Long-term air temperature and precipitation variability in the Warta River catchment area

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For citation: Ilnicki P., Farat R., Górecki K., Lewandowski P. 2015. Long-term air temperature and precipitation variability in the Warta River catchment area. Journal of Water and Land Development. No. 27 p. 3–13.

Abstract

The variability of the mean annual air temperature and precipitation totals in three periods: 1848–2010, 1951–2010 and 1981–2010 was investigated in the large Warta River basin, being the area with lowest rainfall in Poland. For the purposes of research, nine meteorological stations with the longest measurement series were selected. Air temperature increase in this river basin was similar than in neighbouring countries. In the last 30 years this trend kept increasing. The precipitation in the whole studied period was slightly increasing in the northern part of the Warta River basin, but decreasing in the southern part. The mean annual precipitation totals in the catchment area did not change visible. In the period 1981–2010, the precipitation totals show a small increase in the winter and spring and a decrease in summer. A negative influence of this climate change was not visible in the Warta River discharge. The main objectives of this study were the collection long-term records of air temperature and precipitation in the Warta River basin, and the statistical analysis of climate variability.

Key words: precipitation totals, air temperature, trend analysis, Poland, Warta River basin

INTRODUCTION

In Europe after a slight period of coolness from the middle of the 19th century to about 1890, a statistically significant warming occurred from 1890 to 1950 (by 0.15°C per decade). Then, there followed a cooling from 1950 to 1970 and again a slight warming from the early 1970s [BALLING et al. 1998]. The European Climate Assessment data set comprises about 200 series of temperatures and precipitations from nearly all European countries and shows that in the period 1976–1999, the temperature trends were positive all over Europe and the strongest warming was visible in winter. Apart from the north-south gradient [TRENBERTH et al. 2007], there was a weaker gradient from the ocean to the continent. The highest temperature rises were found over central and north-eastern Europe, while the lowest over the Mediterranean. The spatial coherence of precipitation and their trends were generally lower due to their inherent higher variability [KLEIN TANK et al. 2002].

In most European investigations the number of Polish station was very small and the analysed series changed from 1961–2004 [SCHERRER et al. 2005] to 1901–1999 [KLEIN TANK et al. 2005], 1911–2000 [JONES, LISTER 2009] and 1753–2011 [ROHDE et al. 2013]. Long-term European temperature research in 1751–1995 used only two Polish meteorological stations [BALLING et al. 1998] and reconstruction of records 1500–2007 for Central Europe used no one Polish station records after 1760 [DOBROVOLNÝ et al. 2010]. This shows a large lack of meteorological data.
used in European investigations from the Polish territories.

Air temperature and precipitation long-term series were studied in different periods in most European countries, but not in catchment areas. From the Polish point of view, of particular interest are the results from neighbouring countries. The mean temperature series for the Czech Republic showed in the period 1848–2000, a statistically significant positive linear trend, which reached 0.69°C per 100 years. An insignificant trend towards precipitation rise was evident in winter and in autumn [BRAZDIL et al. 2009]. In Germany the trends of temperature and precipitation were studied for the period 1901–2000 and 1971–2000, where the temperature rise was about 0.7°C and 0.3°C respectively. In Germany, the trends increased from the north to the south, though weakened from east to west. The areally averaged annual precipitation total increased in Germany for the period 1901–2004 from 735 mm to 800 mm, mainly in winter [SCHÖN-WIESE, JANOSCHITZ 2008]. Between 1951–1988 and 1989–2008, the average annual temperature in the flat part of Ukraine increased by 0.8°C. The highest increase was recorded in winter (January) and in spring (March). The annual precipitation totals in that time did not change significantly, while the change was most significant in spring (March) and autumn [NABYVANETS et al. 2011].

In central Poland long-term meteorological records exist only for Bydgoszcz, Poznań, the Leszno region [HOHENDORF 1966; SMOSARSKI 1925] and Łódź [WIBIG et al. 2004; WIBIG, RZEPÄ 2007]. Longer was time series in Warsaw, Wrocław and Brno [BRAZDIL et al. 2009]. In Warsaw in the period 1779–1998 the air temperature trend was 0.055°C per decade [LORENC 2000] and in Wrocław, in 1791–2007, it was higher (0.085°C per decade) [BRYŚ, BRYŚ 2010]. In Poznań in the period 1848–1922 the mean temperature was 0.9°C lower than for 1960–2009, while for 2000–2009 it was much as 1.9°C higher [NYCKOWIAK et al. 2014]. For the period 1951–2000 in Poland the trend was significant and positive in the annual temperature (0.2°C per decade), and in March and April. During this period there was a weak, insignificant increasing trend in the annual precipitation totals, but significant only in March and the precipitation decreased mainly between June and August [DEGIRMEN-DŽIĆ et al. 2004]. The variability of the thermal and precipitation conditions in Poland in the second half of the 20th century show a significant increase of temperature in the spring and winter, but the amount of precipitation total does not show any significant trend [ZMUDEZKA 2004]. The myth of the steppe forming process in the Wielkopolska region from the viewpoint of long investigations of water circulations was presented by ILNICKI et al. [2012].

The main objectives of this study were the collection of all published and unpublished, long-term records of air temperature and precipitation in the Warta River basin, boasting the lowest annual rainfall in Poland, and the statistical analysis of climate variability. Data for this region was not available and used in most European climate investigations. In the 1848–2010, 1951–2010 and 1981–2010 periods the trend of this most important climate parameters were calculated and analysed. The climatic variability in the Warta River basin has been compared with the numerous results of similar studies carried out mainly in Central Europe, to ascertain the differences of climate change in the region and their influence on water management, environment and agriculture production.

DATA AND METHODOLOGY

Climatic changes include the variability of the hydrological cycle and water resources, connected with precipitation and air temperature. Therefore it is logical when climatic changes are studied not in terms of administrative units, but in river basins. We analysed the Warta River basin (54 519 km²) which in the period 1896–2010 showed a mean annual specific run-off amounting only to 3.86 dm³·s⁻¹ km⁻² [ILNICKI et al. 2014]. In Poland it is the basin with the lowest precipitation totals, being a region potentially threatened by an intensive drought, especially through increasing air temperature.

In the Warta River basin nine meteorological stations with long-time series of air temperatures and precipitations were analysed (Fig. 1). The observations started in 1848 in Bydgoszcz, Poznań and the region of Leszno (Czechnów, Góra, Wschowa), in the
1890s in Częstochowa, Gorzów Wlkp., Kalisz (Ostrów Wlkp.) and Piła (Walcz) region; in 1903, in Łódź and in 1931, in Koło. Through this, in Central Europe an evaluation of the meteorological stations was realized progressive; the mean values of temperature and precipitation in the river basin could be calculated at first only for three and seven stations respectively, and from 1931 for nine.

The stations in Bydgoszcz, Czechów, Góra, Leszno, Ostrów Wlkp. and Poznań had been established and originally they conducted observations in schools. Later, that function was taken over by the Prussian and German meteorological offices until 1918, whereas in Gorzów Wlkp., Walcz and Wschowa as late as 1945. The stations in Częstochowa, Kalisz and Łódź were organized and observed by the Russian authorities until 1918. That same year and again in 1945 the state borders in this region changed and consequently all the stations were taken over by the Polish State Institute of Hydrology and Meteorology (PIHM) and later, the Institute of Meteorology and Water Management (IMGW). Throughout these political changes and station relocations, to create mean values for the Warta River basin for Leszno and to a lesser extent for Kalisz and Piła, we used the data from stations located nearby (less than 20 km), which had been earlier established in that flat and rural region. The characteristics of stations inform about their relocations in the period 1848–2010 (Tab. 1). The stations in the most towns were located in the outlying suburbs. Differences in the terrain height of subsequent stations are the greatest (about 30 m) in Częstochowa, lying on the highland and in Gorzów Wlkp., and Kalisz, situated near deep river valleys. However, the differences were not very great. In 1972, only Łódź and Poznań had over 500 000 inhabitants, while the bigger towns included Bydgoszcz (280 000) and Częstochowa (190 000 inhabitants). The remaining stations were located in towns counting at that time about 30–80 thousand inhabitants. An analysis of the impact of station relocation on the mean annual air temperature did not show any unexpected changes.

### Table 1. Characteristics of meteorological stations and their relocations in the Warta River basin

| Station | Code WMO | Neighbouring station and relocations | Elevation m a.s.l. | Coordinates | Period examined | Neighbouring station and relocations | Elevation m a.s.l. | Coordinates | Period examined |
|---------|----------|------------------------------------|------------------|-------------|----------------|------------------------------------|------------------|-------------|-----------------|
| Bydgoszcz | 240 | Bydgoszcz | 46 | 53°08' E 18°00' E | 1848–1897 1861–1897 | Agricultural School | 46 | 53°08' E 18°00' E | 1897–1908 1897–1908 |
| Agricultural School | 46 | | 53°08' E 18°00' E | | | Agricultural Institute | 259 | 50°49' N 19°09' E | 1921–1939 1891–1939 |
| Częstochowa | 550 | Częstochowa | 293 | 50°49' N 19°05' E | 1939–2010 1939–2010 | Częstochowa, airport | 70 | 52°44' N 15°14' E | 1891–1945 1875–1945 |
| Gorzów Wlkp. | 300 | Gorzów Wlkp. | 44 | 52°44' N 15°15' E | 1946–1954 1946–1954 | Gorzów Wlkp. | 67 | 52°44' N 15°16' E | 1954–1974 1954–1974 |
| Kalisz | 435 | Ostrów Wlkp. | 143 | 51°39' N 17°49' E | 1891–1920 1891–1920 | Kalisz | 109 | 51°46' N 18°06' E | 1921–1945 1921–1945 |
| Koło | 345 | Koło | 97 | 52°12' N 18°38' E | 1931–1968 1931–1968 | Koło | 116 | 52°12' N 18°40' E | 1968–2010 1968–2010 |
| Leszno | 418 | Czechów | 102 | 51°40' N 16°42' E | 1848–1871 1848–1871 | Góra | 87 | 51°40' N 16°33' E | 1871–1882 1871–1882 |
| Wschowa | 102 | 51°48' N 16°19' E | 1883–1918 1883–1918 | | | | |
| Strzyżewice, airport | 91 | 51°50' N 16°32' E | 1919–1960 1919–1960 | | | | |
| Łódź | 465 | Tramway depot, city | 208 | 51°46' N 19°29' E | 1921–1930 1904–1930 | Lubliniec, airport | 187 | 51°43' N 19°24' E | 1931–2010 1931–2010 |
| Piła | 230 | Wschowa | 118 | 53°17' N 26°28' E | 1891–1969 1883–1909 | Piła | 73 | 53°08' N 16°45' E | 1970–2010 1910–2010 |
| Poznań | 330 | Zielona street | 80 | 52°25' N 16°56' E | 1848–1910 1848–1910 | University, Coll. Min. | 78 | 52°25' N 16°54' E | 1911–1935 1911–1935 |
| Lawica, airport | 83 | 52°25' N 16°50' E | 1924–2010 1924–2010 | | | | |

Source: own study.

Used data are part of the quality controlled data base in the Institute of Meteorology and Water Management (IMGW), some of them were published. Their quality control included detection, verification and possible correction of outliers, elimination of wrong values and addition of missing data in the time series. In Poland in the analysed time, there were no significant changes in equipment facilities, or in observation principles. An automation of stations was carried out at the turn of the 20th and 21st centuries. However, changes in observation terms and averaging methods occurred without any great differences in the data obtained. Monthly data of air temperature and rainfall for every year were available only for Bydgoszcz (rainfall from 1861), Leszno and Poznań in 1848–2010 and for all stations in 1981–2010. For the
periods 1881–1930, 1931–1950 and 1951–1980 for the remaining six stations, only the mean monthly data for periods of air temperature were available, not the monthly data in every year. Similarly in the case of precipitations, but these periods were different in the 19th century (1848–1860, 1861–1890 and 1891–1930). We analysed the variability of air temperature and precipitation totals in terms of years and four seasons. Annual air temperature and precipitation totals were collected for all years and all stations, and used for trend calculations. Mean values of air temperature and precipitation for the whole Warta catchment were calculated as the mean values from all nine analysed stations.

The coefficient of variation was used for describing the variability of air temperature and precipitation totals, as well as standard air temperature deviation. Because it is not certain that these two parameters have a normal distribution, for the calculation of trend values, we used linear regression and the non-parametric Mann–Kendall test with the aid of Hydrospect software, version 2.0 [RADZIEJEWSKI, KUNDZEWICZ 2000; 2004]. The calculations were completed for nine meteorological stations and with their mean annual values for the whole Warta River basin. We presented trends for air temperature and precipitation totals in the whole basin for three periods: 1848–2010, 1951–2010 and 1981–2010 and for all meteorological stations in their longest periods. The p-values are calculated for the trend values (slopes) and by linear regression for correlation coefficients. This makes possible a comparison between the longest analysed periods and the last two periods in which global climate change was observed. Data for periods mentioned were compared with the variability of the Warta River discharge in the 20th century. The correlation existing in the series of the mean annual temperatures and the precipitation totals between the particular stations is regarded as good and very good according to the value of the correlation coefficient shows $r > 0.7$, or $r > 0.9$ respectively [SCHÖNWIESE, JANOSCHITZ 2008]. In air temperature, these values from nine stations were mainly in the interval of $0.87–0.98$, while in reference to precipitation, the values were significantly lower (0.54–0.63). For a pair of closely situated stations, the correlation coefficient for precipitation range was found to be within 0.60–0.74. Low values of the correlation coefficient in precipitation result from a significantly higher spatial variability. The above calculations indicate that the density of the stations studied is representative for Warta River basin research.

**RESULTS**

**AIR TEMPERATURE CHANGES**

**IN THE PERIOD 1848–2010**

In the Warta River basin in the longest time-series (1848–2010) the mean annual air temperature was $8.1^\circ C$. It increased in 1951–2010 to $8.2^\circ C$, and in the last 30 years (1981–2010) to $8.6^\circ C$ (Tab. 2). In the north (Bydgoszcz, Piła) and south-east part (Częstochowa, Łódź) of the catchment area the mean annual air temperature was slightly lower ($7.8–7.9^\circ C$). The 10-year moving average air temperature for all meteorological stations (Fig. 2) and for the river basin showed periods of higher and lower temperature, with the lowest annual means in 1954–1980, and the highest ones in 1857–1869, 1913–1921, 1931–1950 and especially in 1988–2009 (Fig. 3). These periods do not alternate cyclically. The linear trend of the mean annual air temperature in all analysed stations and in three periods in the total Warta River basin was positive and significant. For shorter time periods in stations it increased slightly (Tab. 3) but in the river basin in three periods it was quite different. In the relevant base of 163 years the linear trend of temperature differences was only 0.039°C/10 years. In the period 1951–2010 this trend was much higher (0.232°C/10 years) through the long cold period 1954–1980. In the last 30-years period the trend was very high (0.351°C/10 years) – through the volcano eruption in Iceland in 2010 decreased the annual air temperature.

| Meteorological station | Period | Annual mean air temperature °C | Coefficient of variation | Standard deviation | Linear trend °C per decade | Mann–Kendall’s statistics** |
|------------------------|--------|--------------------------------|--------------------------|-------------------|---------------------------|----------------------------|
| Bydgoszcz              | 1848–2010 | 7.8                            | 0.107                    | 0.84              | 0.042*                    | 2.98                       |
| Leszno                 | 1848–2010 | 8.3                            | 0.101                    | 0.84              | 0.035*                    | 2.53                       |
| Poznań                 | 1891–2010 | 8.3                            | 0.101                    | 0.84              | 0.046*                    | 3.26                       |
| Gorzów Wlkp.          | 1891–2010 | 8.3                            | 0.102                    | 0.85              | 0.099*                    | 4.44                       |
| Kalisz                 | 1891–2010 | 8.3                            | 0.104                    | 0.86              | 0.063*                    | 2.88                       |
| Piła                   | 1921–2010 | 7.8                            | 0.109                    | 0.85              | 0.075*                    | 3.55                       |
| Częstochowa            | 1921–2010 | 7.9                            | 0.112                    | 0.89              | 0.094*                    | 3.36                       |
| Łódź                   | 1931–2010 | 7.9                            | 0.110                    | 0.87              | 0.102*                    | 3.55                       |
| Koło                   | 1931–2010 | 8.2                            | 0.109                    | 0.90              | 0.096*                    | 2.07                       |
| The Warta River basin (9 stations) | 1848–2010 | 8.1                            | 0.102                    | 0.82              | 0.040*                    | 2.79                       |
|                        | 1951–2010 | 8.2                            | 0.106                    | 0.87              | 0.232*                    | 3.60                       |
|                        | 1981–2010 | 8.6                            | 0.100                    | 0.85              | 0.351*                    | 2.15                       |

Explanations: *significant at the 0.05 level, ** the trend is statistically significant if the test statistic is higher than 2.

Source: own study.

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In the Warta River basin the increase of air temperature in the period 1981–2010 (Tab. 3) was most visible in spring (March–May) and winter (December–February). The trend was positive and significant (0.63°C/10 years) only in spring (Fig. 4). In other seasons, it was positive, mostly in winter, but not in autumn. This indicates a gradual increase of spring and winter air temperature, one that subsequently generates slow snow cover persistence and higher water infiltration into the soil.

**PRECIPITATION CHANGES IN THE PERIOD 1848–2010**

In the Warta River basin (Tab. 4) in all three analysed time series (163, 60 and 30 years) the mean annual precipitation totals were very similar (548, 547 and 544 mm). In eight stations this mean fluctuated only between 510.5 mm in Poznań to 578.6 mm in Łódź. It was higher (648.6 mm) only in the upper part of the river basin (Częstochowa). The lowest annual...
Fig. 3. Trend of annual mean air temperature (°C) and precipitation totals (mm) in the Warta River basin in the period 1848–2010; source: own study

Table 3. Mean air temperature and precipitation totals in the Warta River basin in seasons and various periods

| Period       | Air temperature | Precipitation totals |
|--------------|-----------------|----------------------|
|              | mean in season, °C | mean in season, % |
|              | annual | spring | summer | autumn | winter | annual | spring | summer | autumn | winter |
| A 1848–2010  | 8.1     | 7.7    | 17.5    | 8.3    | −1.2   | 548    | 21.9   | 37.9   | 22.0   | 18.2   |
| B 1951–2010  | 8.2     | 7.9    | 17.4    | 8.5    | −1.0   | 547    | 22.0   | 37.8   | 22.2   | 18.0   |
| C 1981–2010  | 8.6     | 8.5    | 17.7    | 8.6    | −0.6   | 544    | 22.8   | 36.4   | 22.0   | 18.8   |
| Difference B–A | 0.1     | 0.2    | −0.1    | 0.2    | 0.2    | 1      | 0.1    | −0.1   | 0.2    | −0.2   |
| Difference C–A | 0.5     | 0.8    | 0.3     | 0.1    | 0.6    | 4      | 0.9    | −1.5   | 0.2    | 0.6    |

Explanations: MAM = March, April, May, JJA = June, July, August, SON = September, October, November, DJF = December, January, February.

Source: own study.

Fig. 4. Variability of the mean air temperatures (°C) in four seasons in the Warta River basin in 1981–2010; source: own study
precipitation totals (<450 mm) were measured in the extremely dry years 1857–1865, 1951–1959 and 1982–1992. Fluctuations between succeeding years was often very high (Fig. 5). The linear trend of mean annual precipitation totals in the Warta River basin was small (1.1 mm/10 years), positive but not significant. The same result was given according to Mann–Kendall statistics. The small differences of annual precipitation in the longest periods in Kołobrzeg, Poznań, Bydgoszcz and Gorzów Wlkp., situated in the northern and central part of the Warta River basin was positive, and negative in Kalisz, Częstochowa, Leszno, Łódź and Pila, situated in its southern and eastern part. The change in these stations was never statistically significant (Tab. 4) and the coefficient of variations was high. In the periods 1951–2010 and 1981–2010 the linear trend of the mean annual precipitation totals in the Warta River basin was higher and positive, but not statistically significant. In the last period the influence of extremely dry years in the period 1982–1992 was visible.

The highest share in seasons for this period of 163 years was in summer (37.9%). It was very similar in spring and autumn and the lowest in winter. In the Warta River basin the share of precipitation totals in the seasons observed for three periods changed visibly only in 1981–2010 (Tab. 3). There was a slight rise in the percentage of precipitation in spring and winter and a decrease followed in summer. A very similar phenomenon was also observed for the period 1891–1930. In the period 1981–2010 the change was positive (Fig. 6) and the trend significant only in spring (13.6 mm per decade).

**DISCUSSION**

In the second half of the 20th century, the mean global temperature increased from 1956 to 2005 by 0.13°C per decade [TRENBERTH et al. 2007] and between 1950–2010 by 0.14°C per decade [ROHDE et al. 2013]. The temperature series in the Northern Hemisphere showed a statistically significant linear trend of 0.24°C per decade for annual value in the period 1961–2005, with highest temperatures in winter and spring [BROHAN et al. 2006].

In the Baltic Sea region during in the period 1871–2013 the near surface temperatures showed continued warming, in particular during spring and winter and this has been shown to be stronger over northern regions. No long-term trends are detectable for precipitation, although some regional indications exist for an increased length of precipitation periods [RUTGERSSON et al. 2014].

In our longest time-series (1848–2010) in the Warta River basin the linear trend of mean annual air temperature (0.04°C per decade) was small, positive and statistically significant. In the period 1951–2010 in the Warta River basin the annual mean temperature increased by 0.23°C per decade. A similar trend (0.20°C per decade) occurred in 1951–2000 in Poland [DEGIRMENDIČ et al. 2004] and in Germany [SCHÖNWIESE, JANOSCHITZ 2008]. In a shorter period (1971–2000) the trend was higher in the Czech Republic (about 0.3°C per decade) [BRAZDIL et al. 2009] and on the Germany–Poland border (0.24–0.33°C per decade) [SCHÖNWIESE, JANOSCHITZ 2008].

Because the climate change had a large impact on water management, our investigations were realized also in large river basins. Similar idea have given birth to investigations in the Yangtze River [ZHANG et al. 2014], as well as in the Betwa Basin in India [SURYAVAVANSHI et al. 2014].

In the period 1981–2010 in the Warta River basin the trend of air temperature was also higher (0.35°C per decade), but in Germany in the period 1971–2000 it was still 0.3°C per decade [SCHÖNWIESE, JANOSCHITZ 2008]. These data show that the comparison of air temperature trends in various regions without taking into consideration the relevant analysed periods will not produce the correct results.

In the Warta River basin, for the period 1848–2010, there was a typical significant fluctuation in the

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**Table 4. Statistical analyses of annual precipitation totals (mm) variability in the Warta River basin**

| Meteorological station | Period       | Annual mean precipitation totals mm | Coefficient of variations | Linear trend* mm per decade | Mann–Kendall’s statistics** |
|------------------------|--------------|-------------------------------------|---------------------------|-----------------------------|-----------------------------|
| Leszno                 | 1848–2010    | 546                                 | 0.179                     | −2.01                       | −0.91                       |
| Poznań                 | 1848–2010    | 511                                 | 0.190                     | 2.11                        | 1.22                        |
| Bydgoszcz              | 1861–2010    | 517                                 | 0.187                     | 1.51                        | 0.91                        |
| Gorzów Wlkp.           | 1875–2010    | 552                                 | 0.176                     | 0.12                        | 0.62                        |
| Pila                   | 1883–2010    | 561                                 | 0.181                     | −0.48                       | −0.02                       |
| Częstochowa            | 1891–2010    | 649                                 | 0.171                     | −3.78                       | −1.17                       |
| Łódź                   | 1904–2010    | 579                                 | 0.174                     | −1.25                       | −0.21                       |
| Kalisz                 | 1921–2010    | 524                                 | 0.193                     | −7.66                       | −1.65                       |
| Koło                   | 1931–2010    | 523                                 | 0.180                     | 5.24                        | 1.45                        |
| The Warta River basin  | (9 stations) |                                     |                           |                             |                             |
|                        | 1848–2010    | 548                                 | 0.146                     | 1.10                        | 1.06                        |
|                        | 1951–2010    | 547                                 | 0.156                     | 5.95                        | 1.10                        |
|                        | 1981–2010    | 544                                 | 0.164                     | 34.6                        | 1.87                        |

Explanations: * trend is not significant at the 0.05 level; ** the trend is statistically significant if the test statistic is higher than 2 or lower than −2.

Source: own study.
Fig 5. Long term variability of mean annual and 10-year moving average precipitation totals (mm) in Leszno, Poznań, Bydgoszcz, Gorzów Wlkp. Piła, Kalisz, Łódź, Częstochowa and Koło in 1848–2010; source: own study.
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Fig. 6. Variability of precipitation totals in the Warta River basin in four seasons in 1981–2010; source: own study

annual mean precipitation totals and a high variability. In three analysed time-series, the trend of annual precipitation was small and positive, but never statistically significant. In the period 1981–2010, the linear trend of the mean annual precipitation totals in all stations was positive (3.5 mm per decade), but significant only in two out of nine stations. In four seasons, the share of precipitation trend was positive, but significant only in spring (13.6 mm per decade). A weak increment (14 mm in 50 years) of annual precipitation totals in 1951–2000 was observed in Poland [Degirmendzic et al. 2004], Ukraine [Nabyvanets et al. 2011] and Czech Republic [Braudil et al. 2009]. In Germany for the period 1951–2000 the trend was +6% and in 1971–2000 it increased to +18% [Schönwiese, Janoschitz 2008].

Low annual precipitation and increasing air temperature, may lead to a decrease of agricultural production and available water resources. The impact of climate change on agriculture in Europe was analysed in the project “Impact of climate change in Europe” [Peseeta 2006–2008]. According to the IPCC SRES scenario A2 and the model HadCM3/HIRHAM, in Poland the change of yields in 2080 in comparison to 1961–1990 would be only about ±5%. The increase of air temperature causes an increase of potential (not of effective) evaporation and should be reflected in a decrease of water flow in rivers. In 1971–2010 the significant increase in Penman–Monteith reference evapotranspiration in the growing season in Poland (30 mm per 10 years) showed a similar trend to that of air temperature and sunshine hours [Labędzki et al. 2014]. However, one must keep in mind that both, the increase of temperature and precipitation occur in the cool half-year accompanied by a significantly decreased evaporation. Soil that is not frozen and rain instead of snow, permit a deeper water percolation into the soil and enrich the groundwater resources. In the period 1896–2010, in Gorzów Wlkp., the mean discharge (210.5 m³ s⁻¹) in the Warta River showed a positive but insignificant trend (1.11 m³ s⁻¹ per decade) and a very high variability. The annual mean discharge of 1981–2010 was nearly the same (208.7 m³ s⁻¹) as for the period 1896–2010 [Ilnicki et al. 2014].

CONCLUSIONS

In the Warta River basin, in the periods 1848–2010 and 1951–2010, the annual mean temperature increased by 0.04°C and 0.23°C per decade respectively. This was similar that the mean trend measured in the second half of the 20th century in Poland and Germany (0.20°C per decade) and in the Northern Hemisphere (0.24°C per decade). During the last 30 years (1981–2010) in the Warta River basin, the trend increased to 0.35°C per decade. In the Warta River basin the increase of air temperature in the period 1981–2010 was most visible in spring (March–May) and winter (December–February). In the period 1848–2010, the mean annual precipitation totals (mean 548 mm) do not change visible. In the last 30 years an
increase of precipitation totals mainly occurred in the spring and winter and a decrease in summer. In the period 1896–2010, the mean discharge (209 m$^3$·s$^{-1}$) in the Warta River showed a positive, but insignificant trend (1.11 m$^3$·s$^{-1}$ per decade). It can be argued therefore that climate changes do not change the long-term mean in the Warta River discharge.

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Wieloletnia zmienność temperatury powietrza i opadów atmosferycznych w zlewni rzeki Warty

STRESZCZENIE

Słowa kluczowe: analiza trendów, opady atmosferyczne, Polska, temperatura powietrza, zlewnia rzeki Warty

W zlewni rzeki Warty, położonej w rejonie o najniższych w Polsce opadach atmosferycznych, analizowano zmienność średnich rocznych wartości temperatury i sum opadów w latach 1848–2010, 1951–2010 i 1981–2010. W tym celu wykorzystano dane z dziewięciu stacji meteorologicznych dysponujących najdłuższymi seriami pomiarowymi. Głównym celem tych badań było zebranie wieloletnich danych dotyczących temperatury powietrza i sumy opadów atmosferycznych w zlewni Warty i statystyczna analiza ich zmienności. Temperatura powietrza wzrastała w tej zlewni w podobny sposób, jak w sąsiednich krajach. W ostatnich 30 latach zaobserwowano niesieć tego trendu. Opady atmosferyczne w całym badanym okresie nieco wzrosły w północnej i zmalały w południowej części zlewni, ale średnia roczna suma opadów w całej zlewni nie zmieniła się istotnie. W latach 1981–2010 roczna suma opadów nieco wzrosła zimą i wiosną oraz małała latem. W średnich rocznych przeplatach Warty negatywny wpływ tych zmian nie był widoczny.