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The use of archived precipitation data in the assessment of soil erosion risk in the Świętokrzyskie Province of central-southern Poland

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Abstract: The usefulness of archived IMGW–PIB published reports was discussed as a source of information on high total and intensity precipitation that generates the risk of soil erosion. The study area consist of the Świętokrzyskie Province of central-southern Poland. The data were obtained mainly from yearbooks: *The Atmospheric Precipitation Yearbooks* and *Results of pluviographic studies and precipitation of high intensity* for the period 1959–1981. The analysis is limited to the occurrence of rainfall events that produced at least 30 mm of rainwater and were classified as A_3 or higher on the Chomicz scale of rainstorms and downpours. A total of 247 rainstorms and downpours were recorded at 74 weather stations in the Świętokrzyskie Province. The utilized data sets allowed he estimation of erosivity index values using a simplified Wischmeier and Smith equation. Their erosivity index reached up to 6,387.8 $\mathrm{MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}}$ with a median value of 455.8 $\mathrm{MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}}$. This maximum value of *EI* was recorded at the Słupia weather station in the southwestern part of the study area. However, high erosivity rainfalls most often occurred in the lower section of the Nida Valley (in the Wiślica weather station). Precipitation characterized by the greatest erosivity occurred in June and July.

Keywords: rainfall erosivity index, archived precipitation data, Świętokrzyskie Province

INTRODUCTION

Precipitation characterized by high totals and intensity is a natural phenomenon, which poses a severe threat to the population and economy of Poland (Lorenc 2012). This threat may intensify in the future, as increasing frequency of high daily precipitation is listed as part of ongoing climate change (Hartmann et al. 2013).

Threats resulting from the occurrence of precipitation characterized by high amounts and high intensity (rainstorms and downpours) are associated first and foremost with increases in flood risk, especially the risk of flashfloods (Zieliński 1998, Bryndal 2011, Suligowski 2013).

The kinetic energy of raindrops is also an important relief-forming factor that leads to the erosion of soil. Many research studies dedicated to soil erosion risk aim to identify the relationship between rainfall parameters and erosion intensity. This problem is solved via the monitoring of erosion intensity on hillside runoff plots. Precipitation is measured too, which helps to determine the threshold level of precipitation needed for the triggering of erosion processes. In Poland, these types of studies are carried out in the following catchments: (1) Dworski Potok in the Wiśnicz Foothills marginal zone (Święchowicz 2012), (2) Bystrzanka in the Low Beskidy Mountains (Bochenek & Gil 2007), (3) Chwalimski

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Potok in the Drawsko Lake District (Szpikowski 2012), (4) Szeszupa in the Suwałki Lake District (Smolska 2008). Precipitation intensity can vary substantially over time and across geographic space. Hence, the capacity to measure and determine maximum precipitation intensity even in areas close to the runoff plots is limited. Research experiments based on the artificial irrigation of runoff plots can reduce the severity of this problem (Jóźwiak 1992, Majewski 2014).

A second approach calls for a post-fact analysis of precipitation conditions which led to extreme erosion events. These studies focus on a determination of the degree of change in relief and the magnitude of material losses caused by extreme events. Precipitation data such as totals and intensities serve to help establish the cause of events (Starkel 1998, Janicki et al. 2010).

The relationship between precipitation total, precipitation intensity, and the intensity of erosion studied on experimental hillside runoff plots made it possible to determine erosion-triggering rainfall parameters applied in the Universal Soil Loss Equation (Wischmeier & Smith 1978).

Historical meteorologic data from selected Polish weather stations were used too in a research effort designed to identify erosion-rainfall parameters. The data were used to determine monthly and annual values of rainfall erosivity for selected sites (Banasik & Górski 1992), i.e. *R*-factor as used in USLE and the revised USLE (RUSLE) (Wischmeier & Smith 1978) and the erosivity of precipitation with a given probability of exceedance (Baryła 2010). These studies used both pluviographs and daily precipitation totals calculated using data collected by Hellmann rain gauges.

Long-term precipitation data were also used to estimate rainfall erosivity in other European states, e.g. in Ebro Basin in north-eastern Spain (Angulo-Martinez & Begueria 2009), central Belgium (Verstraetel et al. 2006) and Czech Republic (Janeček et al. 2013).

Recently, an international research project was carried out to assess rainfall erosivity in Europe (Panagos et al. 2015, Ballabio et al. 2017). Data from 1568 precipitation stations in all EU Member States and Switzerland were used to produce maps of rainfall erosivity. However, the precipitation data accessibity collected in particular states was very different. Number of precipitation data sets used in the study amounted from 3 in Lithuania up to 251 in Italy. Likewise, the authors utilized only few precipitation data sets from Poland (Panagos et al. 2015, Ballabio et al. 2017).

Thus far, data on precipitation characterized by high totals and intensity collected by the Institute of Meteorology and Water Management – National Research Institute (Polish acronym IMGW-PIB) and published up until the early 1980s have not been commonly used in research on precipitation-driven erosion in Poland.

This paper has two main scientific goals: (1) To prove the usefulness of the archives of the published reports of the Institute of Meteorology and Water Management – National Research Institute as sources of information on high total and intensity precipitation that generates the risk of soil erosion, (2) To estimate the erosivity of rainstorms and downpours, which had occurred over the course of more than 20 years in Świętokrzyskie Province in Poland in the second half of the 20th century, as well as to determine their spatial distribution.

METHODS

Precipitation data obtained for rain gauging stations located within the current boundaries of Świętokrzyskie Province (central-southern Poland) were used in this study. It is precisely *The Atmospheric Precipitation Yearbooks* (1961–1981) which are the main source of information. The yearbooks were published by IMGW-PIB and prior to 1973 by PIHM. Data found in Chapter 9 of the yearbooks were used in the study (rainstorms and downpours). In addition, precipitation data from 1959 and 1960 were also used. These data were published as yearbooks with the title: *Results of pluviographic studies and precipitation of high intensity.*

The study area consists of the Świętokrzyskie region of central-southern Poland. The authors of the paper made the key decision to simplify the study by assuming that the Świętokrzyskie region is synonymous with Świętokrzyskie Province. The geographical area of this province featured more than 67 weather stations (rain gauging stations) in the study period (1959–1981). The number of rain gauging stations varied from 67 in 1959 to 81 in the years 1975–1976.

The study area is characterized by geological and climatic distinctness and varies strongly in terms of elevation, climate, and soil type. The highest points in the area are found in the Świętokrzyskie Mountains, which are situated in the central and northern parts of the region. The highest range is known as the Łysogóry ("Bald Mountains"), which reach more than 600 meters above sea level. The topographic prominence of the Łysogóry exceed 300 m. This range also experiences the highest total of precipitation in the study area, exceeding 800 mm per year. The lowest precipitation (<550 mm) is noted in the Nida Basin situated in the southern part of the study area (Żarnowiecki 1991). Świętokrzyskie Province also experiences substantial hailstorms (Koźmiński 1994). Given that precipitation in the form of hail is associated with *Cumulonimbus* clouds, the high frequency of their occurrence also implies the frequent occurrence of both rainstorms and downpours in the studied region. Soils in the Świętokrzyskie Province are characterized by varying susceptibility to water erosion. The most susceptible to water erosion are soils in loess areas with high relative relief, occurring in the following geographical regions: Wodzisław Hills, Proszowice Plateau and Sandomierz Upland (Józefaciuk & Józefaciuk 1987).

The analysis in the paper is limited to the occurrence of rainstorms and downpours that produce at least 30 mm of rainwater. The research literature (Janicki et al. 2010, Święchowicz 2010) suggests that rainstorms and downpours that produce 30 mm of rainwater or more also produce substantial geomorphological changes.

The paper analyzes the following types of data:
- time and place of precipitation,
- amount of precipitation (in mm),
- duration of precipitation (in min),
- classification of rainstorms and downpours using the Chomicz (1951) scale (from A_3 to B_4).

The next step consisted of the calculation of the mean intensity of each analyzed rainfall event.

The number of rainstorm and downpour events reaching and exceeding selected rainfall threshold values (30, 40, 50, 60, 70, and 80 mm) was determined for the area of the Świętokrzyskie Province.

The mean number of rainstorm and downpour events per year was also determined, as was the event pattern over the course of the year as a whole.

The next stage of the research consisted of the calculation of kinetic energy E_{kin} and the erosivity index EI for the analyzed precipitation events.

The erosivity index EI [MJ·mm·ha^{-1}·h^{-1}] for individual precipitation events was calculated using the modified Wischmeier and Smith equation (1978):

$$EI = E_{\mathrm{kin}} \cdot I,$$

where:

E_{kin} – kinetic energy of rainfall per unit area [MJ·ha^{-1}],

I – intensity of rainfall [mm·h^{-1}].

In this paper, EI is slightly modified by substituting mean precipitation intensity for the maximum 30-minute precipitation intensity which appears in the original formula.

The kinetic energy E_{kin} [MJ·ha^{-1}] for individual rainfall events was determined using the Brown and Foster formula (1987). In its original form, the formula is written as follows:

$$E_{\mathrm{kin}} = \sum_{i=1}^{n} 0.29 \cdot \left[1 - 0.72 \cdot \exp\left(-0.051 \cdot I_i\right)\right] \cdot \Delta P_i,$$

where:

I_i – rainfall intensity for a period with constant partial intensity i [mm·h^{-1}],

ΔP_i – rainfall total for events with constant partial intensity i [mm].

The yearbooks used in the study do not contain data on changes in precipitation intensity for the duration of each precipitation event. Hence, this paper provides a simplified version of the Brown and Foster equation, which has been altered to use mean precipitation intensity and precipitation totals.

Box plots are used to show statistical parameters for values of EI and E_{kin}. E_{kin} and EI values larger than the upper quartile by 1.5 times interquartile range and 3.0 times interquartile range were deemed moderate and extreme outliers respectively (Tukey 1977). In addition, the Spearman rank correlation coefficient was calculated for the erosivity index EI and kinetic energy E_{kin} as well as rainfall amount, intensity, and duration. The Student's t-test was used to evaluate the statistical significance of the relationships determined in the study. Regression curves were also produced for precipitation amounts and intensities versus the erosivity index.

The meteorological conditions needed for the occurrence of rainstorms and downpours that possess the highest erosivity index were also determined. Surface weather analysis determined by the IMGW-PIB were used in the study (IMGW-PIB Meteorologic Bulletin). In addition, the distribution of precipitation events characterized by erosivity index exceeding the upper quartile was also analyzed for loess areas in Świętokrzyskie Province.

RESULTS

Characteristics of the analyzed rainfall events

A total of 247 rainstorms and downpours were recorded at 74 weather stations in the period 1959 – 1981 within the current administrative boundaries of Świętokrzyskie Province. These events were classified as A_3 or higher on the Chomicz scale (Chomicz 1951), and produced at least 30 mm of rainfall (Tab. 1).

Table 1

Characteristics of rainstorms and downpours, class A_3 or higher on the Chomicz scale, recorded within the current administrative boundaries of Świętokrzyskie Province in 1959–1981

Precipitation total class	Number of events	Precipitation total [mm]		Rainfall duration [min]		Rainfall intensity [mm·min^{-1}]		Most commonly occurring Chomicz class of rainstorms and downpours
		arith. mean	median	arith. mean	median	arith. mean	median	
≥30.0	243	46.0	40.5	82	65	0.86	0.70	A_4 (34%)
≥40.0	127	56.9	50.6	105	85	0.84	0.63	A_4 (31%)
≥50.0	69	67.2	61.2	117	95	0.93	0.74	B_2 (29%)
≥60.0	37	78.0	71.1	120	120	0.95	0.74	B_2 (40%)
≥70.0	22	86.9	77.2	136	142	0.95	0.69	B_2 (45%)
≥80.0	10	104.4	98.2	142	148	0.82	0.69	B_2 (50%)

The mean duration of these 247 rainstorms and downpours is 82 minutes, while the mean rainfall total is 46 mm, and mean intensity is 0.86 mm·min^{-1}. The characteristics of the analyzed precipitation events is positively skewed, which means that median values of these characteristics are smaller than corresponding arithmetic mean values. The median precipitation total is 40.5 mm, median duration is 65 min, and median intensity is 0.70 mm·min^{-1}. The most common type of rainfall event (34% of cases) over the study period was rainfall classified as A_4 on the Chomicz scale (Tab. 1).

Slightly more than 50% of the analyzed rainfall events (n = 127) consisted of events with a precipitation total of ≥40 mm, while about 28% (n = 69) were of events yielding at least 50 mm (Tab. 1). The most common type of rainfall event producing 50 mm or more consisted of downpours was classified as B_2 on the Chomicz scale (Chomicz 1951). Ten events produced at least 80 mm of rainfall or more (Tab. 1), with four producing more than 100 mm of rainfall. Research has shown that increases in precipitation totals were accompanied by increases in mean precipitation durations. This type of dependence was not observed in relation to rainfall intensity (Tab. 1).

Rainstorms and downpours (class A_3 or higher) producing 30 mm of precipitation or more occurred from around April 10th to around September 15th. These events occurred most frequently in

June (70 events, 28%) and July (109 events, 44%). Precipitation events in the months of June and July together account for 72% of all studied precipitation events (Fig. 1).

The average number of heavy rainstorms and downpours per year was found to be 10. However, the actual number of events varied strongly from 3 to 21 in a given year.

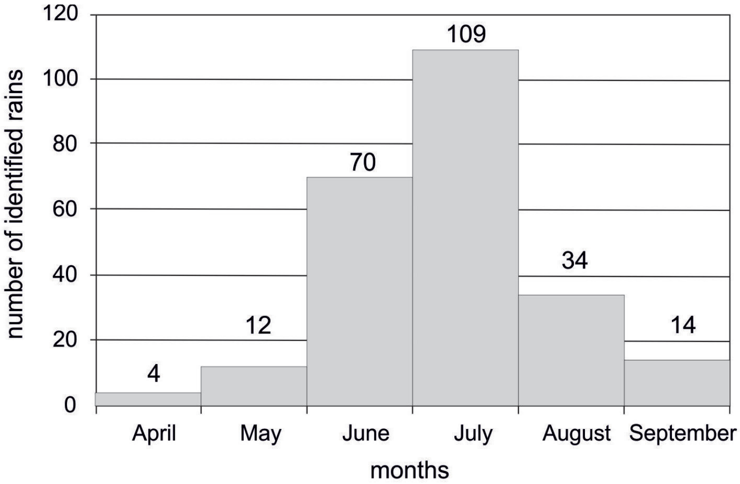

Fig. 1. *Intra-annual occurrence variability of A_3 class rainfall and higher in the Chomicz scale producing at least 30 mm of rainfall identified in the study area*

Erosivity index of the identified rainfall events

The rainfall events identified in this study featured kinetic energy in the range from 5.6 to 47.5 MJ·ha^{-1}, while their erosivity index values ranged from 59.6 to 6,387.8 MJ·mm·ha^{-1}·h^{-1} (Fig. 2).

The median value of the erosivity index for the analyzed events is 455.8 MJ·mm·ha^{-1}·h^{-1}, and the median value of their kinetic energy is 10.4 MJ·ha^{-1}. The arithmetic mean values for kinetic energy of rainfall and the erosivity index are markedly higher than their corresponding median values, which suggests they are positively skewed. The quartile for the erosivity index ranges from 232.4 to 856.8 MJ·mm·ha^{-1}·h^{-1} yielding a value of 624.4 MJ·mm·ha^{-1}·h^{-1}. The quartile for the kinetic energy of rainfall ranges from 8.6 to 13.1 MJ·ha^{-1} yielding a value of 4.5 MJ·ha^{-1} (Fig. 2).

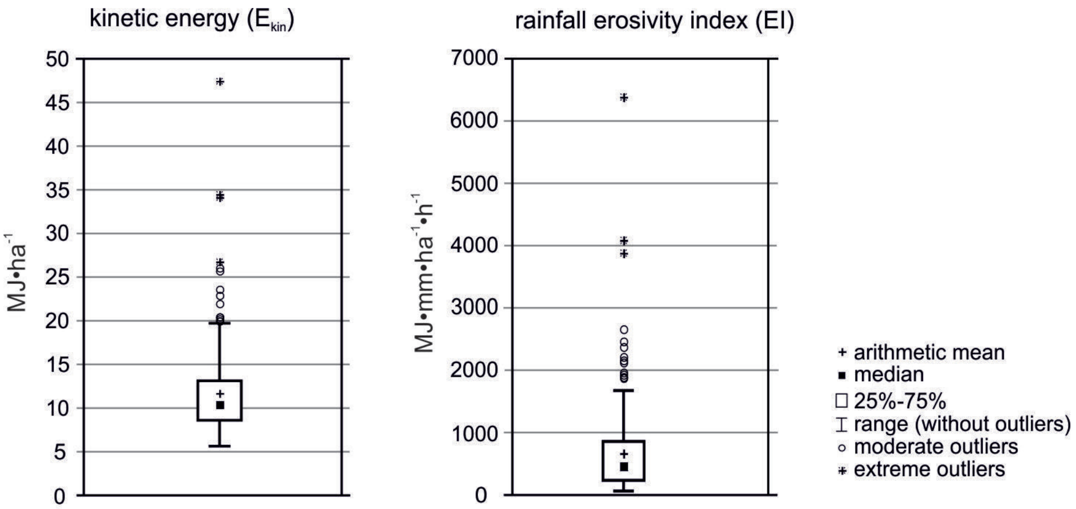

Fig. 2. *Box plots for kinetic energy values (E_{kin}) and the erosivity index (EI) for A_3 class rainfall or higher in the Chomicz scale producing at least 30 mm of rainfall identified in Świętokrzyskie Province in the years 1959–1981*

The median of the erosivity index for June and July or months characterized by the largest number of precipitation events with the highest erosion potential is 526.3 MJ·mm·ha^{-1}·h^{-1} and 464.5 MJ·mm·ha^{-1}·h^{-1}, respectively. Average erosion index values for other months featuring erosion-triggering precipitation events were lower.

Analysis of erosivity index values with the use of a box-plot allowed the determination of 13 cases of the largest *EI* values which constitute outliers, including 3 extreme outliers. Erosivity index values for outliers were higher than 1,673.5 MJ·mm·ha^{-1}·h^{-1}. All of the 13 outlying values of the erosivity index were associated with the movement of a cold front or occluded front over Poland (IMGW-PIB Meteorological Bulletin; see sample weather maps: Fig. 3).

The largest erosivity index (6,387.8 MJ·mm·ha^{-1}·h^{-1}) can be attributed to a downpour that occurred on July 27, 1976 at the Słupia Jędrzejowska site. It was also characterized by the highest intensity (4.65 mm·min^{-1}), which classifies it as a B_4 event on the Chomicz scale (Chomicz 1951). On this particular day, high intensity rainfalls with significant erosivity index wear also recorded at a number of other weather stations in the studied region (Fig. 3). The next two largest rainfall events in terms of erosion index values occurred on July 22, 1976 at Mniów and lasted for almost two hours (*EI* = 4,092.6 MJ·mm·ha^{-1}·h^{-1}) and also on August 11, 1970 at Wiślica and lasted for only 15 minutes (*EI* = 3,875.4 MJ·mm·ha^{-1}·h^{-1}).

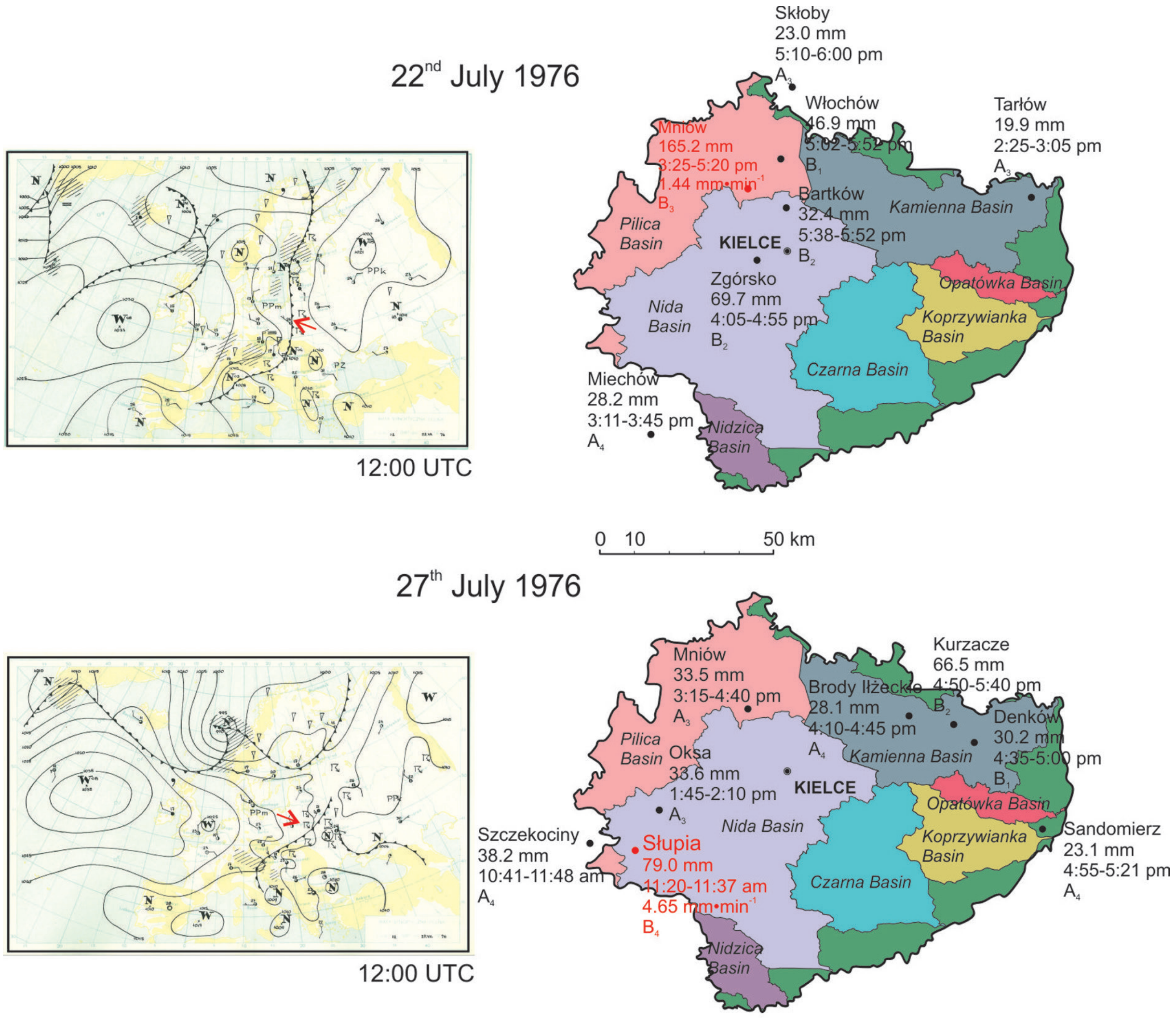

Fig. 3. *Location of downpours during precipitation events with the largest erosivity index (EI) in main drainage basins of the Świętokrzyskie Province in the years 1959–1981 and its meteorologic conditions (red arrows in the weather maps indicate location of the study area)*

The downpour recorded at Mniów (B_3 on the Chomicz scale) on July 22, 1976 was also the largest rainfall event in the sample of events in this study with a total of 165.2 mm. As in the case of the precipitation situation from July 27, 1976, rainstorms and downpours of varying intensity were noted on this particular day at multiple weather stations in the studied region (Fig. 3). The erosivity index for all other rain events did not exceed 2,680 $\mathrm{MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}}$.

The erosivity index for the analyzed precipitation events was most closely correlated with mean rainfall intensity. The correlation is positive and the coefficient of correlation $r_{xy} = 0.94$ (Tab. 2, Fig. 4B). The longer the given precipitation event, the smaller its erosivity index value. The coefficient of correlation for the erosivity index and precipitation duration was $r_{xy} = -0.70$. This is primarily due to the fact that longer lasting precipitation events are characterized by lower intensity. The erosivity index for the studied rainfall events was also moderately related, and also statistically significant, with precipitation amounts (Tab. 2, Fig. 4A). The correlation between the erosivity index of rainfall and kinetic energy was also high (Tab. 2), although the correlation between kinetic energy and precipitation amount was even higher ($r_{xy} = 0.86$). The kinetic energy of the examined rainfall events doesn't exhibit a correlation with rainfall duration. The regression relationship between the erosivity index and precipitation totals, as well as the mean precipitation intensity, was approximated using a second degree polynomial (Fig. 4).

Research work on the geographical distribution of precipitation events characterized by the highest erosivity index values (above upper quartile) indicates that high erosivity precipitation events occurring in the period 1959–1981 at 41 weather stations occurred most often at Wiślica in the Nida river valley (4 times). High erosivity index events also occurred more than once at these other weather stations: Mokoszyn, Jędrzejów, Słupia, Oksa, Suchedniów, Brody Iłżeckie, Tarłów, Sadków and Staszów. Three out of thirteen precipitation events characterized by peak erosion and deemed to be outliers in the context of the statistical distribution of this metric occurred at the Wiślica, while two occurred at the Słupia (Fig. 5).

Table 2
Spearman's rank correlation coefficient for erosivity index and kinetic energy of the studied precipitation events versus precipitation characteristics

Rainfall parameter	Rainfall energy	Precipitation total	Precipitation duration	Mean rainfall intensity
Erosivity index	0.70*	0.30*	−0.70*	0.94*
Rainfall energy	X	0.86*	−0.06	0.45*

The asterisk denotes coefficients statistically significant at $p < 0.05$

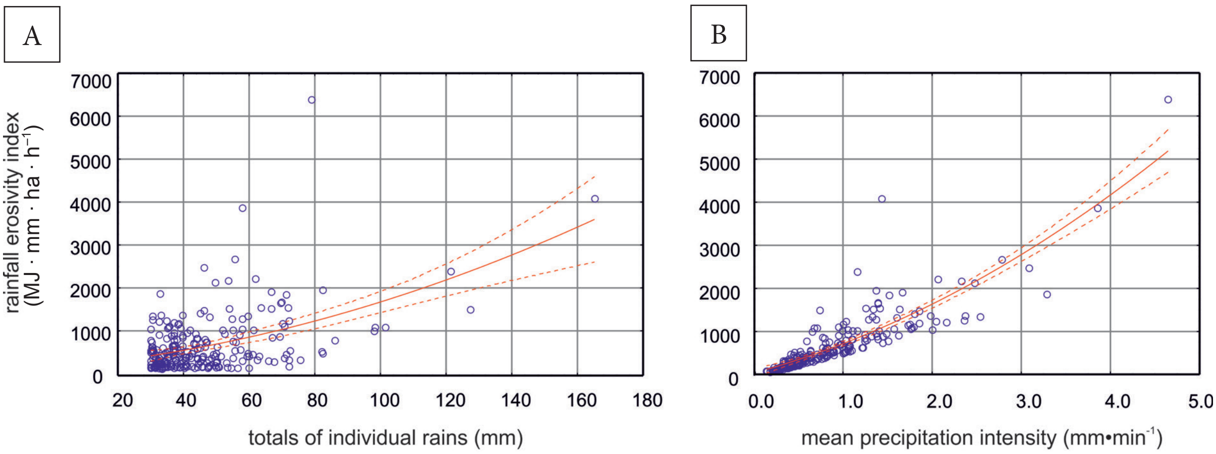

Fig. 4. *Regression relationship between the rainfall intensity index (EI) and totals of individual rains (A) and mean precipitation intensity (B)*

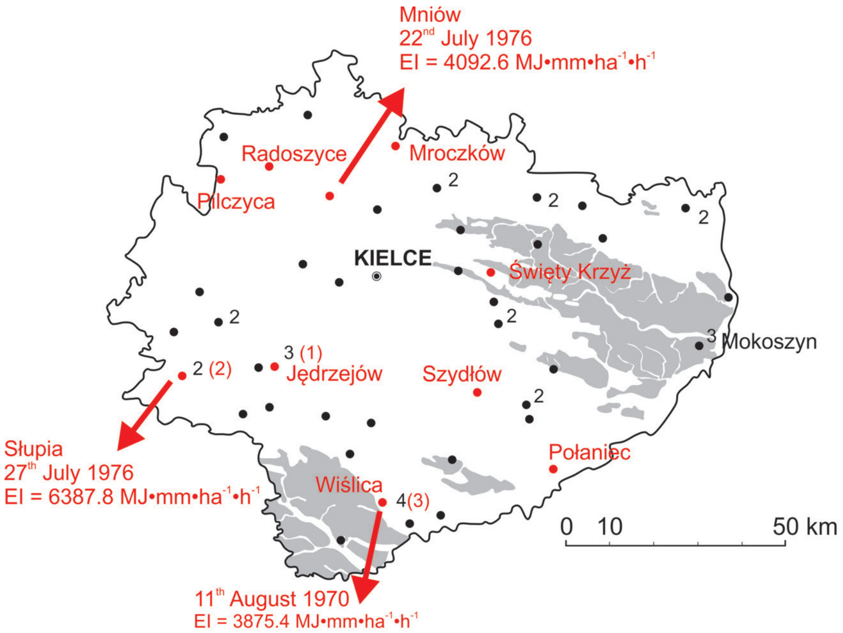

***Fig. 5.** Distribution of precipitation with the highest erosivity index (EI above upper quartile) relative to the occurrence of loess formations (outliers marked in red)*

The erosion potential of precipitation not only depends on precipitation intensity and the amount of precipitation, but also on the susceptibility of the parent material. Water erosion in the Świętokrzyskie Province poses the greatest threat to soils formed across loess areas.

The province features two large areas of loess:

1) Sandomierz Upland (eastern area),
2) southern fringes of the province encompassing the northern edge of the Miechów Upland and the Proszowice Plateau (Fig. 5).

In the period 1959–1981, high erosivity index rainfall occurred across these areas at nine weather stations: Bodzentyn, Nosów, Bieliny, Łagów, Bogoria, Mokoszyn, Zawichost, Stopnica and Kazimierza Mała.

DISCUSSION

Long-term data series collected by IMGW-PIB weather stations has already been used in the past to identify the erosivity index of precipitation events (Banasik & Górski 1992, Górski & Banasik 1992). These data made it possible to determine changes in time and spatial patterns of precipitation erosivity index. Both intra-annual and multi-annual changes were analyzed. The data were also used to identify the frequency distribution of the annual rainfall erosivity index values (Banasik & Górski 1992, Górski & Banasik 1992). Other researchers calculated the intensity of erosive rainfalls with a different probability of occurrence in order to forecast soil loss according to the USLE model (Baryła 2012). Studies such as these, however, were largely based on hyetograph analysis. Given that the analysis of such data is laborious, most studies were limited to one or several weather stations.

Data on the occurrence of rainstorms and downpours found in the *Atmospheric Precipitation* yearbooks published by IMGW-PIB may serve as a valuable resource designed to supplement existing studies. The data make it possible to quickly analyze the spatial differentiation of the rainfall erosivity index using a regional or larger scale. These data may also serve as a source of information needed to supplement erosion monitoring work on experimental runoff plots, which would make it possible to assess the threat of soil erosion in the vicinity of research sites over a longer period of time. However, it is important to note that the yearbook data are historical in nature, as publication ended in 1981.

Data available in the *Atmospheric Precipitation* yearbooks are characterized by a number of specific limitations. These include a lack of precipitation events classified lower than A_3 in the classification system by Chomicz (Chomicz 1951). Hence, it is difficult to know whether the data would make it possible to identify all erosive rains consistent with the assumptions of the Universal Soil Loss Equation model (Wischmeier & Smith 1978). Therefore, the paper does not identify erosive rains, although all the analyzed precipitation events may be described as such in light of the fact that their totals substantially exceed 12.7 mm or 0.5 inches.

In addition, the precipitation yearbooks only list mean intensity values for rainstorms and downpours, while erosivity index calculations demand the use of maximum 30-minute rainfall intensity values (Banasik & Górski 1992, Święchowicz 2012). Hence, equations designed to calculate E_{kin} and EI must be simplified relative to the original, as has been done in this paper.

The next task should be to test the usefulness of precipitation data available in the *Atmospheric Precipitation* yearbooks in the assessment of the USLE *R*-factor. The yearbooks have been published for 23 years, which potentially make these data capable of accurately predicting a long-term mean value of rain erosivity. Verstraeten et al. (2006) proved that rainfall records shorter than 22 years do not ensure such capability.

The maximum erosivity index values *EI* calculated in our study in a simplified manner, turned out to be almost twice as large as the maximum value (6,387.8 $\mathrm{MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}}$) for the period 1987–2009, as measured at the Lazy research station in the Wiśnicz Foothills, Southern Poland (Święchowicz 2012). However, the order of magnitude of maximum *EI* values remains the same, while the difference appears to be due to the different spatial scale of the two studies. Point measurements are limited in their ability to register maximum values of phenomena that dynamically change across geographical space, which here includes rainstorms and downpours.

The use of data from weather stations operated by IMGW-PIB also does not guarantee this when interpreting the causes of strong erosion episodes. Local rainstorms and downpours can range up to 100 $\mathrm{km^2}$ in area (Lenart 1993), which may be illustrated with a circle with a diameter of about 11.2 km. The problem of the accurate assessment of the maximum precipitation total occurred in the case of a rainstorm on July 15, 1995, when relief across the Miechów Upland became substantially altered in the area of Kalina Wielka. The center of this storm cell was situated between two weather stations. The Książ Wielki station recorded an approximately 3-hour rainfall event yielding 78 mm of water. The amount of precipitation in the center of the storm cell had to be estimated indirectly (approx. 150 mm) (Niedźwiedź 1997).

Currently, the number of weather stations in the study area is much smaller than it was in the early 1980s when IMGW-PIB ended its publication of the *Atmospheric Precipitation* yearbooks. In 2016, there were only 27 gauging sites within the boundaries of Świętokrzyskie Province based on information from the Pogodynka web portal (http://www.pogodynka.pl/). Hence, the ability to measure local rainstorms and downpours using the IMGW infrastructure has decreased. However, new weather radar data are now available for Świętokrzyskie Province that can be used to show the location of high precipitation. Weather radars operate near the city of Rzeszów and near the town of Miechów. More than ten years of data are now available from these sites.

A median value of the erosivity index *EI* was 455.8 $\mathrm{MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}}$. This value appears to be 50–75% of average *R*-factor values estimated by Panagos et al. (2015) for south-eastern Poland. The *R*-factor is an aggregated annual value of the erosivity indices of all erosive rainfall events. Thus, it is apparent that the most intensive rainfalls have a paramount influence on the average rainfall erosivity. *R*-factor values in Poland given by Panagos et al. (2015) are much higher than in Scandinavia but lower than in the Mediterranean region.

Otherwise, at least part of our study area was identified as a high erosion risk area (Panagos et al. 2015). Relatively low annual precipitation is accompanied by high erosivity there. Thus, highly erosive rainfall frequently affects dry soils and can cause great damages.

The seasonality of precipitation characterized by high amounts and intensities is the norm in the study area, with maxima occurring in June and July. Other studies have also described this pattern; e.g. the highest mean erosivity index values has been noted in Limanowa and Puławy just in

June and July (Banasik & Górski 1992). Ballabio et al. (2017) described similar pattern of the *R*-factor's seasonal variability. Its highest values occur in southern Poland in June and July. Equally high erosivity is observed in Romania, Bulgaria and Alpine countries during these months. Besides, Eastern and Central Europe as well as Scandinavia experience the biggest intra-annual erosivity variation (Ballabio et al. 2017).

Research on runoff plots has shown that not all rainfall events designated erosion-triggering actually trigger erosion on hillsides. Whether erosion occurs or not depends on the type of land use. In most cases, erosion occurs on slopes devoid of vegetation (arable lands) where the number of incidences of erosion is larger than the number of erosive rains (Święchowicz 2012). Given that land use changes on arable fields in a seasonal manner, erosion can be more effective prior to the development of vegetation and after the harvest season (in May and September). Higher amounts of rainfall and higher rainfall intensities measured in July can turn out to be less effective in erosion triggering as the soil is protected by vegetation.

The paper also provides a list of weather stations in Świętokrzyskie Province that have experienced the largest number of rainfall events characterized by a large erosivity index. One such site is Wiślica, located in the Nida river valley. This pattern may be due to enhanced convection over the hills surrounding the valley and especially relatively warmer south-facing valley sides. This pattern was observed over the Pińczów Hills that tower over the Nida river valley (Żmudzka et al. 2000). Loess soils that tend to be susceptible to erosion are situated south of the Nida river valley – across the Wodzisław Hills and Proszowice Plateau. Local rainstorms have generated strong soil erosion twice in the study area in the last few decades – September 15, 1995 and April 25, 2000 (Czyżowska 1996, Cabaj & Ciupa 2001).

CONCLUSIONS

1. Data on the occurrence of precipitation characterized by high totals and intensities that is available in the yearbooks published by IMGW–PIB (*Atmospheric Precipitation*) allow for the analysis of the precipitation erosivity index on a regional scale. Analyses can be performed for different time periods and geographical spaces.
2. The erosivity index for the examined precipitation events characterized by high totals and intensities ranged from 59.6 $\mathrm{MJ{\cdot}mm{\cdot}ha^{-1}{\cdot}h^{-1}}$ to 6,387.8 $\mathrm{MJ{\cdot}mm{\cdot}ha^{-1}{\cdot}h^{-1}}$ with a median value of 455.8 $\mathrm{MJ{\cdot}mm{\cdot}ha^{-1}{\cdot}h^{-1}}$.
3. Precipitation with the highest erosivity index were recorded at the Słupia weather station in the southwestern part of the study area. However, high erosivity rainfalls most often occurred in the Nida Valley (Wiślica site). Loess areas are likely to experience the highest risk of soil erosion there.
4. Precipitation characterized by the greatest erosivity index consisted of rainstorms and downpours occurring in June and July. The mean erosivity index for the two months was 526.3 $\mathrm{MJ{\cdot}mm{\cdot}ha^{-1}{\cdot}h^{-1}}$ and 464.5 $\mathrm{MJ{\cdot}mm{\cdot}ha^{-1}{\cdot}h^{-1}}$ respectively.
5. The usefulness of the data from the *Atmospheric Precipitation* yearbooks needs to be tested in the assessment of the USLE *R*-factor in the next stage of the research.

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