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ANNUAL VARIATIONS AND TENDENCIES OF CHANGES IN ATMOSPHERIC FALL SUMS IN LĘBORK IN 1861-2000

Małgorzata Kirschenstein

Institute of Geography, Pomeranian Academy,
ul. Partyzantów 27, 76-200 Słupsk, Poland
e-mail: mjk67@tlen.pl

Abstract

The present paper concentrates on the basic features of an annual precipitation course (monthly, seasonal and annual sums) registered between 1861-2000. The paper also defines an amount of precipitation sums' deviations from the many years' average, factor of monthly precipitation sums' changeability and trends of their changes. The characteristics of the annual precipitation sums in an annual course allow to define which months, seasons and half-years were characterized by more intensive changeability and discover if there was recorded a considerable asymmetry between the particular months, seasons and half-years and what were the reasons of the asymmetry.

Key words: precipitation totals, trends of precipitations' changes, Lębork

INTRODUCTION

Lębork is situated in a Southbaltic coastal area, in a proglacial stream valley of the Łeba and Reda Rivers about 25 km from the shore. According to the W. Okołowicz's (1978) classification Lębork is characterized by a climate influenced by the Baltic Sea. The author (Kirschenstein 2008) in her previous factors' analysis of the annual many years' precipitation sums recorded in Lębork estimated a degree of precipitations' time differentiation. The author managed to determine that precipitation's time differentiation is caused by changeability of both features – the oceanic and the continental ones – that are generated by a changeable atmospheric circulation from the Baltic Sea, the Atlantic Ocean or the continental areas. The results of the research show that 60% out of the analyzed 140 years were characterized by intensified oceanic features. The present paper focuses on the characteristics of an annual precipitation's course with a special consideration of the maximal and minimal sums and trends of theirs changes in the analyzed period.

Annual precipitation coefficients are calculated on the basis of average monthly precipitation sums registered between 1861-2000. The data come from the various sources. The data registered before the Second World War come from the Atlas of atmospheric precipitation frequency in Poland (1961) and from Works and Studies KGW (1959). The data registered after the Second World War come from the annals and archives of IMGW. All missing information the author supplemented by using the quotient method based on data provided by various observation centers. In order to verify the hypothesis of homogeneity of processes precipitation series the author used non-parametric Smirnov-Kolmogorov test. The author also checked accordance of constant precipitation series registered between 1861 and 1949, and 1950 and 2000. The result of the test $\lambda = 0.95$ is lower that the critical value of statistics on the significance level 0.05 ($\lambda_{0,05} = 1.36$). If $\lambda < \lambda_{0,05}$ we can assume the series is probably homogenous. While analyzing the annual precipitation sums the author used a 7-word triangular filter: $a`_i = 1/16 (a_{i-3} + 2*a_{i-2} + 3*a_{i-1} +4*a_i + 3*a_{i+1} + 2*a_{i+2} - a_{i+3})$ in order to eliminate short-period fluctuations. The author used 31-word triangular filter to describe their changes in years.

ANNUAL PRECIPITATION TOTALS

The annual precipitation sum registered in 140 years is 663 mm. The highest annual sum 974 mm was recorded in 1998 (147% of many years' average), the lowest – 419 mm was recorded in 1876 (63% of many years' average). 51% of the analyzed years are characterized by annual sums that exceeded the many years' average. Data alignment by 31-word filter shows an increase of annual precipitation sums from 1861 to the forties of the 20th century (Fig. 1). Another increase was recorded in the seventies. The author recorded a tendency to increase the precipitation amount equal 0.77 mm per year.

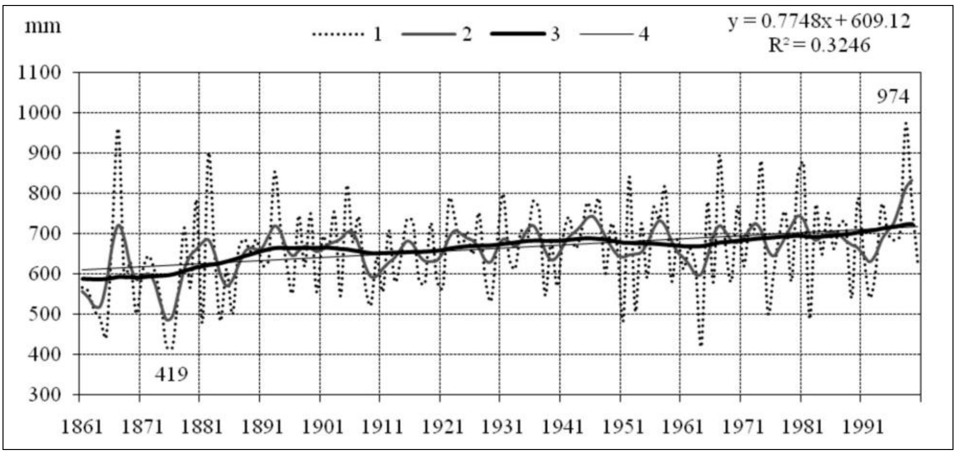

Fig. 1. Mean annual precipitation totals (1), smoothed with a 7-item filter (2) and with a 31-item filter (3), line trend (4)

MONTHLY PRECIPITATION SUMS

Maxima and minima of precipitation in an annual course are recorded in various months and they depend on the air temperature, the steam content and favorable conditions of the steam condensation. In Poland the average maximum is recorded in July, the minimum in February (Kirschenstein and Baranowski 2008).

In Lębork the average many years' maximum of precipitation in an aspect of annual course was recorded in July (84 mm), while the minimum was recorded in February (33 mm), (Fig. 2). In the analyzed period of 140 years the maximum most often occurred in July (24%), August (20%) and September (17%), however it had never occurred in February or March (Fig. 3). The minimum occurred in all months, with the most intensive frequency recorded in February (18%), March (14%) and April (14%).

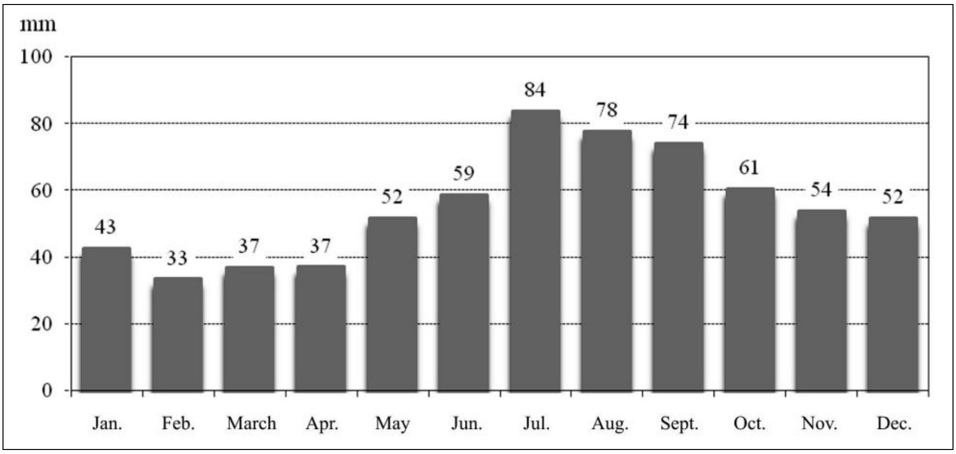

Fig. 2. Average monthly precipitation's sums (1861-2000)

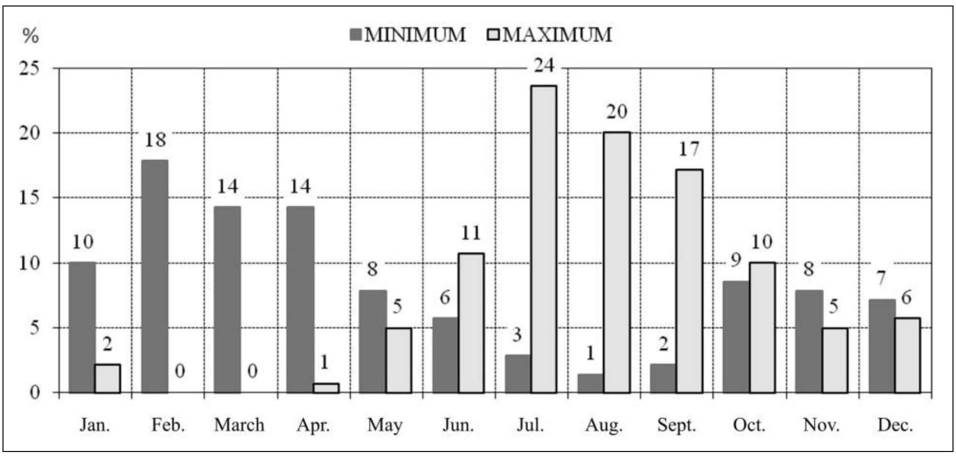

Fig. 3. Frequency of maximum and minimum of the precipitation's sums (1861-2000)

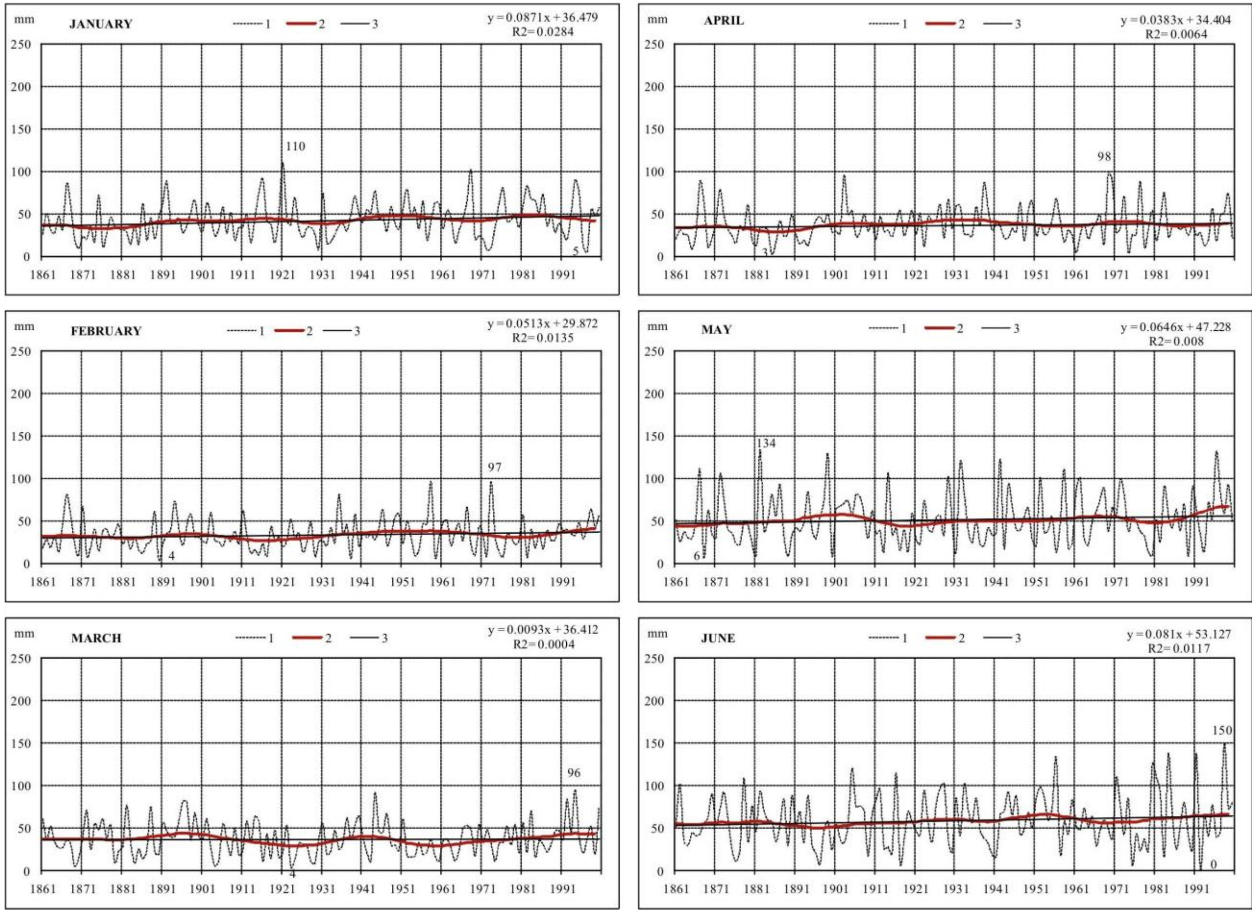

Fig. 4.1-4.6. Average monthly precipitation's sums (1), data alignment with the use of 31-word filter (2) and line trend (3)

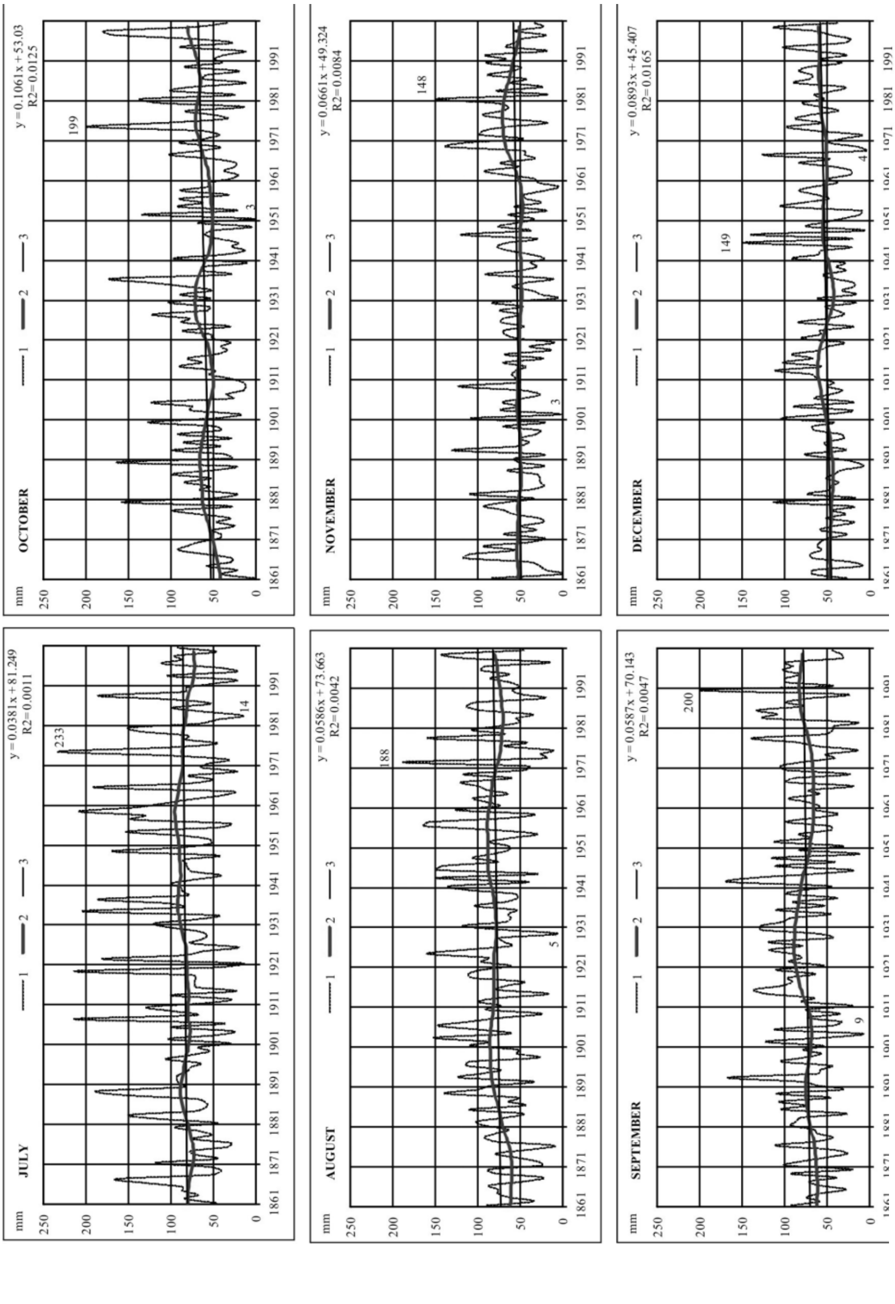

Fig. 4.7-4.12. Average monthly precipitation’s sums (1), data alignment with the use of 31-word filter (2) and line trend (3)

The July maximum is an effect of intensive heating up of the subsoil. However in Lębork the maximum is very often shifted to August, September or even November. This specific situation is caused by the influence of the Baltic Sea. In spring and early summer the Baltic Sea produces an effect of cooling down, that caused limiting of convection development (that is why the minimum is most often recorded from February to April) and in effect it might cause the maximum to be shifted to later months. According to M. Kirschenstein (2004) the zone of the most intensive rain falls recorded from July to November is located in the vicinity of the coast, in the area situated under the sea level. The distribution of the rain fall is influenced by increased thermal contrasts recorded at the border of the land and the sea, development of coastal convergence (it causes considerable increase of rain fall from August till November) and increasing influence of west circulation.

The highest sum of maximum is 233 mm, recorded in July (in 1974) and the highest sum of minimum is 45 mm, recorded in November (in 1967). High monthly precipitation averages were also recorded in September – 200 mm (in 1990), October – 199 mm (in 1974) and August – 188 mm (in 1972), (Fig. 4.1-4.12).

The second group consists of November, December, May and June with the sums exceeding 100 mm. The third group includes February, March and April with the average monthly precipitation sums under 100 mm (Fig. 4.1-4.12). The records show high deviations from the many years' average in the described period. All months were characterized by considerably high deviations from the many years' average: January – 12-258%, February – 12-290%, March – 11-259%, April – 8-264%, May – 12-259%, June – 0-255%, July – 17-278%, August – 6-242%, September – 12-269%, October – 3-329%, November – 4-274%, December – 8-288%.

An increase trend of monthly rain fall sums occurred in all months (Fig. 4.1-4.12). The highest increase was recorded in October (0.11 mm per year), December (0.09 mm per year), January (0.09 mm per year) and June (0.08 mm per year). The least increase was recorded in March (0.01 mm per year), April (0.04 mm per year) and July (0.04 mm per year).

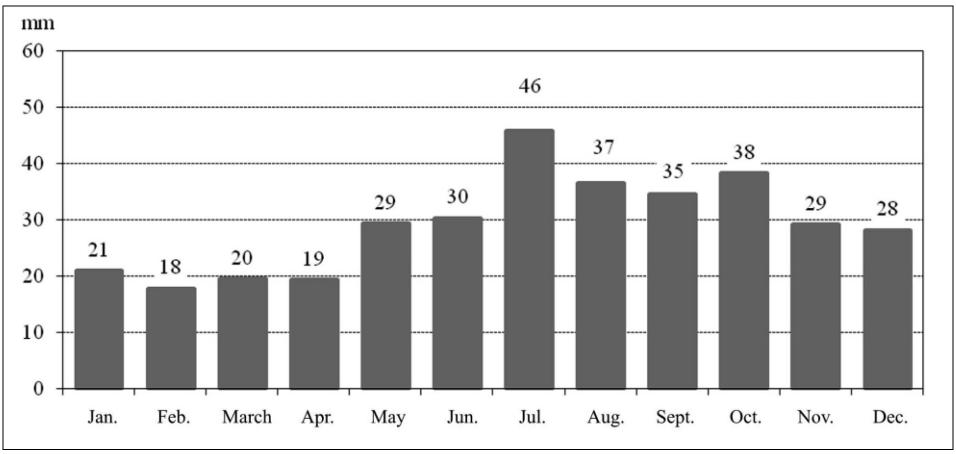

Fig. 5. Standard deviation (1861-2000)

After analyzing the records the author noticed a considerable asymmetry between sums of spring and fall months' precipitation in an annual course. September and October are particularly interesting due to the fact that they were characterized by high sums of rain recorded in some years. Moreover October remains a month characterized by the highest increase trend of precipitation's sums and the highest deviation from the many years' average (329%). Furthermore August was characterized by high sums of precipitation and frequent occurrence of the maximum.

Since monthly sums in a many years' course were characterized by considerably high variability, the author of the present paper calculated a standard deviation (Fig. 5). It is a measure characterizing value of monthly sum's deviation from the many years' average. The obtained values confirm that July, October, August and September are characterized by the highest deviation while February, March and April the least one.

Afterwards the author calculated a factor of precipitation's variability determining which part of the many years' average of precipitation's sum remains a standard deviation. The higher value of the factor, the stronger differentiation of rain fall in the many years' course. The highest variability factor was recorded in October, the least in August and September (Fig. 6).

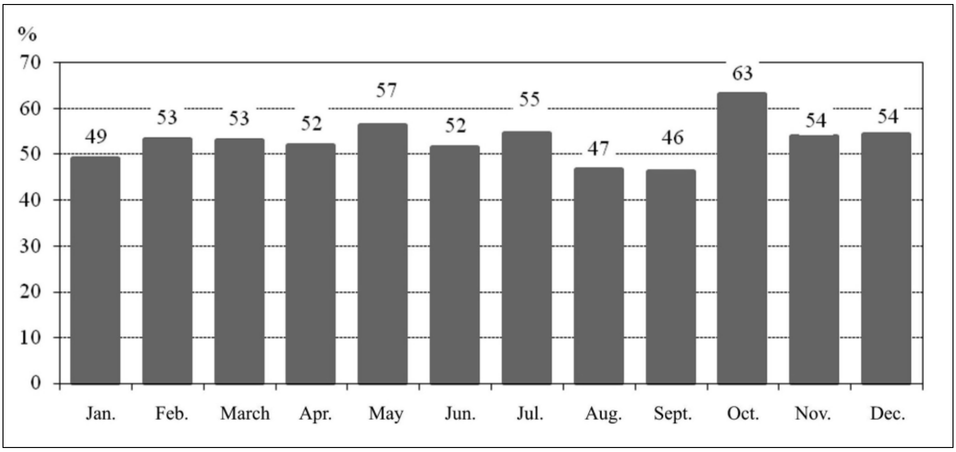

Fig. 6. Coefficient of variability (1861-2000)

One of the most important factors characterizing an annual precipitation's course remains an annual amplitude – the difference between maximal and minimal monthly precipitation, expressed in millimeters or per cent of an annual sum. It is average value calculated of 140 amplitudes is 107 mm (Fig. 7) and ranges from 50 mm (in 1898) to 228 mm (in 1974). However the amplitude expressed in per cent of an annual sum, calculated of average monthly precipitation's sums recorded between 1861 to 2000 is 7.6% and according to a K. Chomicz's (1971) classification indicates the sea-continental type of an annual precipitation's course. However an average amplitude calculated of 140 annual amplitudes indicates (16.2%) the quasi--continental type.

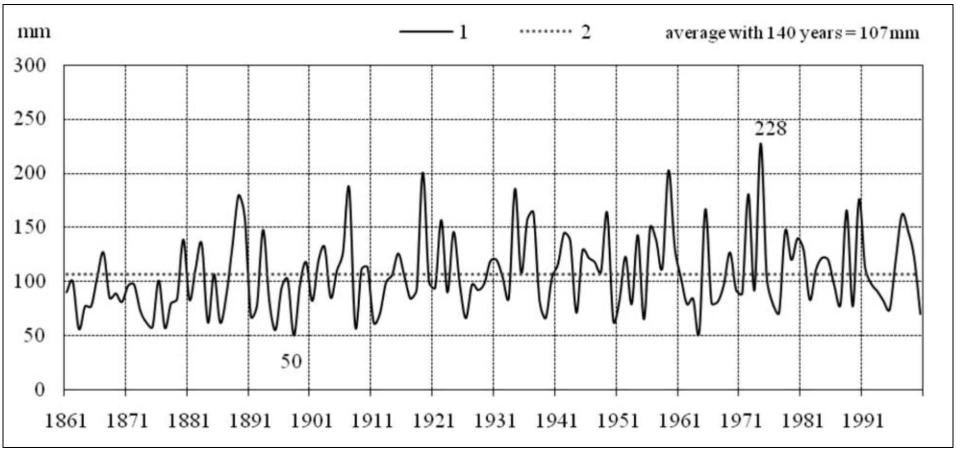

Fig. 7. Mean annual precipitation amplitudes (1), average with 140 years (2), (1861-2000)

The PCI factor is considered a good example of a factor determining regularity of monthly precipitation's sums distribution. The factor is also known as an index of precipitation's concentration (Kirschenstein 2008). PCI values may theoretically vary from 8.3 with regular monthly sums distribution in a year to 100 with extreme irregularity (rainfall concentration in a single month). If PCI values are < 10 it indicates the lack of a seasonal character of rainfall, values $11 \leq$ PCI ≤ 20 – a seasonal character of rainfall and PCI ≥ 21 – strong seasonal variability. In Lębork PCI index varied from 9.2 (in 1939, 1998) to 17.7 (in 1865), (Fig. 8). The 140 year average value is 11.2 and indicates a seasonal character of rainfall in annual precipitation course. However the results recorded in the described period show that 28 years' (20%) index was < 10 and 36 years' (26%) index was < 11. We can acknowledge that 46% of the analyzed years were characterized by a lack of seasonality and intensifi-

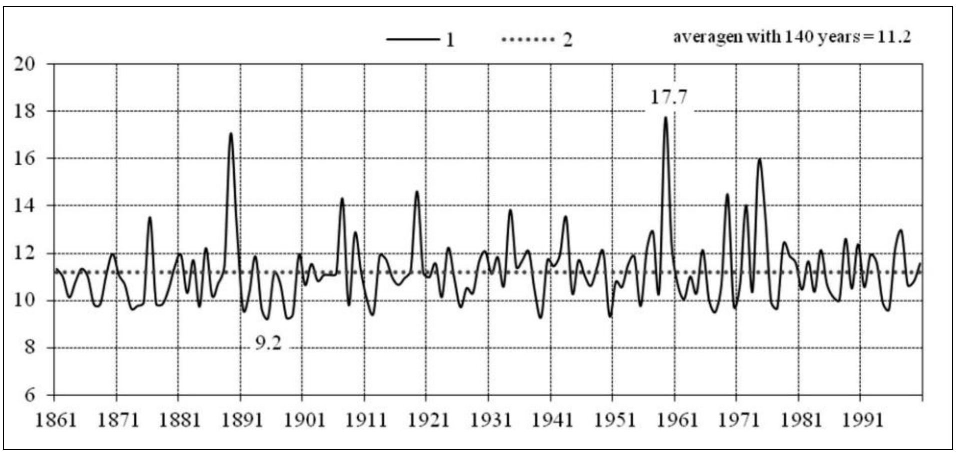

Fig. 8. Precipitation concentration index PCI (1), average with 140 years (2), (Kirschenstein 2008)

cation of oceanic features that remained the effect of the Atlantic Ocean influence and above all influence of the Baltic Sea.

PRECIPITATION'S SUMS IN PARTICULAR SEASONS AND HALF-YEARS

Making the comparison between the seasons and half-years allows to define an asymmetry of an annual precipitation's course and indicate the seasons characterized by maximal and minimal precipitation. Setting them in order in relation to distribution in an annual sum indicates that Lębork is characterized by an SuAWSp type (summer – 33.2%, autumn – 28.5%, winter – 19.3%, spring – 19.0%). K. Kożuchowski and J. Wibig (1988) determined this type – a pomeranian type. The authors distinguish three types in Poland: the pomeranian type – SuAWSp, the central zone – SuASpW, and the south Poland type – SuSpAW. However the records show high variability of types that occurred in the described period. Summer was recorded in the first position in 61% of years, autumn in 33%, spring and winter in 3% of years.

The author also compared the seasons by calculating the quotients of autumn and spring, autumn and summer, autumn and winter, summer and spring, summer and winter and spring and winter. The results indicate that:

– the sums of autumn precipitation were higher in 84% of the analyzed years from the spring and winter sums and in 37% from the summer ones,
– the sums of summer precipitation were higher in 89% of the analyzed years from the spring sums and in 85% from the winter ones,
– the sums of spring precipitation were higher in 44% of the analyzed years from the winter sums.

An analysis of season influence in the described period shows high variability (Fig. 9, 10). The level of spring precipitation sums ranged from 6% to 39%, summer from 10% to 54%, autumn from 12% to 46% and winter from 4% to 37%. The highest

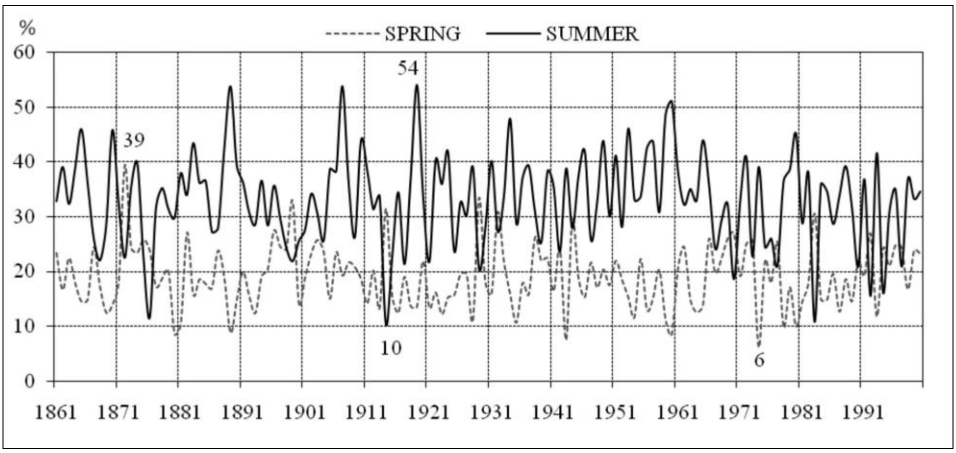

Fig. 9. Percentage of seasons (spring and summer) precipitation sums in the total annual precipitation (1861-2000)

amplitude of fluctuations was registered in summer (44%), then in autumn (34%), the lowest in spring and winter (33% each). The records show that there were 4 years with summer precipitation sums exceeding 50% of an annual sum (1889, 1907, 1919, 1960).

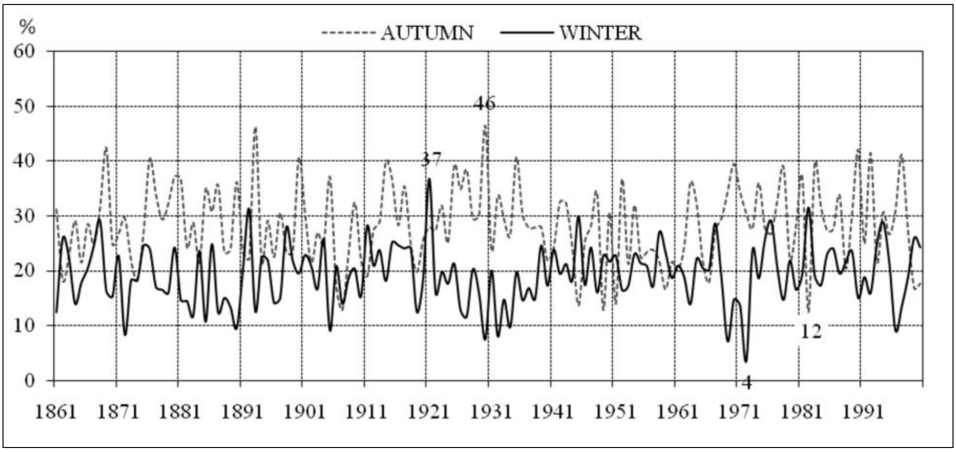

Fig. 10. Percentage of seasons (autumn and winter) precipitation sums in the total annual precipitation (1861-2000)

The seasonal precipitation's sums exceeded the many years' average appropriately: in 48% of the analyzed years in spring, 45% in summer, 46% in autumn and 49% in winter. All seasons were characterized by considerably high deviations from the many years' average (spring – 40-202%, summer – 22-181%, autumn – 32-209%, winter – 20-201%).

High standard deviation was recorded in summer (67 mm) and autumn (60 mm), considerably decreased deviation occurred in spring (43 mm) and winter (41 mm). However the variability factor reached its height in spring (34%), while it reached 32% in autumn and winter and 30% in summer. An increasing trend of the seasonal precipitation's sums was recorded in all the seasons: spring – 0.11 mm per year, summer – 0.18 mm per year, autumn – 0.23 mm per year, winter – 0.23 mm per year.

In connection with the above facts, besides high precipitation's sums in summer recorded in Lębork, there also occurred high precipitation's sums in autumn that were caused by frequent in that time advection of warm and humid air from the Atlantic Ocean and the Baltic Sea (extremely intensive cyclonal activity in the south Baltic Sea recorded at that time) and scant precipitation's sums in spring connected with cooling influence of water reservoirs (Kirschenstein 2008).

Data alignment with the use of 31-word filter allows to specify approximately periods of increased precipitation's sums (Fig. 11): spring precipitation's sums increased from the beginning of the analyzed period till the end of the 19th century, afterwards between 1920 and 1940 and from the beginning of the sixties; summer precipitation's sums approximately increased from the begging of the analyzed period until

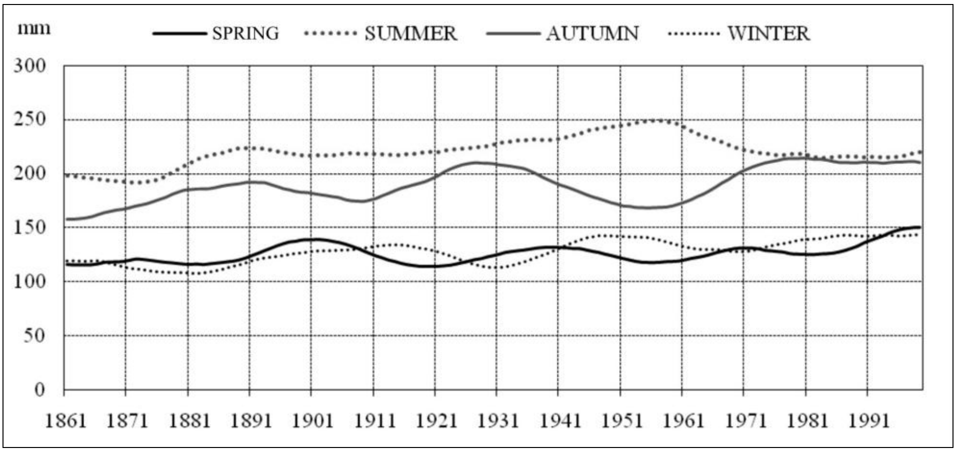

Fig. 11. Precipitation's sums in particular seasons smoothed with a 31-item filter (1861-2000)

the sixties of the 20th century, autumn precipitation's sums increased between 1861 and 1893, 1910 and 1930 and from the sixties, winter precipitation's sums were characterized by the occurrence of two important increasing periods – from the eighties of the 19th century to the twenties of the 20th century and the thirties of the 20th century.

An amount of precipitation's sums of the warm half-year recorded in the analyzed many years' period (May-Oct.) in the annual sum from the many years' period is 61% and ranges from 41% (in 1909) to 80% (in 1885), (Fig. 12).

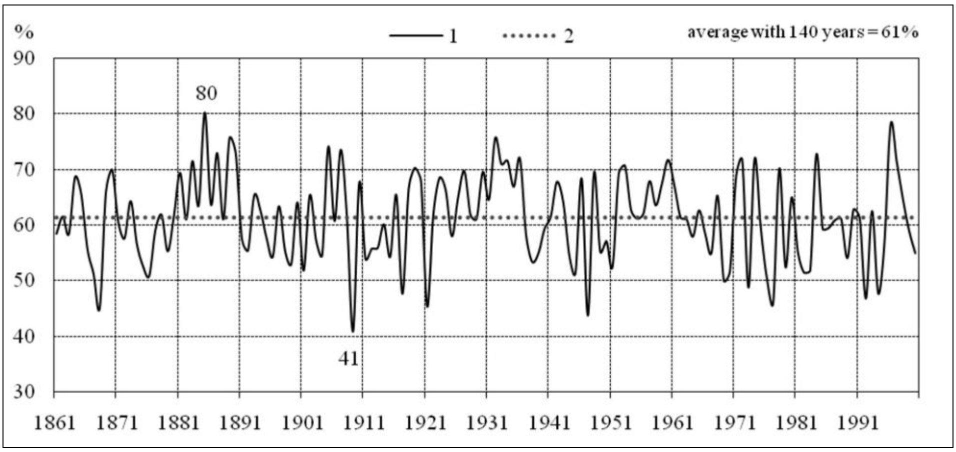

Fig. 12. Percentage of warm half-year precipitation sums in the total annual precipitation (1), average with 140 years (2), (1861-2000)

Despite the predominance of the warm half-year in the analyzed period, a difference between precipitation's sum in the warm half-year and the cold one (Nov.-Apr.) is not significant – 151 mm. Moreover in 7% of the analyzed years an amount of pre-

cipitation's sums in the cold half-year was higher and in 51% below the many years' average. The above results indicate and confirm a significant role of the west circulation and the circulation from the Baltic Sea recorded in this particular period and influence of the mentioned factors on increasing the oceanic features at a precipitation course. The precipitation's sums recorded in the warm half-year exceeded the many years' average in 48% of the analyzed years, and in the cold half-year in 47%. A deviation from the many years' average was characterized by intensive variability both in the warm (52-155%) and cold half-year (47-183%).
A deviation from the many years' average in the warm half-year (82 mm) was higher than in the cold one (73 mm), while a variability factor showed quite the contrary tendency: in the cold half-year it reached 28%, and in the warm one – 20%.

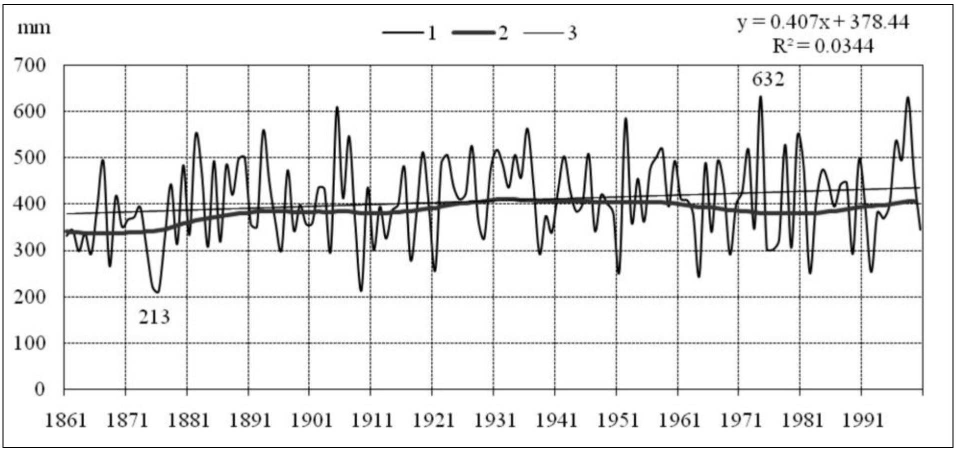

Fig. 13. Precipitation's sums in warm half-year (1), data alignment with the use of 31-word filter (2) and line trend (3), (1861-2000)

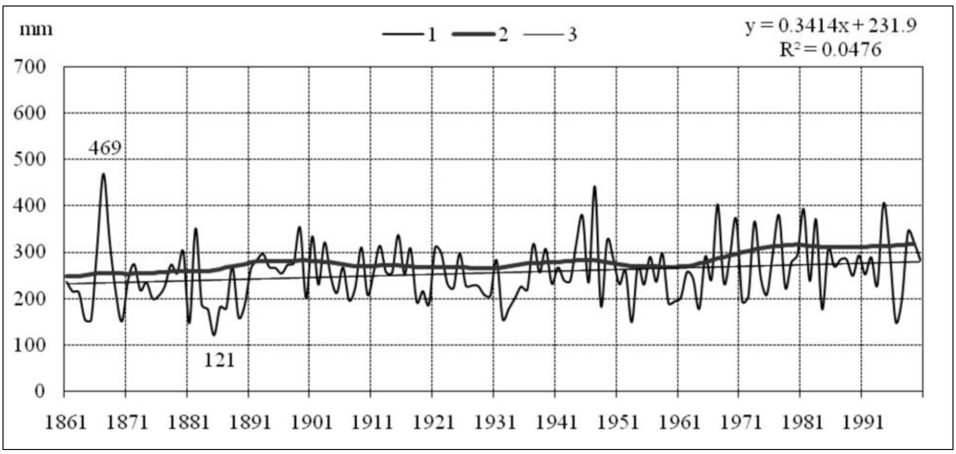

Fig. 14. Precipitation's sums in cold half-year, data alignment with the use of 31-word filter (2) and line trend (3), (1861-2000)

The author noticed a tendency to increase the precipitation, both in the warm (0.41 mm per year) and cold half-years (0.34 mm per year). Data alignment with the use of 31-word filter indicates increasing of precipitation's sums in the warm half-year from the beginning of the analyzed period until the thirties of the 20th century, and then from the seventies of the 20th century (Fig. 13, 14). The changes recorded in the cold half-year were higher, with four distinct increase periods – the first one from the beginning of the analyzed period until 1900, and the following three recorded between 1931-1948, 1960-1980, 1991-1999.

CONCLUSION

The purpose of the present paper was to define the trends of the precipitation changes and their deviation from the many years' average recorded between 1861 and 2000 and estimate, which months, seasons and half-years were characterized by higher variability. The author also presents answers to the question whether there was a significant asymmetry between the particular months, seasons and half-years and what were the reasons of the asymmetry. After analyzing the data the author discovered that the annual precipitation's sums recorded in Lębork were characterized by a considerable changeability. It is considered a result of a changeable influence of the circulation from the Atlantic Ocean, the Baltic Sea and the continental areas and also local conditions, including Lębork's location in the Reda and Łeba Rivers' proglacial stream valley. Frequent occurrence of the precipitation maximum recorded not only in July, but also in August, September and October, low sums in February, March and April indicate and confirm a strong influence of the Baltic Sea. It cools down the temperature and causes decreasing of the precipitation's sums in spring and early summer. However increasing of contrasts at a border of the land and the sea contributes to a considerable increase of the precipitation's sums recorded from July to November. That is why autumn is characterized by high amounts of the precipitation's sums (in 84% of the analyzed years they were higher than the spring and winter sums and in 37% from the summer sums).

Visible changes of precipitation can be noticed in amounts of deviations from the many years' average. All the months were characterized by very high deviations (especially in October), similarly the precipitation's sums recorded in seasons, half-years and year. Such high deviations confirm frequent occurrence of seasons characterized by an excess or deficiency of the precipitation's sums, it means that every month, season, half-year or year in a single year might have been dry, and wet in another.

The highest standard deviation of the precipitation's sums was recorded from July till October, it means that the analyzed period included the seasons of summer and autumn. The deviation was higher in the warm half-year than in the cold one.

A changeability factor was the highest in October, higher in spring than in summer. This situation indicates the more intensive changeability of precipitation in the cold half-year than in the warm one.

A trend of increasing precipitation's sums was observed in every month, season and half-year. The highest increase was recorded in October and December; in autumn and winter, whereas in both half-years the increase tendency was high.

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WAHANIA ROCZNE I TENDENCJE ZMIAN SUM OPADÓW ATMOSFERYCZNYCH W LĘBORKU W LATACH 1861-2000

Streszczenie

Celem pracy było określenie trendów zmian wielkości opadów i odchylenie od średniej wieloletniej w okresie 1861-2000 oraz ocena, które miesiące, pory roku i półrocza charakteryzowały się większą zmiennością, czy wystąpiła duża asymetria między poszczególnymi miesiącami, porami roku i półroczami i jakie były jej przyczyny. Na podstawie przeprowadzonej analizy stwierdzono, że przebieg roczny sum opadów w Lęborku charakteryzował się dużą zmiennością. Wynika ona z wahań oddziaływania cyrkulacji znad Oceanu Atlantyckiego, Morza Bałtyckiego i obszaru kontynentalnego oraz uwarunkowań lokalnych, między innymi położenia w pradolinie Redy-Łeby. Częste występowanie maksimum opadów nie tylko w lipcu, ale również w sierpniu, wrześniu i październiku i niskie sumy w lutym, marcu i kwietniu świadczą o dużym wpływie Morza Bałtyckiego. Wiosną i wczesnym latem jest on ochładzający i powoduje obniżenie sum opadów, natomiast od lipca do listopada wzrost kontrastów na granicy ląd-morze przyczynia się do znacznego ich wzrostu, dlatego jesień charakteryzuje się wysokimi sumami opadów (w 84% lat były one wyższe od sum wiosennych i zimowych oraz w 37% od sum letnich).

Zmienność opadów jest również widoczna w wielkości odchyleń od średniej wieloletniej. Wszystkie miesiące charakteryzowały się bardzo dużymi wahaniami (szczególnie październik), podobnie sumy opadów w porach roku, półroczach i roku. Tak duże wahania świadczą

o występowaniu na przemian okresów z nadmiarem lub niedoborem sum opadów, czyli każdy miesiąc, pora roku, półrocze lub rok w jednym roku mogły być suche, a w następnym wilgotne.

Największe odchylenie standardowe sum opadów wystąpiło od lipca do października, wśród pór roku były to lato i jesień, zaś w półroczu ciepłym odchylenie było większe niż w chłodnym.

Współczynnik zmienności był największy w październiku, większy wiosną niż latem, wskazuje on również na większą zmienność opadów w półroczu chłodnym niż ciepłym.

Trend wzrostu sum opadów wystąpił we wszystkich miesiącach, porach roku i półroczach. Największym wzrostem charakteryzowały się: miesiące – październik (0,11 mm/rok), grudzień (0,09 mm/rok), styczeń (0,09 mm/rok) i czerwiec (0,08 mm/rok); pory roku – jesień (0,23 mm/rok) i zima (0,23 mm/rok), natomiast w przypadku półroczy, w obu tendencja wzrostu była duża: w półroczu ciepłym – 0,41 mm/rok, w półroczu chłodnym – 0,34 mm/rok. W całym wieloleciu wystąpił trend wzrostu rocznych sum opadów – 0,77 mm/rok.