

# Pluviothermal Conditions in Poland in Light of Contemporary Climate Change and Their Consequences for Agriculture and Water Management

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## Abstract

Spatial diversity and total area of thermal-humid regions have been assessed and, in addition, climatic water balance values have been calculated, employing specific time-frames up until the year 2020. The latter calculations have been performed taking into account temperature averages for the period 1971-2000, and constant precipitation. In order to designate thermal-humid regions the Daubenmiere method has been used (version modified by Cherszkowicz) in which thermal conditions are determined on the basis of effective temperature sums  $\geq 10.0^{\circ}\text{C}$ , while pluvial conditions are determined based on the hydrothermal coefficient ( $K=10P/t$ ) for the period from June until August where P signifies sums of precipitation and t daily sums of air temperature values. The climatic water balance was calculated as the difference between precipitation sums and sums of potential evaporation calculated using the Thornthwaite method. A systematic increase of the area of temperate warm and warm regions has been identified (from 62% in the period 1971-2000 to 88% for values estimated for 2000, 98% for values estimated for 2010, and 100% for 2015 and 2020). Meanwhile, a systematic increase in the area of temperate dry regions has been observed (20% of Poland in 1971-2000, 45% for values estimated for 2010, and 48% for values estimated for 2015 and 2020). The values of climatic water balance have decreased in the Nizina Wielkopolska from -160 mm (1971-2000) to -220 mm (for values estimated for 2015).

**Keywords:** global warming, Poland, pluviothermal regions, climatic water balance

## Introduction

The World Meteorological Organization as well as its predecessor the International Meteorological Organization have both initiated and coordinated the preparation of climate norms for member states of the European Union. The climate norm period was designated as a 30-year period and commenced with the 1901-30 time frame. Subsequently, the 30-year period had to be updated every 30 years, and

therefore the norm periods 1931-60 and 1961-90 were implemented. However, already in the year 1956 the World Meteorological Organization recommended that each nation should update the standard period every 10 years. This recommendation has not been implemented in all EU member states [1]. Recently the 1971-2000 and 1981-2010 periods have been commonly used in establishing new climate characteristics.

Taking into account the significant increase of temperature in recent decades [2, 3], it has been confirmed that the unique stationary character of climate statistics cannot be

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taken for granted, and furthermore the legitimacy of analyzing present and future climate conditions by employing 30-year norm periods has recently been seriously undermined [4]. The main problem is that climatic norms are calculated retroactively, which is a serious drawback. At the same time they are frequently used to describe future climate conditions, and therefore should be considered in mid-term and long-term strategic planning. We should mention in particular such examples as: forecasting building energy loads, the selection of plants and time for plant management practices, construction of hydro-technical equipment, and issues related to water supply.

The so-far common practice of employing the standards used in climate norms based on data from the recent past for various tasks, especially economic undertakings, needs to be slightly modified in the near future [5]. This fact is based on universally observed climate change [6] and especially in terms of the increasing temperature worldwide [7]. The description of the future climate requires the implementation of a forecast approach [8]. When assessing future climate change, especially in the upcoming several decades (i.e. until the end of the 21<sup>st</sup> century) scientists usually employ emission scenarios that have been upon elaborated by the Intergovernmental Panel on Climate Change (IPCC), and were subsequently used by climate forecast centers as an integral component that will determine the future variability of the climate of the Earth. Emission scenarios describe the alternative global paths of development and include a number of technological and demographic factors that result from the emission of greenhouse gases. Their principles and detailed characteristics have been included in what is referred to as the Special Report on Emission Scenarios [9]. It should be noted that this particular forecast possesses a high level of uncertainty and the climate models used for the basis of forecasts vary significantly among each other [10].

Due to the fact that climate change emission scenarios are usually valid until the end of the 21<sup>st</sup> century, a new trend has emerged in climatology called decadal prediction. The time frame for regional climate forecasts focuses on the next 10 to 30 years. This particular time scale has been identified as essential to the infrastructure sector, managers of water resources, and others. This type of information is required for an efficient adjustment to climate change [11].

In light of the uncertainty of the causes of climate change and further evolution of climate, it appears that the most appropriate forecast method that may be used for a short period of time is one that features simple extrapolation techniques. This pertains to the extension of time trends observed in the results that have been observed even beyond the 30-year period.

The main objective of this article is to assess the changes in thermal and pluvial resources and the climatic water balance by means of using certain time steps, up until 2020 (in reference to the 1971-2000 norm). The above-mentioned extrapolation techniques have been used. In particular the maps of pluviothermal regions, estimated for: 2000, 2010, 2015, and 2020 have been compared as well as maps of spatial distribution of the climatic water balance values for the period 1971-2000 and estimated for 2015.

## Materials and Methods

In this article the authors used monthly mean air temperature values and monthly precipitation totals (1971-2010) collected from 21 meteorological stations distributed evenly throughout the entire country. The meteorological data has been published in the following Institute of Meteorology and Water Management materials: *Monthly Agrometeorological Review*, *Decadal Agrometeorological Bulletin*, and *National Hydrological and Meteorological Service Bulletin*, as well as materials obtained from the Institute of Meteorology and Water Management archive database. It should be noted that due to the insufficient number of meteorological stations there are practically no observations from the mountainous areas of Poland.

The surface areas of thermal-precipitation (pluviothermal) regions have been compared for 1971-2000. In addition, several other comparisons have been accomplished, such as: precipitation sums in terms of the estimated temperature at the end of 1971-2000, as well as precipitation sums for the temperature estimated at the end of 1971-2015, and finally for precipitation and temperature estimates at the end of 1971-2020. The designation of the pluviothermal regions has been based on the Daubenmiere method [12] modified by Cherszkowicz [13]. In this particular method thermal conditions during the vegetative period are determined using the effective temperature sums  $\geq 10.0^{\circ}\text{C}$ , while humidity is based on the value of the hydrothermal coefficient, which expresses the precipitation efficiency  $K=10P/t$  for the period from June to August. In the aforementioned equation,  $P$  is the sum of precipitation and  $t$  is the sum of the daily value of air temperature in a given month. A linear temperature increase function over time has been assumed. The values estimated for: 1971-2000, 1971-2010, 1971-2015, and 1971-2020 have been calculated by means of using the same equation that has been used for 1971-2010.

The climatic water balance has been calculated as the difference between the sum of precipitation and sum of potential evaporation for 1971-2000, and subsequently for temperature estimated at the end of the 1971-2015 period and mean precipitation sums for 1971-2010. Potential evaporation has been calculated on the basis of the Thornthwaite method [14], which enables determining potential evapotranspiration ( $ET_p$ ) based on the climate data obtained from the following equation:

$$ET_p = c \times t_s^a$$

...where  $ET_p$  signifies monthly potential evapotranspiration, and  $t_s$  – mean monthly temperature, while parameters  $a$  and  $c$  depend on the heat coefficient determined in the function that describes mean monthly temperatures and the possible period of insolation. This particular equation refers to a standard month, which consists of 30 days and 12 hours of sunshine possible. The values of actual evapotranspiration are calculated by multiplying evapotranspiration values from standard months by correction coefficient  $b$ , which includes the actual time of insolation.

Table 1. The area of designated pluviothermal regions for mean values for 1971-2000, and estimated for 2000, 2010, 2015, and 2020 (given as a percentage of Poland).

Period	Humidity region and hydro-thermal coefficient	Thermal region and effective temperature sums $\geq 10^{\circ}\text{C}$			
		Cool 1600-2000	Temperate cool 2000-2400	Temperate warm 2400-2800	Warm 2800-3200
1971-2000	Temperate dry 1.0-1.3		1	19	
	Optimal humid 1.3-1.6	1	33	36	
	Humid >1.6		3	7	
Values estimated for 2000	Temperate dry 1.0-1.3			36	
	Optimal humid 1.3-1.6		11	44	3
	Humid >1.6		1	5	
Values estimated for 2010	Temperate dry 1.0-1.3			31	14
	Optimal humid 1.3-1.6		2	38	9
	Humid >1.6			3	3
Values estimated for 2015	Temperate dry 1.0-1.3			28	20
	Optimal humid 1.3-1.6			24	18
	Humid >1.6			10	
Values estimated for 2020	Temperate dry 1.0-1.3			18	30
	Optimal humid 1.3-1.6			21	23
	Humid >1.6			8	

## Study Results and Discussion

In 1971-2000 the largest area (36%) was occupied by the temperate warm region with optimal humidity levels. This particular region includes Nizina Mazowiecka, excluding its central and eastern parts, as well as Nizina Śląska, and Wyżyna Śląska, Wyżyna Krakowsko-Częstochowska, Wyżyna Małopolska, and Kotlina Sandomierska. Both temperate warm and temperate dry regions cover central and western parts of Poland. They include the following geographical regions: Pojezierze Wielkopolskie and Nizina Wielkopolska, as well as enclaves in central and eastern parts of Nizina Mazowiecka. In total, these two regions occupy 19% of Poland.

The majority of the northern part of the country (33%) lies in the temperate cool region with optimal humidity levels. This region includes coastal areas and the districts lands (except its most western parts) as well as Pojezierze Suwalskie. This region includes the following geographic territories: Nizina Podlaska, Wyżyna Lubelska, Świętokrzyskie Mountains, and Roztocze (highlands with dry steppe areas situated in the eastern part of Poland). In the southern part of the country 7% of the area is occupied by a temperate warm and humid region, which encompasses Przedgórze Sudeckie and Pogórze Karpackie, along with the terrain lying to the north of Pogórze (Table 1 and Fig. 1).

For the values estimated in 2000 a characteristic feature is the significant decrease in the area of the temperate cool region (from 37 to 12%) and the appearance of the warm

region with temperature sums  $\geq 10^{\circ}\text{C}$ , which is situated in the Dolina Środkowej Odry (in the vicinity of Opole and Wrocław). The prevailing area of Poland (85%) belongs to the temperate warm region with temperature sums above  $10^{\circ}\text{C}$  (consequently the temperature sums are within the 2400-2800 $^{\circ}\text{C}$  range). In terms of the humidity conditions we can distinguish a temperate dry zone that runs through the central part of Poland, from western to eastern borders, and which comprises about 36% of its area.

From the north and south of the temperate warm and temperate dry regions, the area of Poland occupied by the temperate warm region with optimal humidity covers 44% of the total area of our country. The southern part of Wyżyna Małopolska, Pogórze Karpackie, and the lower parts of Karpaty and Przedgórze Sudeckie are situated within the temperate warm and humid region (Table 1 and Fig. 2).

A characteristic further decrease in the surface area of the temperate cool region has been observed for the values estimated for the year 2010. This particular region covers merely 2% of Poland near the vicinity of the city of Suwałki. Another characteristic feature is the significant increase in the surface of the warm region in southwestern Poland (from 3 to 26%) and expansion of the latitudinal belt of dry region (up to 45%), which possesses the lowest value of the hydrothermal coefficient – 1.1 to 1.3 (Table 1 and Fig. 3).

We can distinguish a clear lack of the temperate cool region for the values estimated for 2015. In addition, a sig-

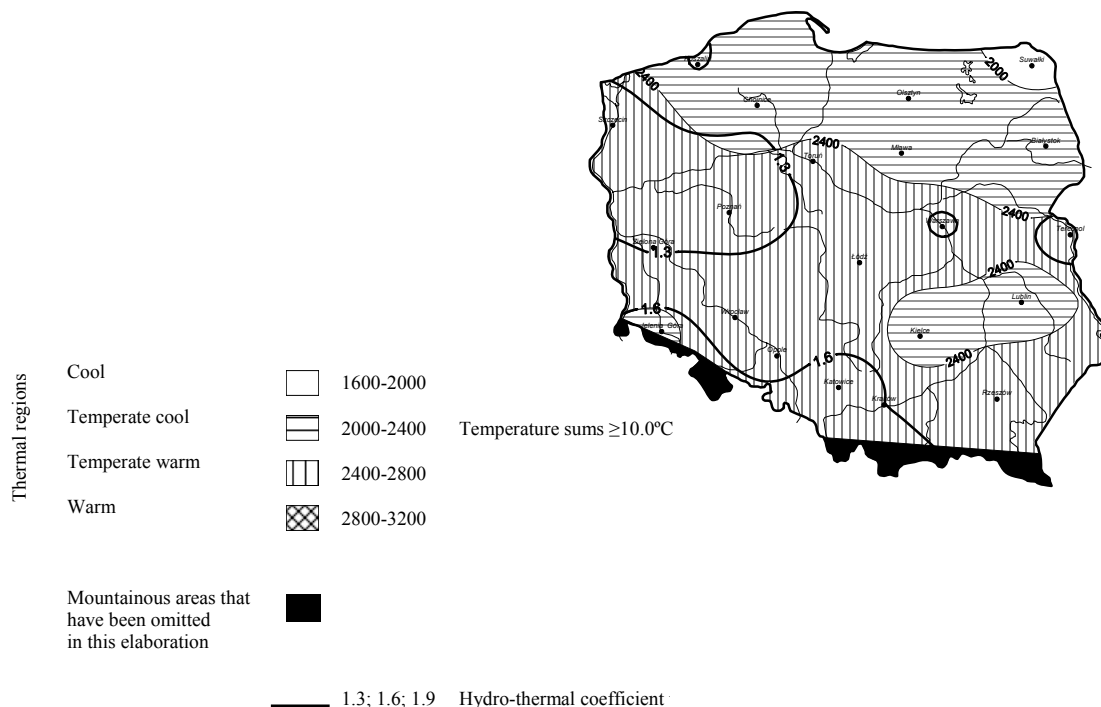


Fig. 1. Pluviothermal regions in Poland, 1971-2000.

nificant increase in the surface area of the warm region can be observed with temperature sums above 10°C (from 26 to 38%). The temperature sums are within the 2800-3200°C range. In terms of humidity conditions we can observe a further increase in the surface of the latitudinal belt (Table 1 and Fig. 4).

More than 53% of Poland is occupied by the warm region for the values estimated for 2020. For the remaining area of Poland the temperate warm region prevails. We can also observe an increase in the surface of warm/dry region (from 20 to 30%) and the expansion of the warm region with optimal humidity (from 18 to 23%; Table 1 and Fig. 5).

Besides analyzing the changes in pluviothermal regions, the authors also have compared the course of the isolines of climatic water balance in the vegetative period (for 1971-2000 and estimated values for 2015). In practice, this analysis has taken into account the presumed changes within a period of 30 years. The values of the climatic water balance in the vegetative period (1971-2000) are distributed as follows: the highest values of deficiencies are situated in the central part of Poland with maximum in the vicinity of Poznań, Szczecin, and Warszawa (-160 mm). Slightly lower values occur in the belt that runs from Chojnice to Mława, Terespol, and Zielona Góra (from -140 mm to -120 mm). The lowest values are observed in the vicinity of Koszalin and Katowice (-20 mm – Fig. 6).

The values of the climatic water balance in Poland estimated for 2015 exhibit a further increase in precipitation deficiency. The highest values occur just as before in the areas of Poznań and Szczecin, but they increase to -200 mm. The lowest values of the precipitation deficit are situated in southern Poland (from -60 to -80 mm, near Kraków, Katowice, Jelenia Góra, and Koszalin). The remaining part

of the country has deficits ranging from -100 to -180 mm (Fig. 7).

Similar studies have been performed with regard to the possibility of early-average maturation of corn hybrid in Poland. This particular corn hybrid as well as other crops that require higher thermal conditions are limited to warmer areas of Poland, notably Dolny Śląsk and Kotlina Sandomierska. The probability of maturing of early-average corn in the above-mentioned regions in 1941-90 has exceeded 80%, while north of the Szczecin-Białystok city line it was lower than 20%. From the extrapolation of the

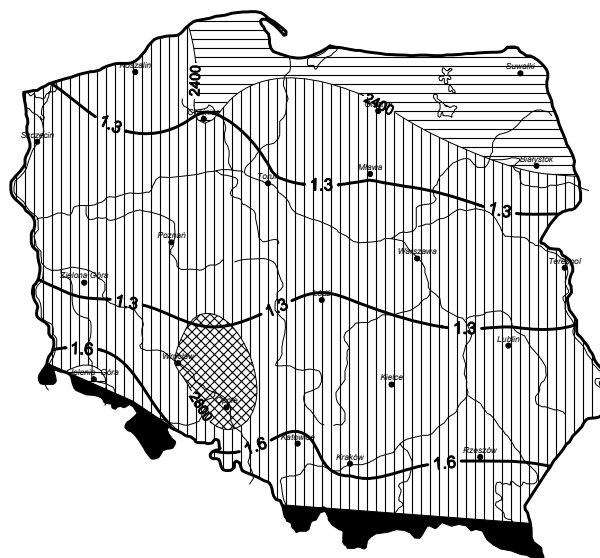


Fig. 2. Pluviothermal regions in Poland for values estimated for 2000.

temperature function trend (2001-10) it has been shown that the probability of corn maturation in the whole of Poland will clearly surpass 80%. This indicates that temperature increase has caused a decrease of restrictions in terms of cultivation of other crops. Also, based on the temperature extrapolation trend for 1941-90 until 2001-10 a meteorological vegetation period was obtained, which indicates a 10-day prolongation [15].

A similar analysis has been performed for central and southwestern Poland, which indicated that according to accepted climate scenarios the growing season in Central Poland will increase by 10-14 days (in 2030) and 18-27 days (in 2050). In southwestern Poland the length of the growing season will increase by 11-17 days (in 2030) and by 22-30 days (in 2050). These values are relative in terms of the norm 1971-2000 period [16].

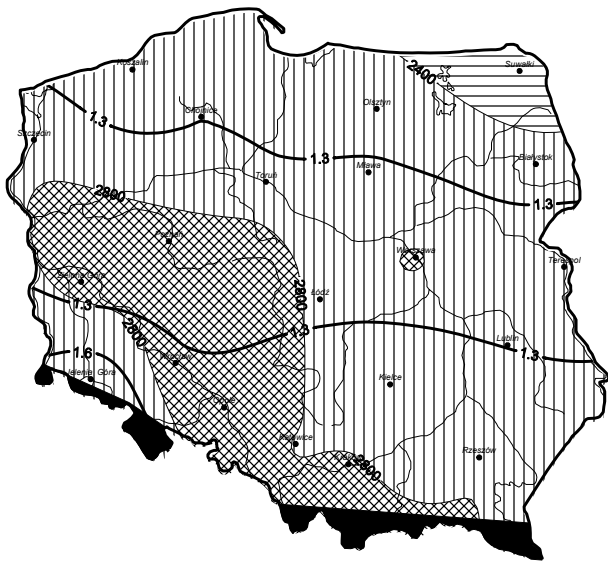


Fig. 3. Pluviothermal regions in Poland for values estimated for 2010.

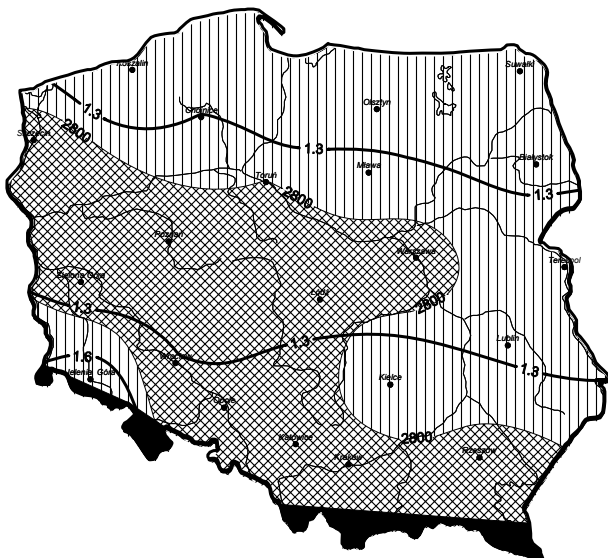


Fig. 4. The pluviothermal regions in Poland for values estimated for 2015.

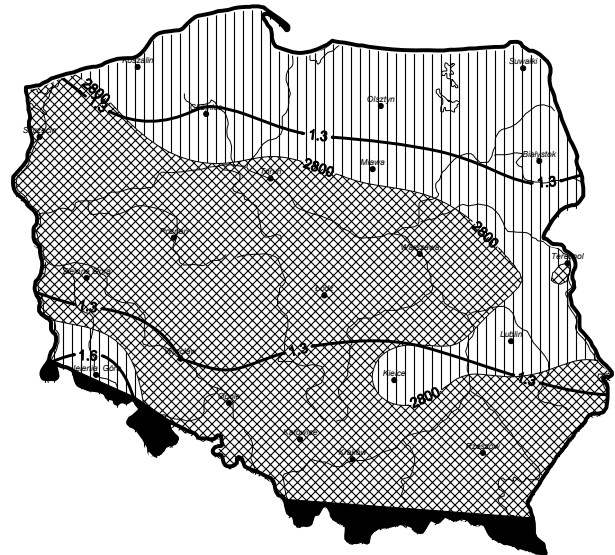


Fig. 5. Pluviothermal regions in Poland for values estimated for 2020.

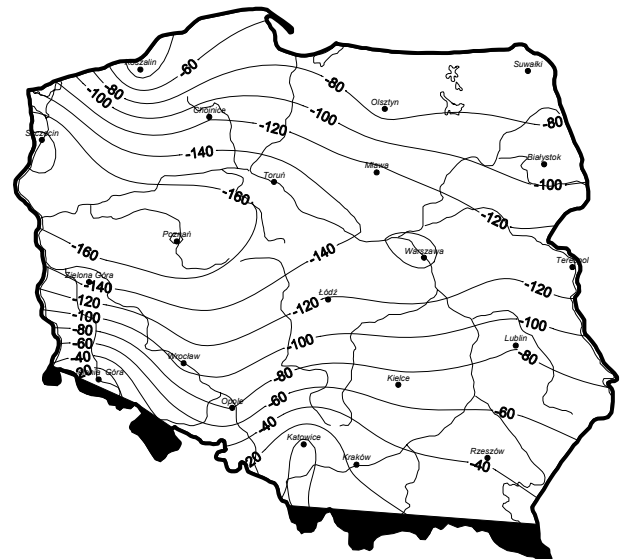


Fig. 6. Climate water balance in Poland in 1971-2000.

The observed and forecasted air temperature increase will lower heat barriers for the cultivation of stenothermal plants, especially in the case of corn, which is used primarily for grain in Poland. The increase in temperature will not only affect the acceleration of cultivated plant growth but will also contribute to an increased growth in the amount of weeds and pests, which are rather tedious for agriculture [17]. According to the IPCC report, until the end of the 21<sup>st</sup> century, the potential corn plantation areas in northern Europe will increase by 30-50% [18].

The research carried out by the authors of this article indicates that with the increase in air temperature the hazard of water deficit also increases. Global warming causes an increase in potential evaporation, which in the case of the Polish climate results in the increase of areas designated as dry. In addition, the values of the climatic water balance indicate a significant decrease. The climatic water bal-

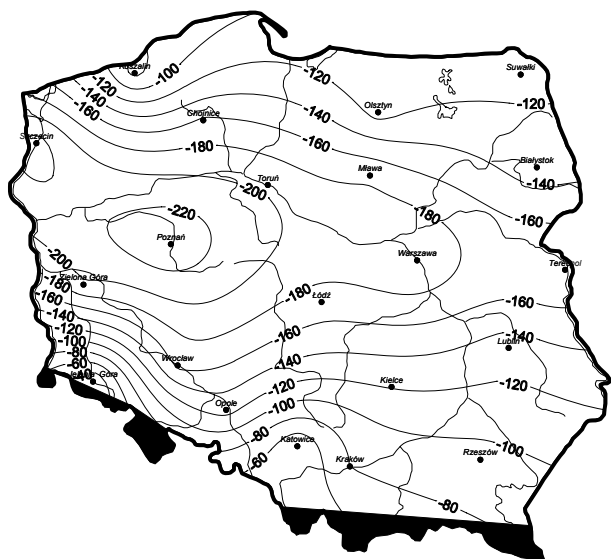


Fig. 7. Climate water balance in Poland for values estimated for 2015.

ance is defined as the difference between the sums of precipitation and potential evaporation. This decrease in water balance can be observed more closely when we compare the results of studies carried out in this paper with results based on meteorological materials dating back to the late 19th and early 20th centuries [19]. In the latter study, some areas in central Poland were characterized by climatic water balance values within the range below  $-100$  mm, against values below  $-160$  mm (1971-2000) and  $-220$  mm (estimated for 2015). It should be mentioned at this point that potential evaporation values have been derived from the Thornthwaite equation.

When we compare maps depicting the values of climatic water balance in summer in subsequent periods (i.e. 1951-70, 1951-80, 1951-90) we can observe an increase in the areas with the lowest water deficiencies [20]. For instance during 1951-70 these values in the areas of Poznań and Warszawa equaled  $-140$  mm; during 1951-80 they amounted to  $-160$  mm, and finally in the last period, 1951-90, these values stayed the same but they spread over larger areas of Wielkopolska and Mazowsze. The potential evaporation in the aforementioned periods has been calculated according to Bac formula [21]. The negative trend values pertaining to climatic water balance coefficient in 1951-2006 in Poland, calculated at specific monthly intervals (1, 3, 6, 12, and 24), indicating that nearly all coefficients are negative, which means that the evaporation is greater than the precipitation. The increase in dryness is statistically insignificant, however the intensification of warming may change this situation [22].

However, it hasn't been true always that the forecasted climate change has been taken into account in future practical activities, such as in the case of meteorological data for the Polish region assembled by the Ministry of Transport, Construction, and Marine Management (2008). This particular task was performed for the purpose of energy calculations in the construction sector and pertains to the norm

1971-2000 period [23]. In light of the observed and well-documented temperature increase, such calculations may seem to be slightly underestimated. The new elaboration of the bioclimatic conditions in Poland is based on data and materials from the recent decade (1991-2000), and the authors compare bioclimate characteristics of particular spas in reference to previous characteristics from the 1971-2000. In light of ongoing climate change the authors propose a verification of climatic standards that are posed for spa locations [24].

## Conclusions

Based on the performed research – analyses of temperature increase and selected coefficients as well as precipitation data for Poland in the period 1971-2010 – we can come to the following conclusions:

1. With the passage of time we can observe a systematic increase in the area of temperate warm and warm regions with effective temperature sums  $\geq 10^{\circ}\text{C}$  (62% in 1971-2000, 88% for values estimated for 2000, 98% for values estimated for 2010, and finally 100% for values assessed for 2015 and 2020).
2. With the lack of clear trends in atmospheric precipitation and, conversely, a clear trend in temperature increase (which results in the increase of potential evaporation), a systematic increase in the area of temperate dry region can be observed. In this particular case the Sielianinov hydro-thermal coefficient (ranging from 1.0 to 1.3) increases its area from 20% (1971-2000) to 36% (for the values estimated for 2000) to 45% (for the values estimated for 2010) up to 48% for the values assessed for both 2015 and 2020.
3. The lowest values of climatic water balance have decreased on the Nizina Wielkopolska in 1971-2000 from  $-160$  mm to  $-220$  mm (2015 estimate).
4. The indicated changes in thermal and pluvial resources as well climatic water balance clearly show that it is essential to implement a forecasting approach that will enable us to describe the future climate in terms of economical factors.

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