–September) shows significant positive trend for Bydgoszcz region (Fig. 2). Forecast air temperatures were calculated in the Interdisciplinary Centre of Mathematical and Computer

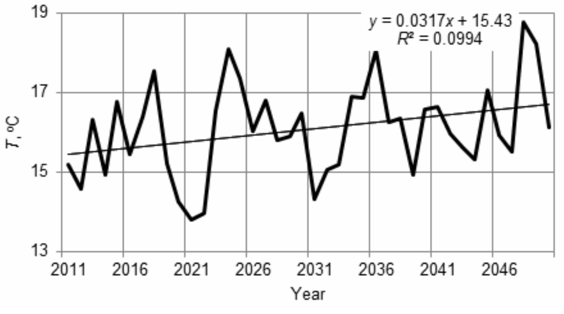

Fig. 2. Predicted mean air temperature *T* (°C) in the growing season in Bydgoszcz region in the years 2011–2050; source: own study

Modelling, Warsaw University with the use of regional model of climate change for Poland RM5.1 [ŁABĘDZKI *et al.* 2013b]. Adopted model assumes spatially differentiated and season-dependent statistically significant temperature increase from 1.5°C to 2.5°C in Poland for the years 2021–2050 [LISZEWSKA 2013].

The increase in air temperature will be followed by seasonal changes in atmospheric precipitation and by increasing number of extreme weather phenomena. Based on two scenarios of global weather changes ECHAM4 and HadCM3 and using the global model of drinking water consumption WaterGap. LEHNER *et al.* [2006] predicted the increasing frequency of droughts and floods in the Vistula River catchment basin. According to DAI *et al.* [2004] the surface area of very dry and moist lands increased from 20% to 38% in the year 2002 compared with 1972. The authors predicted that such increasing trend will maintain in the next 2–3 decades. BORMANN [2011] calculated from Clausius-Clapeyron equation that the increase of air temperature by 1°C will increase water vapour pressure by 6–7% and thus will contribute to the increase of actual evapotranspiration.

Studies by ŁABĘDZKI *et al.* [2012] for two study periods: 2021–2050 and 2071–2100 demonstrated that predicted climate change in selected regions of Poland will result in variable worsening of agri-meteorological conditions. Predicted changes of agri-meteorological, soil and water conditions in Bydgoszcz region are set up in Table 1.

Table 1. Changes of agri-meteorological and soil-water conditions in Bydgoszcz region in the years 2021–2050

Parameter	Period	
	2021–2050	2071–2100
Agri-meteorological conditions	↓↓	↓↓↓
Crop requirements for water	–	↑
Soil moisture conditions	↓↓	↓↓↓
Agricultural drought intensity	↑	↑↑

Explanations:

Changes	no changes	small	big	very big
Decline	–	↓	↓↓	↓↓↓
Improvement	–	↑	↑↑	↑↑↑

Source: elaborated acc. to ŁABĘDZKI *et al.* [2012].

The aim of this study was to analyse the occurrence of precipitation deficit and excess in the growing seasons of the years 2011–2050 in Bydgoszcz region. Estimating future trends for several decades is of key importance in actually created programmes to adapt various economy sectors and public life to climate changes [BĄK *et al.* 2012a; KLIMADA 2013; ŁABĘDZKI 2009].

Climate scenarios are the projections of future climate and they are constructed for the purpose of estimation of the impact of climate change on the environment, society and economic sectors and the sensitivity of these sectors to change. They depend on the assumptions on greenhouse gas emissions, which in turn are related to the socio-economic, demographic and technological development. There is no single proven scenario, you always need to consider a bundle of potential implementations. For example analysis of changes in temperature can be done for a percentile of 10%, 50% and 90%. 10% percentile indicates the value below which 10% of temperature values fall, 50% percentile is the middle value (median), which divides all possible values for the half, while the 90% percentile cut off 10% of the largest value of the temperature in the period [LISZEWSKA *et al.* 2012].

Precipitation is one of the most difficult meteorological elements to forecast. This is because of complex micro-physical processes taking place in clouds, the effect of external factors and geographic conditions and hard to parameterize cloud-forming processes. Despite these doubts and assuming proper selection of climate change scenario for Poland, obtained results may serve as an advisory material supporting long-term development strategy for Kujawsko-Pomorskie Province [Strategia… 2013]. Adaptation actions in agriculture may include creation and utilization of available surface water resources, adjustment of soil cultivation technology for increasing water retention, introduction of new plant varieties more resistant to water stress. Strategy assumes, among others, utilization of the lower Vistula River catchment basin for water transport. Precipitation forecast in a long time scale will allow for distinguishing periods of hydrology droughts and floods. The forecast may be also an indication for emergency services to be prepared for periodical downpours and associated problems for economy and inhabitants of the region.

METHODS

Periods of precipitation deficit and excess in particular months of the growing season (April–September) and in growing seasons for the years 2011–2050 in Bydgoszcz were determined based on standardised precipitation index (*SPI*). Values of the index are the standardised deviations of precipitation from a median in a long-time period.

Many indices and methods have been developed and are used to identify periods of precipitation deficit and excess. Among them the standardized precipitation index *SPI* has been received the special attention in recent years since it was introduced by MCKEE *et al.* [1993, 1995]. It is widely recommended as a very simple and objective measure of precipitation deficit and excess and is commonly cited in both country and international literature [BĄK *et al.* 2012b; BĄK, ŁABĘDZKI 2002; BĄK, MASZEWSKI 2012; BELAYNEH, ADAMOWSKI 2013; IMANOV *et al.* 2012; ŁABĘDZKI 2007; ŁABĘDZKI, BĄK 2002; 2004; 2011; PAULO, PEREIRA 2006; SHAHABFAR, EITZINGER

PAULO, PEREIRA 2006; SHAHABFAR, EITZINGER 2013; VERMES 1998]. It is recommended by the International Commission on Irrigation and Drainage (ICID) and serves operational monitoring of threats caused by drought or precipitation excess [AGROMETEO 2013; IMGW; ŁABĘDZKI *et al*. 2013a; NDMC 2013].

The *SPI* for the years 2011–2050 was calculated from predicted monthly sums of precipitation in Bydgoszcz region. These data are a result of calculations of the regional model RM5.1 which is based on global model ARPEGE. Adopted for the analysis sums of precipitation have been computed for the percentile 50% [LISZEWSKA *et al.* 2012]. This model was initiated in the Interdisciplinary Centre of Mathematical and Computer Modelling (ICM) [ICM 2013; ŁABĘDZKI *et al*. 2012] based on a network of calculation nodes of a resolution of 0.25° (ca. 25 km). Applied downscaling method allows for more detailed forecasting of elements of Polish climate according to adopted emission scenario SRES: A1B. Results of measurements of precipitation in meteorological station Bydgoszcz–ITP in the years 1971–2000 were taken as reference data.

Classes of intensity of precipitation deficit or excess from classification given in VERMES [1998] were assigned to forecast *SPI* values (Tab. 2). Precipitation deficit occurred when *SPI* was continuously (in successive months) negative and assumed values –1.0 or lower and ended up when *SPI* assumed positive value. It means that *SPI* values are positive in the month preceding and following the drought. The excess of precipitation occurred when *SPI* was continuously (in successive months) positive and achieved values 1.0 or higher and ended up when *SPI* assumed negative value.

Table 2. Classification of months and growing seasons based on *SPI* value

Period category	*SPI*
Extremely dry	≤ –2.0
Very dry	$-2.0 < SPI \leq -1.5$
Moderately dry	$-1.5 < SPI \leq -1.0$
Normal	$-1.0 < SPI \leq 1.0$
Moderately wet	$1.0 < SPI \leq 1.5$
Very wet	$1.5 < SPI \leq 2.0$
Extremely wet	≥ 2.0

Source: elaborated acc. to VERMES [1998].

Using the above criteria, duration, magnitude and intensity of precipitation deficit or excess were determined for the years 2011–2050. Magnitude of the phenomenon is estimated as a sum of *SPI* values during the phenomenon. Intensity in a particular month is determined by *SPI* value for this month. For longer periods, mean intensity was determined as a quotient of magnitude and the number of months of phenomenon's duration.

RESULTS

Statistics of the distribution of mean sums of precipitation in particular months and growing seasons in the reference (1971–2000) and forecast (2011–2050) period are presented in Table 3. An increase of mean sum of precipitation in summer months (April–May), a slight decrease in June and significant decrease of precipitation in other months (July–September) is forecast for the years 2011–2050 compared with the reference period 1971–2000. Forecast mean sum of precipitation in the whole growing season will be smaller by 55 mm i.e. 12% than the mean precipitation in the last three decades of the 20th century.

Table 3. Statistics of mean sums of precipitation in 1971–2000 and 2011–2050

Parameter	April	May	June	July	August	September	April–September
1971–2000							
Mean	28	49	67	75	57	47	323
Minimum	7	7	18	19	13	4	113
Maximum	70	112	317	194	210	98	651
Median	22	38	53	69	52	45	319
SD	16	30	57	45	36	27	106
VC, %	55	62	86	60	64	57	33
2011–2050							
Mean	51	64	62	41	21	32	270
Minimum	8	7	22	2	0	0	90
Maximum	126	209	152	126	59	104	529
Median	46	67	58	37	16	26	257
SD	28	38	30	24	15	24	77
VC, %	55	61	48	58	73	75	29

Explanations: *SD* – standard deviation, *VC* – variability coefficient.
Source: own study.

Figure 3 presents forecast monthly means of precipitation in the growing seasons of 2011–2050 and Table 4 contains trend equations. In April and May the forecast sums of precipitation will be higher compared with the reference, however, predicted trend of precipitation in these months of the years 2011–2050 will be negative and will amount 2.6–3.2 mm per decade. An increase trend of precipitation by 2.3 and 0.6 mm per decade is predicted for July and August, respectively, in 2011–2050. Negative trend of 6.4 mm per decade is forecasted for the growing seasons.

Table 4. Trend equations of the sums of precipitation in Bydgoszcz (2011–2050)

Month, period	Trend equation	R^2	Tendency of precipitation mm·decade^{-1}
April	$Y = -0.2563x + 55.979*$	0.0113	–2.6
May	$Y = -0.3199x + 70.106$	0.0095	–3.2
June	$Y = -0.2702x + 67.143*$	0.0113	–2.7
July	$Y = 0.2337x + 36.101*$	0.0134	2.3
August	$Y = 0.0568x + 19.605$	0.0019	0.6

September	$Y = –0.0835x + 33.729$	0.0017	–0.8
April– September	$Y = –0.6393x + 282.66$	0.0093	–6.4

Explanations: R^2 – determination coefficient, * – statistical significance at α = 0.05.
Source: own study.

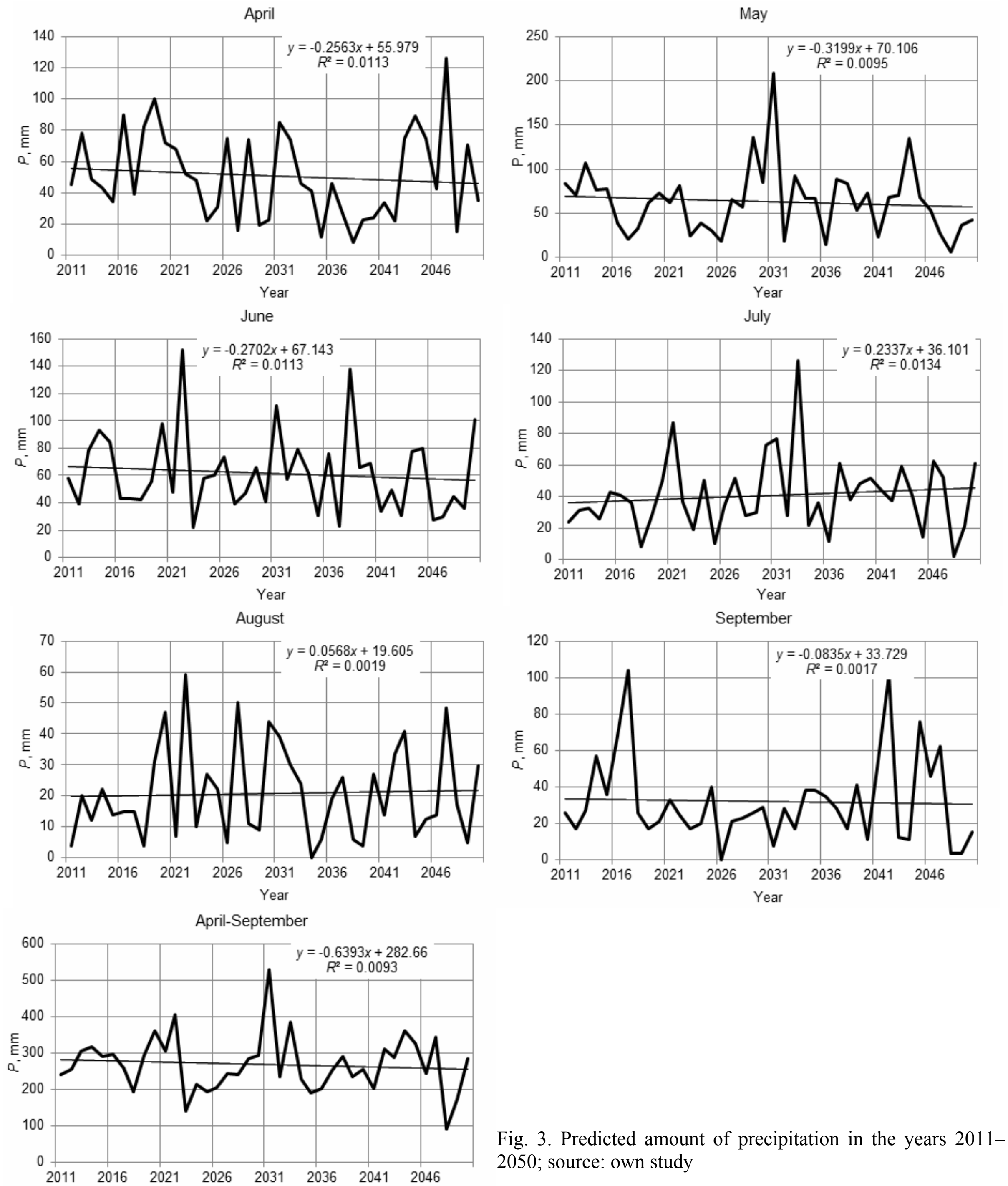

Fig. 3. Predicted amount of precipitation in the years 2011–2050; source: own study

Distribution of the *SPI* values and classes of precipitation deficit and excess for the years 2011–2050 are set up in Table 5. Most wet among forecast months will be: May 2031 (*SPI* = 2.6), June 2022 and July 2033 (*SPI* = 2.5) and the growing season 2031 (*SPI* = 2.7). Most dry months in the years 2011–2050 will be: September 2026 (*SPI* = –3.4), August 2034 (*SPI* = –3.2) and July 2048 (*SPI* = –2.9). One may expect an extremely dry growing season in 2048 (*SPI* = –3.0).

Thirty eight months with the excess of precipitation and 40 months with precipitation deficit are forecast for the years 2011–2050 (Tab. 6). Dry months will constitute 16% of all months, wet months – 13% and normal ones – 71%. Similar distribution of frequencies is expected for the growing seasons (15, 13 and 73%, respectively).

Based on adopted criteria, duration of precipitation deficit and excess in forecast period were determined (Tab. 7). Thirteen several-month periods with precipitation excess and 14 periods with precipitation deficit are predicted. The longest (5 months from April till August) wet period is forecast for the years 2020, 2022 nd 2031. Four-month long wet periods will appear in 2033 and 2044. In some months, wet period will appear in consecutive years e.g. April (2018, 2019), July (2020–2022) and September (2016, 2017).

The longest periods of precipitation deficit are forecast for the years 2023 and 2049 (5 months from May till September) and for the years 2018 and 2048 (4 months). Particular concentration of this periods may be expected in the years 2017–2018, 2023–2024 and mainly in 2046–2049.

Table 5. *SPI* values and the distribution of deficit and excess of precipitation in 2011–2050

Year	*SPI* in month, period						
	April	May	June	July	August	September	April–September
2011	0.0	0.7	0.1	–0.6	–1.2	0.0	–0.3
2012	1.0	0.3	–0.7	–0.2	0.2	–0.5	–0.1
2013	0.1	1.1	0.7	–0.1	–0.3	0.0	0.5
2014	–0.1	0.5	1.2	–0.5	0.3	1.0	0.7
2015	–0.5	0.5	0.9	0.3	–0.2	0.4	0.4
2016	1.2	–0.6	–0.6	0.2	–0.1	1.3	0.4
2017	–0.2	–1.3	–0.6	0.0	–0.1	2.0	0.0
2018	1.1	–0.8	–0.6	–1.9	–1.2	0.0	–0.9
2019	1.5	0.1	0.0	–0.4	0.8	–0.5	0.4
2020	0.8	0.4	1.3	0.6	1.4	–0.2	1.1
2021	0.7	0.1	–0.3	1.6	–0.8	0.3	0.5
2022	0.2	0.6	2.5	0.1	1.7	–0.1	1.6
2023	0.1	–1.1	–1.7	–0.9	–0.5	–0.5	–1.9
2024	–1.1	–0.6	0.1	0.6	0.6	–0.3	–0.6
2025	–0.6	–0.9	0.1	–1.6	0.3	0.5	–1.0
2026	0.9	–1.4	0.6	–0.1	–1.1	–3.4	–0.8
2027	–1.4	0.2	–0.7	0.6	1.5	–0.2	–0.2
2028	0.9	0.0	–0.4	–0.4	–0.4	–0.1	–0.3
2029	–1.2	1.6	0.3	–0.3	–0.6	0.0	0.3
2030	–1.0	0.7	–0.6	1.3	1.3	0.1	0.4
2031	1.1	2.6	1.6	1.4	1.1	–1.1	2.7
2032	0.9	–1.4	0.0	–0.4	0.7	0.1	–0.3
2033	0.0	0.8	0.8	2.5	0.4	–0.5	1.4
2034	–0.2	0.3	0.2	–0.7	–3.2	0.4	–0.4
2035	–1.8	0.3	–1.2	0.0	–0.9	0.4	–1.0
2036	0.0	–1.7	0.7	–1.4	0.2	0.3	–0.8
2037	–0.8	0.8	–1.7	0.9	0.5	0.1	–0.1
2038	–2.2	0.7	2.2	0.1	–0.9	–0.5	0.4
2039	–1.0	–0.1	0.3	0.5	–1.2	0.5	–0.4
2040	–0.9	0.4	0.4	0.6	0.6	–0.9	–0.1
2041	–0.5	–1.2	–1.0	0.4	–0.2	0.9	–0.8
2042	–1.1	0.3	–0.3	0.1	0.9	1.9	0.6
2043	0.9	0.3	–1.2	0.9	1.2	–0.7	0.3
2044	1.2	1.6	0.7	0.2	–0.8	–0.8	1.1
2045	0.9	0.3	0.8	–1.3	–0.3	1.4	0.8
2046	–0.1	–0.1	–1.4	1.0	–0.2	0.7	–0.2
2047	2.0	–1.1	–1.2	0.6	1.4	1.1	1.0
2048	–1.5	–2.4	–0.5	–2.9	0.1	–1.7	–3.0
2049	0.8	–0.6	–0.9	–0.7	–1.1	–1.7	–1.3
2050	–0.4	–0.4	1.4	0.9	0.7	–0.6	0.3

🟥	Extremely dry	🟦	Moderately wet
🟧	Very dry	⬛	Very wet
🟨	Moderately dry	🟪	Extremely wet
⬜	Normal		

Source: own study.

Table 6. Frequency of classes of precipitation deficit and excess in 2011–2050

Classes of precipitation deficit and excess	Month/period						
	April	May	June	July	August	September	April–September
Extremely dry	1	1	0	1	1	1	1
Very dry	1	1	2	2	0	2	1
Moderately dry	7	6	4	2	5	1	4
Normal	27	28	28	31	27	30	28
Moderately wet	3	1	3	2	6	4	4
Very wet	1	2	1	1	1	2	1
Extremely wet	0	1	2	1	0	0	1

Source: own study.

Table 7. Magnitude and distribution of periods with precipitation deficit and excess in 2011–2050

<table>
<tr><th rowspan="2">Year</th><th colspan="7">Magnitude in month, period</th></tr>
<tr><th>April</th><th>May</th><th>June</th><th>July</th><th>August</th><th>September</th><th>April–September</th></tr>
<tr><td>2011</td><td></td><td></td><td></td><td colspan="2">–1.8</td><td></td><td></td></tr>
<tr><td>2012</td><td colspan="2">1.3</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2013</td><td colspan="3">1.9</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2014</td><td></td><td></td><td></td><td></td><td></td><td>1.0</td><td></td></tr>
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<tr><td>2017</td><td colspan="3">–2.1</td><td></td><td></td><td>2.0</td><td></td></tr>
<tr><td>2018</td><td>1.1</td><td colspan="4">–4.5</td><td></td><td></td></tr>
<tr><td>2019</td><td colspan="2">1.6</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2020</td><td colspan="5">4.5</td><td></td><td>1.1</td></tr>
<tr><td>2021</td><td></td><td></td><td></td><td>1.6</td><td></td><td></td><td></td></tr>
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<tr><td>2023</td><td></td><td colspan="5">–4.7</td><td>–1.9</td></tr>
<tr><td>2024</td><td colspan="2">–1.7</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2025</td><td></td><td></td><td></td><td>–1.6</td><td></td><td></td><td>–1.0</td></tr>
<tr><td>2026</td><td></td><td>–1.4</td><td></td><td colspan="3">–4.6</td><td></td></tr>
<tr><td>2027</td><td>–1.4</td><td></td><td></td><td></td><td>1,5</td><td></td><td></td></tr>
<tr><td>2028</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2029</td><td>–1.2</td><td>1.6</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2030</td><td>–1.0</td><td></td><td></td><td colspan="3">2.7</td><td></td></tr>
<tr><td>2031</td><td colspan="5">6.6</td><td>–1.1</td><td>2.7</td></tr>
<tr><td>2032</td><td></td><td>–1.4</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2033</td><td></td><td colspan="4">4.5</td><td></td><td>1.4</td></tr>
<tr><td>2034</td><td></td><td></td><td></td><td colspan="2">–3.9</td><td></td><td></td></tr>
<tr><td>2035</td><td>–1.8</td><td></td><td>–1.2</td><td></td><td></td><td></td><td>–1.0</td></tr>
<tr><td>2036</td><td></td><td>–1.7</td><td></td><td>–1.4</td><td></td><td></td><td></td></tr>
<tr><td>2037</td><td></td><td></td><td>–1.7</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2038</td><td>–2.2</td><td colspan="3">3.0</td><td></td><td></td><td></td></tr>
<tr><td>2039</td><td colspan="2">–1.1</td><td></td><td></td><td>–1.2</td><td></td><td></td></tr>
<tr><td>2040</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2041</td><td></td><td colspan="2">–2.2</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2042</td><td>–1.1</td><td></td><td></td><td></td><td></td><td>1.9</td><td></td></tr>
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<tr><td>2043</td><td></td><td></td><td>–1.2</td><td colspan="2">2.1</td><td></td><td></td></tr>
<tr><td>2044</td><td colspan="4">3.7</td><td></td><td></td><td>1.1</td></tr>
<tr><td>2045</td><td></td><td></td><td></td><td colspan="2">–1.4</td><td>1.4</td><td></td></tr>
<tr><td>2046</td><td colspan="3">–1.6</td><td>1.0</td><td></td><td></td><td></td></tr>
<tr><td>2047</td><td>2.0</td><td colspan="2">–2.5</td><td colspan="3">3.1</td><td>1.0</td></tr>
<tr><td>2048</td><td colspan="4">–7.3</td><td></td><td>–1.7</td><td>–3.0</td></tr>
<tr><td>2049</td><td></td><td colspan="5">–4.8</td><td>–1.3</td></tr>
<tr><td>2050</td><td></td><td></td><td colspan="3">3.0</td><td></td><td></td></tr>
</table>

🟨 deficit of precipitation 🟦 excess of precipitation

Source: own study.

The biggest excess of precipitation, for which the sum of *SPI* values for the months of occurrence is 6.6, is forecast for April till August 2031. Wet period of the sum of *SPI* values equal 5.1 is expected in the same months of the year 2022.

The largest precipitation deficit will last from April till July 2048. For this period the sum of *SPI* values will amount –7.3. Since July till September 2026 the sum of *SPI* values will reach –4.6 and since May till August 2018 it will amount –4.5.

It was found that the highest mean intensity of precipitation excess will be 1.0–1.1 (for example in April–August 2022 and May–August 2033). For periods with precipitation deficit, the smallest mean intensity will be –1.8 and it is forecast for July–September 2026 and April–July 2048.

SUMMARY

Studies on climate change in the 21st century predict global increase of air temperature in Europe, hence also in Poland. Seasonal changes in the amount of atmospheric precipitation, the increase of extreme weather phenomena and evapotranspiration and worsening of agri-meteorological conditions will be a consequence of temperature rising.

Mean sum of precipitation in growing seasons (April–September) of the years 2011–2050 is predicted to decrease by 55 mm compared with mean sum of precipitation in the last three decades of the 20th century. An increase of the mean sum of precipitation in spring months (April–May), slight decrease in June and marked decrease of precipitation in other months (July–September) are predicted in the monthly course of precipitation.

Predicted distribution of precipitation will be favourable for crops in most of the spring months and in successive phenological phases (sowing, germination and seedling). In subsequent months, depending on season, plant growth may be at risk from precipitation deficit or excess.

A high variability may be observed in the distribution of months and growing seasons with precipitation deficit and excess. Sometimes the periods of both unfavourable phenomena will appear one by one.

Obtained scenario of the distribution of precipitation deficits and excesses and forecast trends of monthly sums of precipitation suggest, that meteorological, agricultural and hydrological drought will still present problems in agricultural production and water availability in Bydgoszcz region. The number of months and longer periods with drought will increase starting from the 2020s. They will pose a greatest threat in the end of forecast period 2011–2050. One should also expect long periods with precipitation excess. The first such period is predicted at the break of 2010s and 2020s, the next will appear every 10–12 years.

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Prognoza niedoboru i nadmiaru opadu w rejonie Bydgoszczy w świetle przewidywanej zmiany klimatu

STRESZCZENIE

Słowa kluczowe: *modele klimatyczne, nadmiar opadów, opady, susza, wskaźnik standaryzowanego opadu SPI*

W pracy przedstawiono prognozę niedoboru i nadmiaru opadów w rejonie Bydgoszczy w okresach wegetacyjnych (kwiecień–wrzesień) wielolecia 2011–2050 w świetle zmian klimatycznych. Na podstawie prognozowanych miesięcznych sum opadów dla percentyla 50%, obliczonych z wykorzystaniem regionalnego modelu zmian klimatu RM5.1 dla Polski, bazującego na modelu globalnym ARPEGE, przewiduje się w badanym regionie zmniejszenie sumy opadów w okresie wegetacyjnym o ok. 55 mm w stosunku do wielolecia referencyjnego 1971–2000. Na podstawie miesięcznych wartości wskaźnika standaryzowanego opadu *SPI* prognozuje się w wieloleciu 2011–2050 wystąpienie 38 miesięcy z nadmiarem opadów i 40 miesięcy z niedoborem opadów. Miesiące suche będą stanowiły 16% wszystkich miesięcy, miesiące wilgotne – 13%, a miesiące normalne – 71%. Prognozowane jest pojawienie się 13 kilkumiesięcznych okresów z nadmiarem opadów i 14 okresów z suszą, przy czym najdłuższe okresy obu zjawisk będą trwały pięć miesięcy. Takich okresów wilgotnych można oczekiwać w latach: 2020, 2022 i 2031 r., a okresów suszy – w latach 2017–2018, 2023–2024 i w wieloleciu 2046–2049.