

MEAN ANNUAL PRECIPITATION IN A MOUNTAIN RIVER CATCHMENT AREA IN THE PERIOD 1984–2012 (THE CASE OF KAMIENICA RIVER)

Agnieszka Cupak, Anna Górka, Bogusław Michalec, Andrzej Wałęga

Summary

The aim of the study is to evaluate the mean annual precipitation in the mountain river catchment area, in the period between 1984–2012. Data on daily rainfall totals was obtained from IMGW PIB in Warsaw, and it came from two weather stations: one in Nowy Sącz, and the other in Krynica. It has been demonstrated that during the multi-year period covered by the study, there were variations in terms of precipitation levels; the year 1987 should be considered extremely dry, while 2010, extremely wet – in the latter year, extreme rainfall was noted. In the analysed multi-year period, within the total annual precipitation, rain dominated during the first half year, which undoubtedly affects the hydrological regime of the Kamienica river.

Keywords

precipitation • extreme rainfall • annual precipitation • mountain river catchment (basin)

1. Introduction

The issue of water systems is a very important for the management of river basin districts. To a large extent, the nature of the catchment area determines the physical and chemical characteristics of rivers. When analysing these features, we can get an idea of the hydrological processes occurring within a given catchment area and riverbed. Observations of a series of hydrological and meteorological data, over the multi-year period, permits developing a description of the formation of the runoff and the assessment of water resources of the region concerned [Banasik and Hejduk 2011]. Furthermore, these observations provide the basis for the assessment of the dynamics of water flow in some periods of the year. For this purpose, trend analysis and the analysis of cyclical nature in the occurrence hydro-meteorological phenomena are typically applied [Skowera et al. 2014].

Precipitation is the main source of rivers' water feed, and it is the rainfall, which largely shapes the hydrological regime. A number of factors influence the occurrence of precipitation, including altitude, atmospheric circulation and orographic conditions. It is extremely important from the point of view of the analysis of water resources, and the analysis of extreme hydro-meteorological phenomena, to recognize the progress of

rainfall in the aspects of time and space. For the area of Polish, of all natural hazards caused by natural factors, the biggest threat is posed by high precipitation and maximum wind speed. Intensive outpours of rain lasting for many days cover large areas and are often cause flooding, while the short heavy rains and torrential rains cause flooding and local flash flood [Lorenc et al. 2012].

Precipitation in times of floods constitutes a direct source of the water streams supply. According to Wrzesiński [2014], in the case of rivers outside the areas subjected to strong human pressures (urbanization), climatic conditions have a greater impact on modifying the characteristics of the hydrological regime. Research by Bartczak et al. [2014] also confirms this. Precipitation events of extreme character cause serious hydrological effects such as floods, which pose a threat to humans, and to many sectors of the economy [Szalińska and Otop 2012]. Dong et al. [2015], on the other hand, claim that the variability of the direct runoff from direct catchment areas is not only affected by the changes in land use, but also by the changes in the progress of precipitation, especially in catchment areas of medium size.

The purpose of this study is to evaluate the characteristics of the formation of annual precipitation in the area of Kamienica (a mountain river), in the period 1984–2012. The analysis was performed based on the sequences of daily precipitation totals for Krynica and Nowy Sącz weather stations.

2. Research area

Research area covers the Kamienica river – also known as Kamienica Nawojowska, but henceforth referred to simply as Kamienica – flowing through the Nowy Sącz district in the Małopolska province. The length of the river is 33.079 km, and the catchment area equals 237.83 km² [Szafarska 2015]. Sources of Kamienica river are located on the north side of the Jaworzyna Krynicka mountain range, where mountain streams of Krzyżówka and Roztoka flow in, while its outlet is located in the Dunajec river, which flows on the east in Nowy Sącz. The studied catchment area is located in the area of two climatic regions of the upper basin of the Vistula river: the mountain climate and climate the Carpathian foothills [Cebulska et al. 2013].

Predominant form of the natural landscape in the district of Nowy Sącz is the Carpathian flysch in the form of stratified clastic sediments, which have been folded in the Neogene, and then in the Miocene. Flysch sediments occurring in this area are mainly sandstone, shale and conglomerates. In terms of land use, the predominant part of the basin – 58.7% is covered with forests, which determine the types of soil conditions, topography and climatic conditions. Other uses include: built-up areas 11.8%, grassland 7.4%, arable land 6.5%, and wasteland 15.6% [Szafarska 2015].

3. Material and methods

The basis for the study was provided by the daily precipitation totals from the period of 1984–2012, measured at two weather stations in Nowy Sącz (geographic coordi-

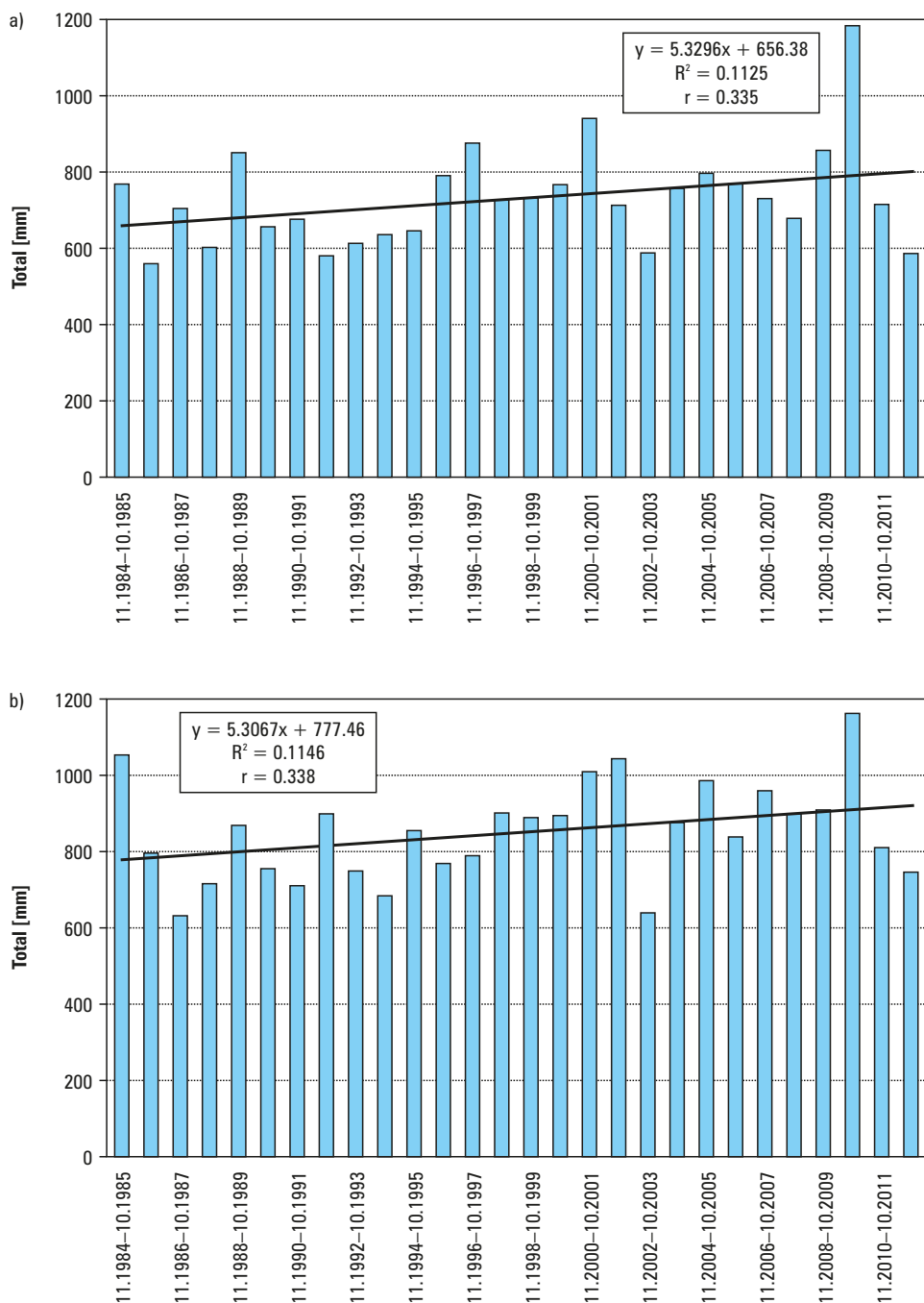
nates N: 49°37'38.29"; E: 20°41'19.3") and Krynica near Muszyna (geographic coordinates N: 49°26'58.79"; E: 20°58'10.23"). The data was obtained from the Institute of Meteorology and Water Management of the National Research Institute in Warsaw. In the study, we have calculated the total precipitation on the annual and monthly basis, we classified mean annual precipitation according to Kaczorowska's [1962] classification, we calculated the amount of the sum of intense daily rainfall events for the summer season (half year), in individual years of the studied period, for the following ranges: $P \geq 30$ mm (threatening rainfall), $P \geq 50$ mm (dangerous rainfall), $P \geq 70$ mm (flooding rainfall), $P \geq 100$ mm (catastrophic rainfall). Classification of rainfall was applied as per [Climate 2009].

4. Presentation and discussion of results

In the analysed period (1984–2012), annual rainfall for the Nowy Sącz weather station ranged from 561.8 mm in the hydrological year 1986 to 1,183.1 in the hydrological year 2010. At the Krynica weather station, the lowest rainfall occurred in 1987 (637.3 mm), while the highest rainfall was noted in 2010 (1,164.3 mm). For comparison, in the region of the upper Vistula river catchment area, the average rainfall for the period 1951–1970 amounted to 749 mm, and for the 1952–1981, 769 mm.

The average atmospheric precipitation in the catchment area of Dunajec river amounted to 874 mm for the period 1951–1970, and 1014 mm for the period 1952–1981 [Cebulska et al. 2013]. Precipitation totals in individual years, analysed within the discussed multi-year period, exhibit considerable variation. In general, indications in the Krynica station are higher than in the Nowy Sącz station – see Figure 1. The opposite situation occurred only 4 times (1987, 1996, 1997 and 2010). Precipitation totals in individual hydrological years, however, show a certain cyclic nature – with alternating periods of growth and decline, generally involving simultaneously both of the test stations. In the Polish Carpathians, precipitation is affected mainly by circulation and geographical factors – such as varied terrain and high altitude [Woźniak in 2013]. In Nowy Sącz, wet years occurred in 1989, 1997 and 2009, a very humid year, in 2001 and extremely humid, in 2010, when it the highest rainfall was recorded. In Krynica, the following years were considered humid: 1985, 2001, 2002, 2005, and very humid: 2007 and 2010. Dry seasons in Nowy Sącz coincided with the years: 1986, 1988, 1993–1996, 2003, and 2012; in Krynica: 1988 1990, 1991, 1993, 1994, 2003 and 2012. One year, 1987, can be classified as very dry. Long-term trend of annual precipitation at both stations was growing and statistically insignificant.

In the analysed period, in the summer season (half year), rainfall for the weather station in Nowy Sącz ranged from 364.6 mm in 1992 to 915.4 mm in 2010. At the weather station in Krynica, the lowest rainfall occurred in 2003 (419.3 mm), while the highest, as in the case of Nowy Sącz, in 2010 (905.5 mm). Summer season (half years) with low rainfall (< 400 mm) was noted at the Nowy Sącz station in 1986, 1988, 1992–1994, while humid summer seasons (> 700 mm) occurred in 1997 and 2010. In turn, at the station in Krynica, there were no summer seasons (half-years) noted in which precipitation totals

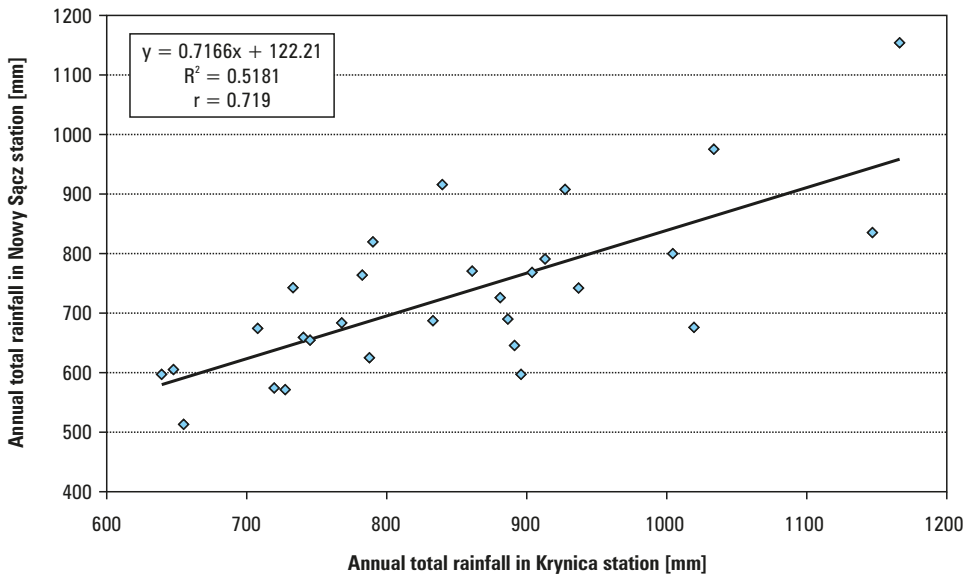


Source: authors' study

Fig. 1. Total rainfall at a) Nowy Sącz station and b) Krynica station in the period 1984–2012

would be below 400 mm. Relatively low rainfall (< 500 mm) occurred in the years 1987, 1988, 1993, 1994, and 2003. The high amount of rainfall (> 700 mm) was recorded four times: in 1985, 2001, 2002, and 2010. In the case of winter seasons (half-year, November-April), the lowest amount of rainfall at the weather station in Nowy Sącz was recorded in the hydrological year 2012 (153.8 mm), while the highest, in 2010 (328.3 mm). At the Krynica weather station, the lowest rainfall occurred in 1987 (186.4 mm), and the highest in 2000 (393 mm). In Nowy Sącz, exceptionally dry winter seasons (precipitation < 200 mm) occurred in the years 1985, 1986, 1991, 1997, 2002, 2009, 2011, and 2012. The winter seasons with a relatively large amount of rainfall (> 300 mm) occurred in the years: 1987, 1989, and 2000. In Krynica, winters with low rainfall (< 200 mm) were recorded in the years 1987, 1991, and 1996, whereas the high amount of rainfall (> 300 mm) was noted in years 1989, 1990, 1992, 1995, 1998, 2000, 2005 and 2007.

There is a statistically significant correlation between the annual precipitation totals at the weather station in Krynica (upper part of the river catchment) and Nowy Sącz (lower part of the river catchment) – see: Figure 2. The calculated correlation coefficient of $r = 0.719$ is statistically significant.

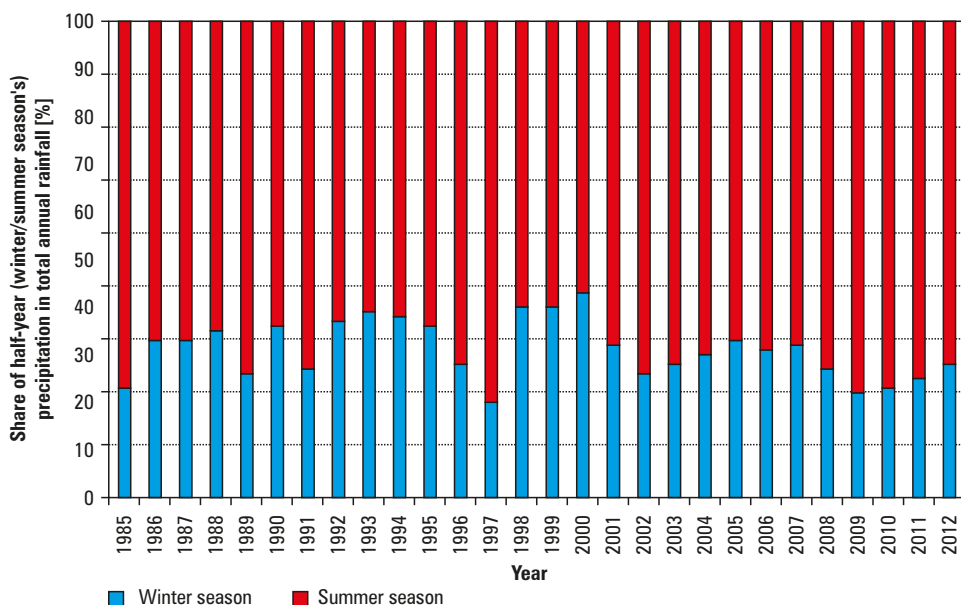


Source: authors' study

Fig. 2. Comparison between annual total rainfall in Krynica and Nowy Sącz stations between 1985–2012

In both studied stations, rainfall in the winter season was much lower than in the summer seasons. In Nowy Sącz, the share of winter season precipitation in annual total rainfall ranges from 20% (1997) to 43% (2000). At the Krynica weather station, the

respective figures were from 22% (2010) to 44% (2000). The average share of precipitation for the two stations, in the analysed period, in the winter season was 31% and in the summer season, 69%. Woźniak reaches similar conclusions as to the share of rainfall in each season are for the region of the Carpathians [2013]. Figures 3 and 4 shows the contribution of the individual seasonal (half-year) precipitation in relation to the total annual rainfall.

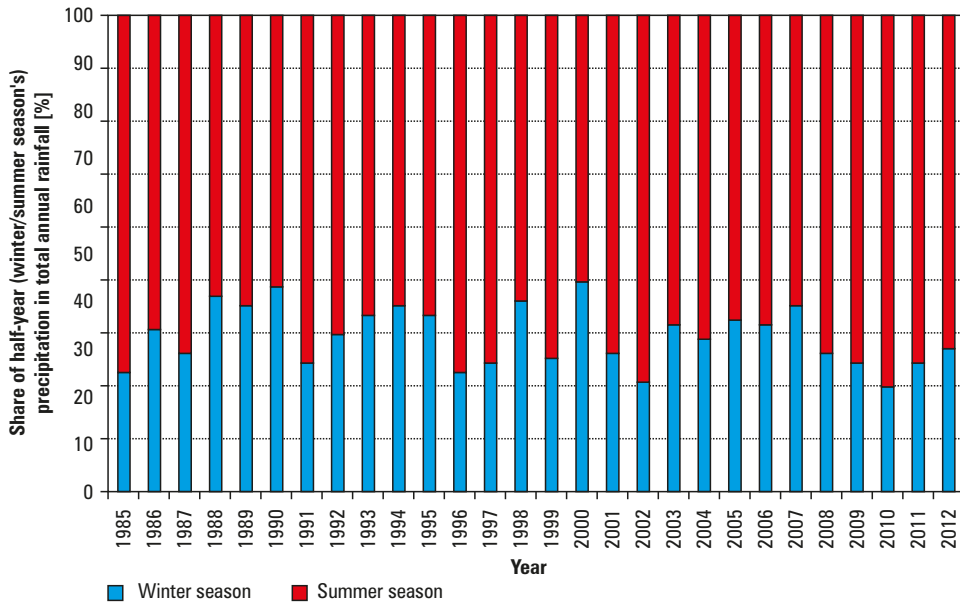


Source: authors' study

Fig. 3. Share of precipitation in individual half-year periods compared to annual totals for the Nowy Sącz station in the period 1984–2012

At the weather station in Nowy Sącz, the minimum value of daily precipitation totals in each year amounted to 0.1 mm. The highest maximum precipitation occurred in the year 2009 and amounted to 82.2 mm. A high total was also observed in 2001 (74.8 mm). Also at the weather station in Krynica, minimum values of rainfall each year amounted to 0.1 mm. The maximum daily totals were recorded in 1999 (94.5 mm) and in 2008 (82.2 mm). A relatively high total of the highest daily rainfall was also noted in 2012 (72.8 mm).

In the Kamienica river catchment area, days with very strong precipitation occur very rarely. Threatening rainfall in analysed period lasted for, on average, 1.6 days as recorded at the weather station in Nowy Sącz and 2.2 days as recorded in Krynica. Most of precipitation days (4 days) in excess of 30 mm in the summer half-year in Nowy Sącz took place in the years 1997, 2007 and 2010. In 2002 and 2005, threatening precipitation occurred each year 3 times.



Source: authors' study

Fig. 4. Share of precipitation in individual half-year periods compared to annual totals for the Krynica station in the period 1984–2012

The highest number of days (4) with a rainfall that exceeded 30 mm in the summer season, in Nowy Sącz, occurred in the years 1997, 2007, and 2010. In 2002 and 2005, threatening rainfall occurred 3 times in each year. Throughout the whole period, only in 4 years, no threatening rainfall was recorded. In other years it occurred at least once. At the weather station in Nowy Sącz, dangerous rainfall ($P \geq 50$ mm) was recorded 5 times (1987, 2001, 2006, 2009–2011), and flooding rainfall ($P \geq 70$ mm) occurred 4 times (2001, 2009–2011). However, there was no incidence of precipitation in excess of 100 mm. Most days of intense precipitation were recorded in 2010 (6 days). Dangerous rainfall and flooding were more frequent at the end of the analysed period (Table 1). In Krynica, most days with precipitation exceeding 30 mm in the summer season were recorded in 2011 (6 days). Also in 2001, their number was significant (5 days), while 4 days with threatening rainfall was observed in 1986, 1992 and 2010. In other years, the summer seasons had an average of 1–3 days with precipitation above 30 mm. In the years 1985, 1999 and 2005 the precipitation $P \geq 70$ mm was recorded one time in each year. Most days of intense precipitation were recorded in 2010 and 2011 (6 days). However, there was no incidence of precipitation in 1990, 1991 and 2003 (Table 1). Dangerous precipitation in Krynica occurred more frequently than in Nowy Sącz. In 1995, it was observed for 2 days, it was recorded for 1 day each year in 1984–1986, 1994, 1999, 2006 and 2007. Also, two days of flooding rainfall were recorded in 2010.

In 1985, 1999 and 2005, the rainfall in the amount of $P \geq 70$ mm occurred once each year. Most days of intense precipitation were found in 2010 and 2011 (6 days). However, it did not occur at all in 1990, 1991 and 2003 (Table 1).

Table 1. Number of total events of intensive daily rainfall in the summer season (half year), in the analysed period for the Nowy Sącz and Krynica stations

| Nowy Sącz | | | | | | | | | | | | | | | |
|----------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|---------|
| Year | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
| $P \geq 30$ | 2 | 2 | 0 | 1 | 2 | 1 | 0 | 0 | 2 | 0 | 1 | 2 | 2 | 4 | 1 |
| $P \geq 50$ | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $P \geq 70$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 2 | 2 | 0 | 2 | 2 | 1 | 0 | 0 | 2 | 0 | 1 | 2 | 2 | 4 | 1 |
| Year | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | Average |
| $P \geq 30$ | 1 | 1 | 2 | 3 | 2 | 1 | 3 | 1 | 4 | 2 | 1 | 4 | 1 | 1 | 1.6 |
| $P \geq 50$ | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0.2 |
| $P \geq 70$ | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0.1 |
| Total | 1 | 1 | 4 | 3 | 2 | 2 | 3 | 2 | 4 | 2 | 3 | 6 | 3 | 1 | 3.0 |
| Krynica near Muszyna | | | | | | | | | | | | | | | |
| Year | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
| $P \geq 30$ | 1 | 3 | 4 | 2 | 2 | 3 | 0 | 0 | 4 | 1 | 0 | 2 | 1 | 1 | 2 |
| $P \geq 50$ | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 |
| $P \geq 70$ | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 2 | 4 | 5 | 2 | 2 | 3 | 0 | 0 | 4 | 1 | 1 | 4 | 1 | 1 | 2 |
| Year | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | Average |
| $P \geq 30$ | 2 | 3 | 5 | 3 | 0 | 3 | 3 | 2 | 1 | 2 | 2 | 4 | 6 | 1 | 2.2 |
| $P \geq 50$ | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0.3 |
| $P \geq 70$ | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0.2 |
| Total | 4 | 3 | 5 | 3 | 0 | 3 | 4 | 3 | 2 | 2 | 2 | 6 | 6 | 1 | 2.7 |

5. Conclusions

The paper presents the analysis of the selected characteristics of mean annual precipitation in the period between 1984–2012, in the catchment area of Kamienica, a mountain river. In the analysed period, the year 2010 has been classified as extremely humid, and 1987 as extremely dry. In the case of both weather stations, average of six years of wet and seven dry years were recorded in the studied period. We have also observed cyclical nature of the annual precipitation totals. In both studied weather stations, rainfall in

the winter season (half year) was much lower than in the summer seasons (half years). The average share of precipitation in the analysed period, in the winter season was 31%, and in the summer season, 69%. In the analysed period rainfall that would qualify as a natural disaster ($P \geq 100$ mm) did not occur. In the case of both stations, particularly common instances of extreme rainfall occurred in 2001 and 2010.

References

- Banasik K., Hejduk L.** 2011. Variability in runoff from a small agricultural catchment – based on long term monitoring data. [In:] Prediction and Reduction of Diffuse Pollution, Solid Emission and Extreme Flows from Rural Areas – case study of small agricultural catchment. K. Banasik, L. Øygarden & L. Hejduk (eds.), SGGW, Warszawa, 7–25.
- Bartczak A., Glazik R., Tyszkowski S.** 2014. Czasowe i przestrzenne zróżnicowanie odpływu jednostkowego w zlewni rzeki Zgłowiączki (wschodnia część Kujaw). *Nauka Przyr. Technol.*, 8(3), 28.
- Cebulska M., Szczepanek R., Twardosz R.** 2013. Rozkład przestrzenny opadów atmosferycznych w dorzeczu górnej Wisły. Opady średnie roczne (1952–1981). WIS PK, IGI GP UJ, Kraków.
- Dong L., Xiong L., Lall U., Wang J.** 2015. The effects of land use change and precipitation change on direct runoff in Wei River watershed, China. *Water Sci. Technol.*, 71(2), 289–295.
- Kaczorowska Z.** 1962. Opady w Polsce w przekroju wieloletnim. *Prace Geograf.*, 33, 7–112.
- Klimat. Wpływ zmian klimatu na środowisko, gospodarkę i społeczeństwo. 2009. Praca zespołowa pod kierunkiem H. Lorenc, IMGW, Warszawa.
- Lorenc H., Cebulak E., Głowicki B., Kowalewski M.** 2012. Struktura występowania intensywnych opadów deszczu powodujących zagrożenie dla społeczeństwa, środowiska i gospodarki Polski. [In:] Klęski żywiołowe a bezpieczeństwo wewnętrzne kraju. Lorenc H. (ed.). Instytut Meteorologii i Gospodarki Wodnej, PIB, Warszawa, 7–32.
- Skowera B., Kopcińska J., Kopec B.** 2014. Changes in thermal and precipitation conditions in Poland in 1971–2010. *Ann. Warsaw Univ. Life Sci. – SGGW, Land Reclam.*, 46(2), 153–162.
- Szalińska W., Otop I.** 2012. Ocena struktury czasowo-przestrzennej opadów z wykorzystaniem wybranych wskaźników do identyfikacji zdarzeń ekstremalnych. *Woda Środ. Obsz. Wiej.*, 12, 2(38), 269–282.
- Szafarska A.** 2015. Analiza kształtowania się reżimu hydrologicznego rzeki górskiej w wieloleciu 1984–2012 (na przykładzie rzeki Kamienicy), UR w Krakowie.
- Woźniak A.** 2013. Opady w 2010 roku w Karpatach Polskich na tle wielolecia 1881–2010. *Prace Geograf.*, 133, 35–48.
- Wrzesiński D.** 2014. Transformacja reżimu odpływu rzek w Polsce. [In:] Współczesne problemy badań geograficznych. R.K. Borówka, A. Cedro, I. Kavetsky (eds), Uniwersytet Szczeciński, Wydział Nauk o Ziemi, Szczecin.

Dr inż. Agnieszka Cupak
 Uniwersytet Rolniczy w Krakowie
 Katedra Inżynierii Sanitarnej i Gospodarki Wodnej
 30-059 Kraków, al. Mickiewicza 24/28
 e-mail: a.cupak@ur.krakow.pl

Mgr inż. Anna Górka – studentka
Uniwersytet Rolniczy w Krakowie
Katedra Inżynierii Sanitarnej i Gospodarki Wodnej

Prof. dr hab. inż. Bogusław Michalec
Uniwersytet Rolniczy w Krakowie
Katedra Inżynierii Wodnej i Geotechniki
30-059 Kraków, al. Mickiewicza 24/28
e-mail: rmmichbo@cyf-kr.edu.pl

Dr hab. inż. Andrzej Wałęga
Uniwersytet Rolniczy w Krakowie
Katedra Inżynierii Sanitarnej i Gospodarki Wodnej
30-059 Kraków, al. Mickiewicza 24/28
e-mail: a.walega@ur.krakow.pl