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LONGITUDINAL VARIABILITY OF RUNOFF AND FLUVIAL TRANSPORT IN THE UPPER WIEPRZ RIVER (IN THE CENTRAL ROZTOCZE REGION)

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ABSTRACT

The variability of water runoff and fluvial transport in the upper Wieprz River catchment (300.3 km^2) in Central Roztocze region is presented, based on results of daily measurements in Guciów from the period of 1996–2016. The study period was characterised by high variability of annual precipitation totals – from 563.2 mm (2003) to 932.9 mm (2010), with the mean annual value of 735 mm. Mean annual discharge flow in the Wieprz River ranged from 0.91 m$^3 \cdot s^{-1}$ (1996) to 2.27 m$^3 \cdot s^{-1}$ (2010), and extreme discharge values varied from 0.5 m$^3 \cdot s^{-1}$ (1996) to 13.1 m$^3 \cdot s^{-1}$ (2005). The variability of annual, monthly, and extreme discharges was moderate. The specific runoff index amounted to 4.5 dm$^3 \cdot s^{-1} \cdot km^{-2}$, and it varied from 3.0 dm$^3 \cdot s^{-1} \cdot km^{-2}$ to 7.6 dm$^3 \cdot s^{-1} \cdot km^{-2}$. The mean annual runoff of the Wieprz River in Guciów amounted to 142 mm, with the variability in the range between 95 and 239 mm in particular years. The runoff regime showed features of nival type, moderately developed. The dynamics of transport of solutions and suspensions corresponded to seasonal and annual changes in the runoff of the Wieprz River. Mean annual fluvial transport varied from 7.8 · 10^3 t (1996 and 2004) to 18.0 · 10^3 t (2010), whereas transport of solutions constituted 89–97% of the total flux. The mechanical and chemical denudation indices calculated for the catchment amounted to 2.4 and 36.1 t · km^{-2} per year, respectively. In spite of the evident increasing trend in annual atmospheric precipitation totals, water runoff did not increase, contrary to forecasts, whereas fluvial transport, particularly that of suspensions, showed a tendency of a slight decrease.

Keywords: Wieprz River, characteristic discharges, total runoff, suspended load, dissolved load

INTRODUCTION

Activity of the river catchment geo-ecosystem is reflected, among other things, in the intensity of hydrological and geomorphological processes taking place therein. The basic element of such a system are flowing waters, acting as the main transport route for matter, whereas the parameters characterizing such a system include, inter alia, the amount of water runoff and the intensity of fluvial transport (Kostrzewski et al. 1994). The runoff of water from the catchment depends mainly on the hydro-climatic conditions, while the transport of river sediment (dragged, lifted and dissolved load), as the final stage of transport of matter in the catchment, depends also on the geological structure, soil cover, form of the terrain, and land cover (Froehlich 1982, Bajkiewicz-Grabowska and Mikulski 1999). In human-developed areas, the intensity and temporal distribution of both parameters is modified by the method and intensity of use, as well as by the spatial distribution of land within the catchment (Kostrzewski et al. 1994, Bodulski et al. 2005).

The present work is a continuation of a series of studies on the runoff and fluvial transport of the upper Wieprz River (Michalczyk 1997, Stępniewska and Stępniewski 2004, Świeca et al. 2004, Rodzik et

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al. 2007, Stępniewska 2007, Stępniewski and Rodzik 2008, Stępniewska and Stępniewski 2008), and its purpose is to determine the variability of these parameters in the long term (1996–2016), as the climate changes progress (Woś 2010).

MATERIAL AND METHODS

Field studies on runoff and fluvial transport of the upper Wieprz River, being part of a larger program carried out at the Roztoczańska Stacja Naukowa (Roztoka Research Station) of the UMCS in Guciów, have been conducted since 1996 (Rodzik and Stępniewski 2010). The input material for calculating and analysing the runoff was a database from the hydrometric profile in Guciów, based on daily readings of water levels and their continuous registration with floating limnigraphs – initially, up to the year 2002, clock-based L-841 produced by SP WSZ "Zootechnika", and from the 2003 onwards, the "Thalimedes" digital recorder by OTT, as well as cyclical flow measurements using the Hega-1 hydrographic current meter. Fluvial transport was calculated on the basis of daily measurements of the charge of suspended load, by using the filters (Brański 1968), and daily measurements of the charge of solutions, using the conductometric method (Markowicz and Pulina 1979). The work omitted trailing transport, as the latter has not been measured in Guciów due to its negligible share (about 1%) in the total amount of fluvial transport (Kociuba 2002). The characteristics of climatic conditions were based on the annual sums of precipitation, and average air temperatures obtained from the IMGW weather station in Tomaszów Lubelski, located near the watershed, as well as data from the weather station Guciów, in the vicinity of the controlled cross-section (see: Fig. 1), which served for the seasonal analysis of rainfall and snow cover.

DESCRIPTION OF THE STUDIED AREA

The upper Wieprz River catchment in Roztocze Tomaszowskie region, up to the water level in Guciów, located at the border of the Roztoczański National Park, covers an area of 300.3 km^2 (see: Fig. 1). Its geological structure, terrain, and land cover refer to the character of the region. The substrate contains chalky rocks, commonly exposed on the hilltops and slopes. Among surface landforms, loess and sands of different genesis dominate, and the bottoms of river valleys are filled with sands above the floodplain terrace, sandy and silty formations of the floodplain terrace, as well as peats, in some locations. The soil cover consists mainly of haptic and albic luvisols complexes. Agricultural land, consisting mostly of arable land, meadows and pastures, constitute 60.2% of the catchment area. Forests cover 33% of the catchment area, and they consist of mainly oak-hornbeam and beech forests in upper areas of mountaintops as well as pine and fir forests in bottoms of valleys and on the slopes (Dębicki et al. 2004).

The upper Wieprz River catchment is varied along the river. Initially, from the sources in Wieprzów Tarnawacki to Krasnobród, Wieprz flows through a regulated channel with an average slope of 1.2 ‰ within a vast hollow, in which the denivelations reach up to 90 m. Approximately 70% of this part of the catchment is occupied by drained meadows in the bottom of the valley, and arable land on the slopes and sides. Forests occupy slightly over 20% of this area. Below Krasnobród, the Wieprz River valley narrows to 1 km in width, the denivelations increase (to over 130 m), and the average gradient of the river (up to 1.7 ‰). The slopes of the valley, and the terrace above the floodplain are overgrown with forests, which occupy over 50% of the area. In this section of the Wieprz River, fed by numerous groups of springs (Bartoszewski and Michalczyk 1996), overgrowing with aquatic vegetation is limited, and ice phenomena occur sporadically. The meandering channel, with a sandy bottom and a width of 5–7 m, cuts to a depth of 1.2–1.5 m into the floodplain terrace, occupied with meadows, and 200–300 m in width (Michalczyk et al. 2004).

Groundwater in the Wieprz River catchment occurs in two levels: Upper Cretaceous, present throughout the entire area, and Quaternary, occurring mainly in the bottoms of the valleys (Bartoszewski and Michalczyk 1996). The permeability of the rocks in the substrate leads to the situation where the abundance of groundwater and the high efficiency of the sources is accompanied by a poor water network. Wieprz, in its section between ca. 31st km from the sources, up to Guciów, receives only two small right-bank tributaries: Kryniczanka and Jacynka (see:

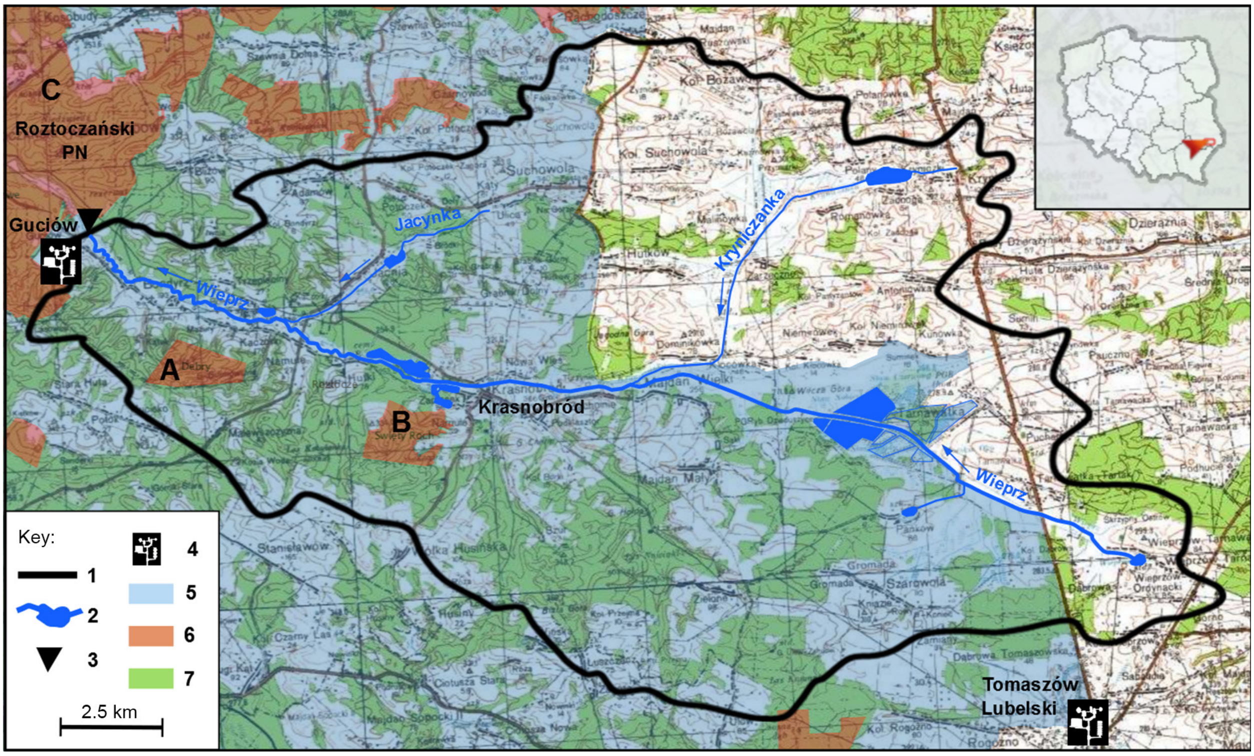

Fig. 1. Location of the upper Wieprz River catchment against the background of the protected areas of Natura 2000 (based on http://mapy.geoportal.gov.pl/imap). Key: 1 – watershed, 2 – rivers and water reservoirs, 3 – hydrometric point, 4 – weather stations, 5 – Natura 2000/ "Roztocze" SPA, 6 – Natura 2000/SACs (A – "Debry", B – "St. Roch", C – "The Central Roztocze"), 7 – forests

Fig. 1), with average annual flows of 196 $dm^3 \cdot s^{-1}$ and 33 $dm^3 \cdot s^{-1}$, respectively. Apart from small and fast-overgrowing old disused riverbeds, there are no natural water reservoirs. In Tarnawatka and Krasnobród, however, large complexes of fish-breeding ponds are located. Small retention reservoirs were built on the tributaries of the Wieprz river, whereas the recreational reservoir in Krasnobród was enlarged in recent years (see: Fig. 1). This is complemented by numerous backyard pools, filled with groundwater or directly from rivers. Towards the end of the 20th century, water reservoirs occupied 1% of the catchment, and their capacity was estimated at 2–3% of the annual runoff of Wieprz (Sadowska 2001). The current surface of water reservoirs is about 1.7% of the analysed catchment.

The Upper Wieprz River catchment, like the entire Roztocze region, is characterized by relatively low population density and urbanization, hence also a low degree of environmental degradation (Świeca et al. 2004). The natural advantages of the region led to the creation of various and numerous forms of nature protection. About 2/3 of the catchment area lies within the area of special protection of birds of the "Roztocze" SPA, within the framework of the Natura 2000 network. Within it, there are also two areas of habitat protection (SAC) of Natura 2000 network, with a total area of about 400 hectares: "Debry" and "St. Roch" nature reserves, and a small fragment of the "Roztocze" SPA nature reserve (see: Fig. 1).

RESULTS

Thermal and rainfall conditions during the studies

Due to the geographical location and the shape of the terrain, Roztocze belongs to the coldest sub-regions of the Lubelszczyzna (Lublin region), as well as most sparse in the atmospheric precipitation (Kaszewski et al. 2015). The average annual air temperature in Tomaszów Lubelski in the years 1996–2016 ranged from +6.8ºC (1996) to +9.3ºC (2015) with a clearly marked upward trend (see: Fig. 2). The average from the research period was calculated as +7.7ºC and was 0.7ºC higher than the average from the years 1951–2000 (Kaszewski 2004). The average temperature course indicated a transitional type of thermal conditions, while the amplitude of the annual temperature was among the highest in Poland (Kaszewski et al. 2015). The temperature-conditioned growing season in the Roztocze region, in Tomaszów Lubelski, lasts on average 213 days: from the beginning of April to the end of October (Kaszewski et al. 2015).

In the years 1996–2016, the upper Wieprz River catchment was characterized by high variability of atmospheric precipitation and the spatial diversity thereof. The lowest rainfall in Tomaszów Lubelski (549.3 mm) was recorded in 2003, and the highest (1029.1 mm), in 2010. In the same years, extreme rainfall amounts in Guciów were also recorded, amounting to 563.2 and 932.9 mm, respectively (see: Fig. 2). The average annual rainfall during the study period increased towards the west, with the simultaneous tendency to increase precipitation totals throughout the catchment area, especially in the eastern part (see: Fig. 2). In Tomaszów Lubelski, the average annual rainfall in the studied period was 710 mm, which was 15% higher than in 1951–2000, while in Guciów the precipitation (735 mm) was higher only by 5%, compared with the average for a multi-year period in nearby Zwierzyniec (Kaszewski 2004).

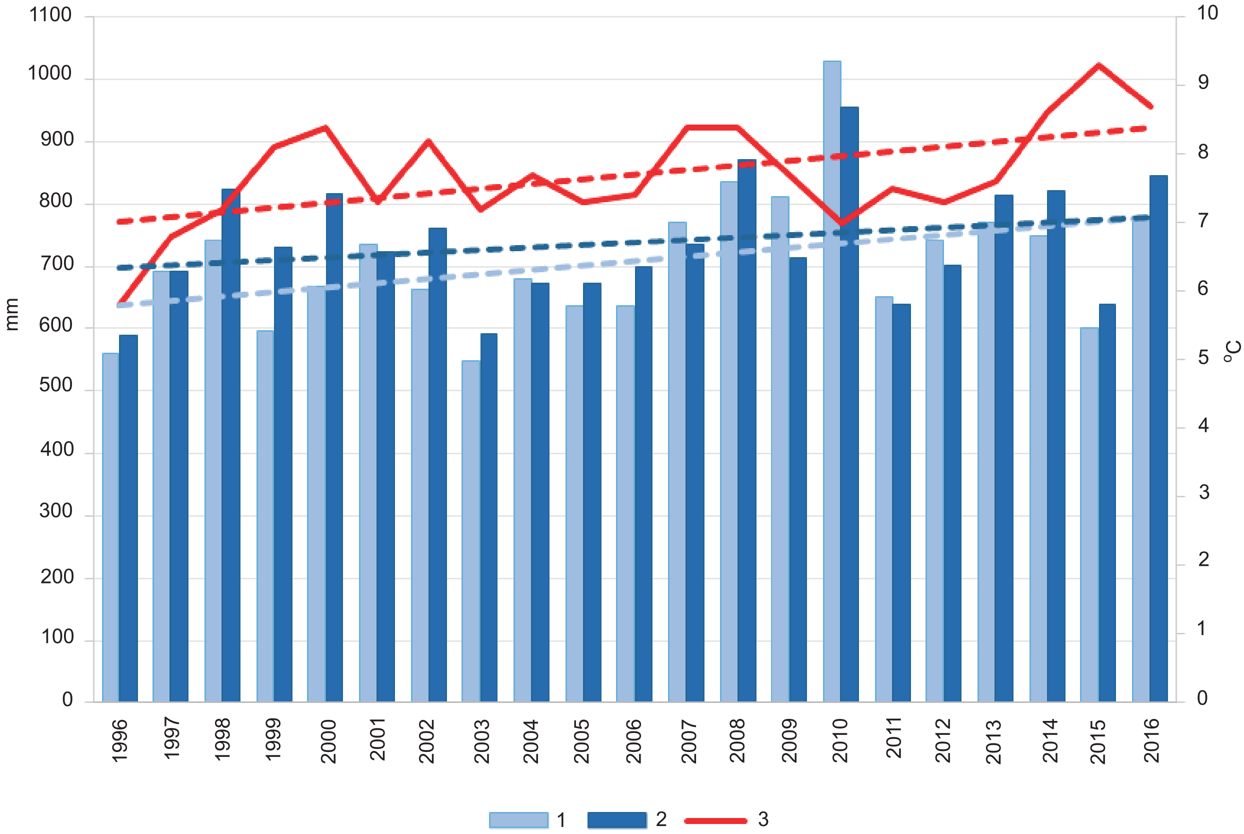

Fig. 2. The annual total precipitation and average air temperatures in the upper Wieprz River catchment in the Central Roztocze region, in the years 1996–2016. Key: 1 – total precipitation in Tomaszów Lubelski, 2 – total precipitation in Guciów, 3 – annual average air temperature in Tomaszów Lubelski, discontinuous lines – linear trends in the courses of precipitation and air temperature

The annual distribution of rainfall was also variable during the studied period. In Guciów, 62–87% of the annual precipitation totals was recorded in the warm half-years, whereas the sum of rainfall in the summer months was on average over twice as high than winter precipitation, showing the continental type of precipitation course (Kaszewski et al. 2015). The lowest rainfall in Guciów was usually recorded in February (at 36 mm), which was also characterized by the lowest variability of precipitation. The highest rainfall occurred in July (at 111 mm), but the highest variability of precipitation was recorded in May. The lowest monthly rainfall in Guciów was recorded in November 2011 (at 1.2 mm), and the highest monthly rainfall occurred in 2010, when in Guciów 231.4 mm of rain was recorded in May, whereas 244 mm of rain was recorded in Tomaszów Lubelski in July, as the highest monthly rainfall in the last 66 years of measurements conducted at this station (Kaszewski et al. 2015).

In the cold season, some rainfall occurred in the solid state, creating a snow cover under if thermal conditions allowed. In Guciów, snow cover appeared sometimes already in October, and it only ceased in April, reaching the maximum thickness (up to 60 cm), typically in January and February. The duration of the snow cover in Guciów, in the hydrological years 1996–2016, differed significantly in individual years – from under 40 days (in 2014 and 2016) to over 120 days (1996 and 2013). On average, this time was 83 days, and it was shortened from 90 days in the first half of the studied period, to 69 days in the second half of the studied period.

Seasonality of runoff and fluvial transport of the upper Wieprz River

The average annual flow of Wieprz River in Guciów, in the hydrological years 1996–2016, amounted to 1.35 $m^3 \cdot s^{-1}$, which corresponds to a unit runoff of 4.5 $dm^3 \cdot s^{-1} \cdot km^{-2}$, and it varied from 1.13 $m^3 \cdot s^{-1}$ to 1.86 $m^3 \cdot s^{-1}$, which means changes in unit runoff of 3.8–6.2 $dm^3 \cdot s^{-1} \cdot km^{-2}$. The annual Wieprz River runoff was on average 42.5 $m^3 \cdot 10^6$ water, corresponding to a runoff layer of 141.6 mm. Water runoff for most of the year fluctuated in the range of 3.1––3.7 $m^3 \cdot 10^6$ per month; only in March and April, as a result of thaw, it increased to nearly 5 $m^3 \cdot 10^6$ (see: Fig. 3). The fish ponds also have a noticeable effect on the seasonal distribution of the Wieprz River runoff. Cyclical filling of reservoirs, or their replenishment in spring and summer causes, among others, the reduction of the runoff, which in the dry years may periodically take the form of deep low flows (Sadowska 2001). Emptying the reservoirs in autumn, combined with lower evaporation and less water demand for vegetation, manifests itself as a secondary maximum (see: Fig. 3).

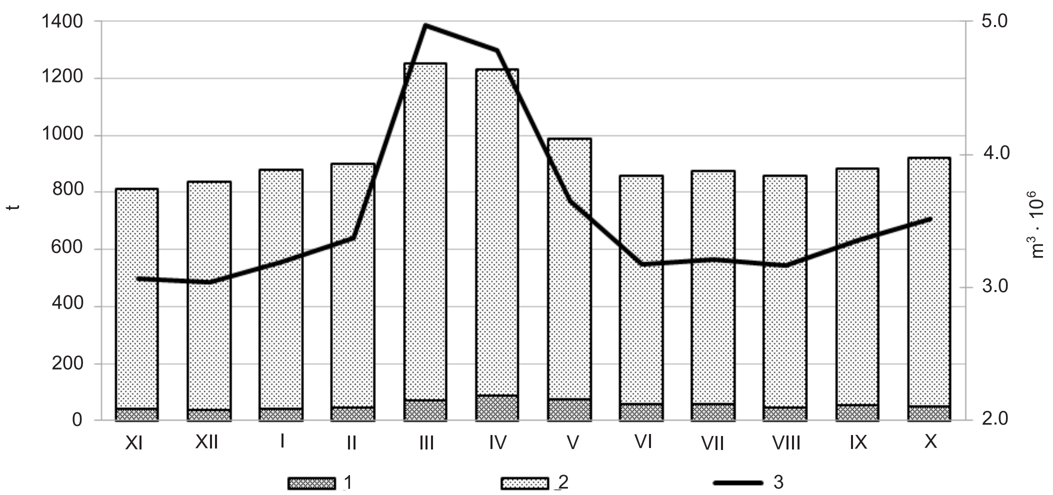

Fig. 3. Mean monthly fluvial transport and runoff in the Wieprz River in Guciów, in hydrological years 1996–2016. Key: 1 – suspended load, 2 – dissolved load, 3 – runoff

In annual terms, the average monthly values of water turbidity varied from approximately 13 mg · dm^{-3} in the period of November-February, to 21 mg · dm^{-3} in May. With an average bed load intensity of 0.032 kg · s^{-1}, the average monthly transport of suspensions amounted to 55 t. The least suspended matter, with minimal runoff and minimum turbidity, is lifted in November and December (about 42 tons per month), and the most (96 tons), in April (see: Fig. 3).

The average monthly total mineralization values ranged from 237 mg · dm^{-3} to 263 mg · dm^{-3} and were inversely proportional to the runoff volume. Least solutions are discharged by Wieprz River in November – 772 t, most in March and April – over 1100 t (see: Fig. 3). During the month, an average of 887 tons of dissolved substances flow out of the catchment, with an average solution load of 0.34 kg · s^{-1}. This represents an average of 94% of the total amount of sediment (suspended and dissolved) transported by Wieprz River, whereas even over half of the material may be discharged during freshets (Kociuba and Stępniewska 2002).

Variability of runoff and fluvial transport of the upper Wieprz River in the years 1996–2016

The average annual flow (SQ) of Wieprz River in Guciów varied over the said period from 0.91 m^3 · s^{-1} in 1996 to 2.27 m^3 · s^{-1} in 2010 (see: Fig. 4), which corresponds to 2.8 dm^3 · s^{-1} · km^{-2} and 7.6 dm^3 · s^{-1} · km^{-2}. The total runoff ranged from 28.6 m^3 · 10^6 to 71.8 m^3 · 10^6 of water (see: Fig. 5), and in terms of the runoff layer, it ranged from 95.4 mm to 239.3 mm (see: Fig. 4), which accounted for 13–27% of the annual amount of rainfall. Extreme flow rates varied during the studied period from 0.5 m^3 · s^{-1} to 13.1 m^3 · s^{-1}, which gives a unit runoff of 1.7 and 43.6 dm^3 · s^{-1} · km^{-2}, respectively.

The concentration of suspended material in the river varied from 0.1 mg · dm^{-3} to 561.9 mg · dm^{-3}. The average annual turbidity rates changed from 5.9 mg · dm^{-3} in 2007 to 30.6 mg · dm^{-3} in 1998, and they affected the volume of runoff of suspensions, the extreme values of which occurred in the same years: 229 and 1607 tons respectively (see: Fig. 5). The concentration of dissolved material (that is, total mineralization) in the analysed period changed from 63 mg · dm^{-3} in 2005 to 372 mg · dm^{-3} in 1998, with slightly differentiated mean mineralization rates – from 235 mg · dm^{-3} in 2010 up to 266 mg · dm^{-3} in 2000. Transport of solutions varied from 7.4 to 16.4 t · 10^3 in individual years (see: Fig. 5), directly proportionally to changes in water runoff, and it accounted for between 89 and 97.5% of the total amount of substances transported by Wieprz River in Guciów.

In the years 1996–2016, two cycles with similar duration, course and volume of water runoff occurred in the upper Wieprz River catchment, separated by the year 2006 (see: Fig. 5). In the first cycle (1996–2006), the average flow was 1.32 m^3 · s^{-1}, which corresponded to a runoff layer of 138.4 mm, and accounted for 19.6% of the average precipitation sum at that time. This period began with the lowest average annual flow in the years 1996–2016, with a slight spring freshet. After heavy rainfall in the summer and autumn of 1997, average flows (SQ) increased, up to the culmination of 1.94 m^3 · s^{-1} in 2000 (see: Fig. 4), which was the effect of high amounts of rainfall in 1998–2000, under conditions favourable to the underground retention, such as widespread rainfall lasting several days, or spring and autumn snowfalls with the thawing on unfrozen ground (Stępniewska 2007). After this culmination, there was a gradual decrease in the average flow down to 0.94 m^3 · s^{-1} in 2006, related to the reduction of rainfall amounts (see: Fig. 4). In their course, the remaining characteristic flows (SWQ, SNQ and NNQ) referred to the average, except for the highest flows (WWQ), which reached the maximum volume in March 2005 (also the maximum for the multi-year period), during intense thaws combined with rainfall, on shallow frozen ground (Stępniewska 2007).

The volatility of fluvial transport in the years 1996–2006 was similar to the changes in the runoff in that same cycle. Initially, the river carried between 380 and 510 tons of material in the form of a suspension, and between 7.4–7.5 t · 10^3 in the form of solutions (see: Fig. 5). The increase in the runoff and in turbidity, as well as the bed load intensity from 0.01 kg · s^{-1} to 0.09 kg · s^{-1} caused more than threefold increase in the transported suspensions, and almost doubled the transport of solutions, after increasing their load from 0.22 kg · s^{-1} to 0.42–0.50 kg · s^{-1} (Stępniewska and Stępniewski 2008). The highest figures for turbidity and runoff of suspended matter (also for the entire multi-year period of 1996–2016) were registered in 1998, that is at the beginning of the humid period. The

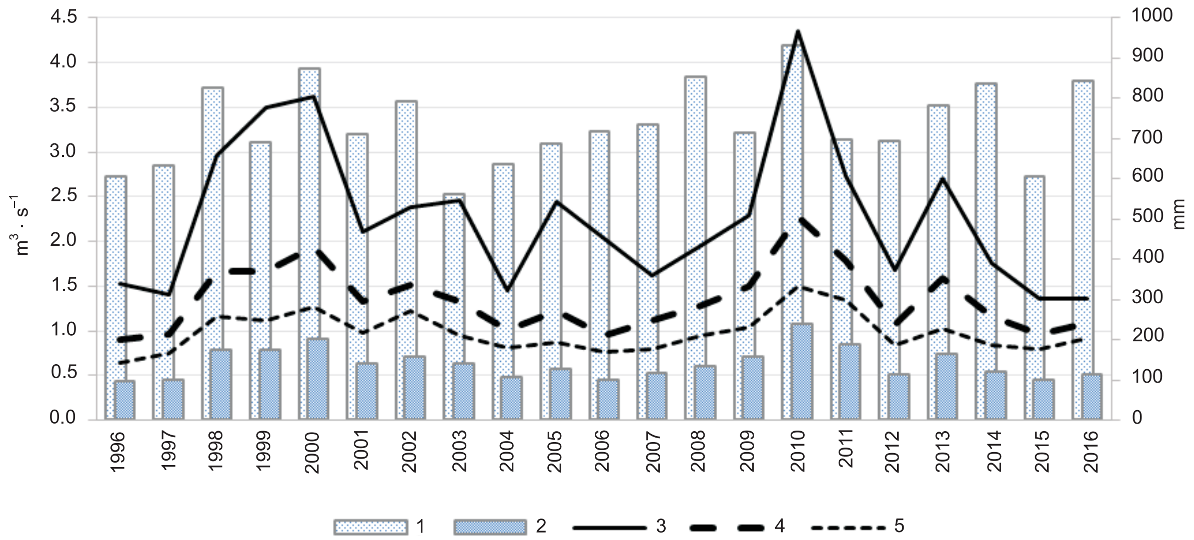

Fig. 4. Characteristic discharges and runoff in the Wieprz River against the background of precipitation totals in Guciów, in the hydrological years 1996–2016. Key: 1 – total precipitation, 2 – runoff rate, 3 – mean maximum discharge (SWQ), 4 – mean discharge (SQ), 5 – mean minimum discharge (SNQ)

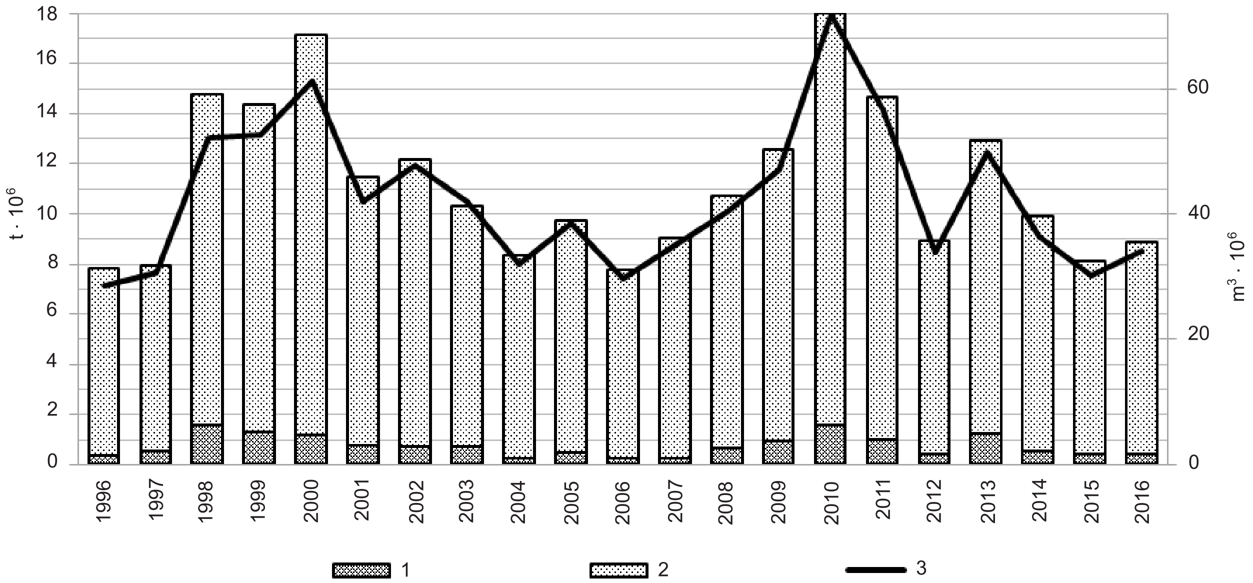

Fig. 5. The fluvial transport and total runoff of the Wieprz River in Guciów in the hydrological years 1996–2016. Key: 1 – suspended load, 2 – dissolved load, 3 – runoff

highest volume of solutions in the 1996–2006 cycle were discharged in 2000, which was characterized by the highest sum of rainfall and the highest total runoff in the cycle, with minor changes in total mineralization (Stępniewska and Stępniewski 2008). In the following years, with rather average rainfall and runoff conditions (Michalczyk et al. 2004), the transport rates have been significantly reduced. This concerned mainly suspensions, the transport of which showed a steady downward trend down to 240 tons in 2004, with a rapidly decreasing turbidity and suspension load (Stępniewska and Stępniewski 2008). Slighter decreases were noted in the amount of transported solutions, which decreased down to $7.5 \cdot 10^3$ t in 2006 (see: Fig. 5).

The average annual flow in the second cycle (2006–2016) increased to $1.34 \text{ m}^3 \cdot \text{s}^{-1}$, but the runoff layer (140.9 mm) decreased to 18.4% of the average amount of precipitation for this period. In the first part of this cycle, a continuous increase was recorded in the average flow volume until 2010, when it reached the highest level in the years 1996–2016 (see: Fig. 4). This was the result of a gradual increase in annual rainfall totals, up to the culmination in the year 2010, additionally characterized by a snowy and lengthy winter, which ended with thaws on unfrozen ground. Since 2011, despite the annual rainfall initially continuing at the medium or higher levels, there was a gradual reduction in average flows down to $0.96 \text{ m}^3 \cdot \text{s}^{-1}$ in the dry year of 2015. The remaining characteristic flows referred in their course to the average (see: Fig. 4), with the highest flows (WWQ) decreased to the lowest level over the multi-year period, namely $1.95 \text{ m}^3 \cdot \text{s}^{-1}$ in 2016.

The volatility of fluvial transport in 2006–2016 was similar to that in the previous cycle. At the beginning of the new cycle, suspended sediment transport amounted to 229–271 tons per year with minimal turbidity, and the transport of solutions was at the level of $7.5–8.8 \text{ t} \cdot 10^3$ (see: Fig. 5). In subsequent, increasingly more humid years, with increasing water runoff and increasing turbidity, with an average bed load intensity reaching up to $0.05 \text{ kg} \cdot \text{s}^{-1}$, the volume of transported suspensions increased up to the peak (1589 t) in 2010, close to maximum from 10 years ago. In the same year, the number of transported solutions reached the highest average in the whole 1996–2016 period, with the highest concentration of solutions ($0.52 \text{ kg} \cdot \text{s}^{-1}$), which was accompanied (unlike 10 years earlier) by the lowest rate of mineralization. The following years (with a short break in 2013) brought a significant reduction in the volume of material transported by the river – up to about 400 tons per year (see: Fig. 5), with stabilized turbidity at the level of approximately $14 \text{ mg} \cdot \text{dm}^{-3}$. The transport of solutions decreased during this time down to $8–10 \text{ t} \cdot 10^3$ per year, with a slightly fluctuating average mineralization.

DISCUSSION

The coefficients of irregularity of the average monthly and annual flows, calculated for the years 1996–2016, amounting to 1.64 and 2.51, respectively, confirm the conclusions based on the measurement interval shorter by half (Stępniewska 2007) that the Roztoka section of the Wieprz River is characterized by generally small variability of flows. Small variability is also typical for yearly and multiannual flows, for which the coefficients of variation Q_{max}/Q_{min} take values below 50. Pointing to the average volatility of flows over the multi-year period is the coefficient of volatility c_v (value of 0.268), expressed as the quotient of standard deviation in relation to average value (Choiński 1988). During the year, the runoff in the cool half-year slightly prevails, constituting approx. 53% of the annual runoff of water, whereas the runoff regime of Wieprz River has features of the moderately developed nival type (Dynowska 1994).

The small variability of flows, and consequently also the total runoff of the upper Wieprz River, results from the dominance of underground supply and long-term retention changes, which are favoured by the permeable substrate and vast meadows in the upper part, and forests in the lower part of the catchment (Bartoszewski and Michalczyk 1996). The low fluctuation of flows is accompanied by equally small variability of fluvial transport, because the calculated r-Pearson correlation coefficients between average annual flow and the volume of transport of suspended matter (0.90, $p < 0.001$) and of solutions (0.99, $p < 0.001$) indicate very strong mutual correlation. Only in the year with more full-scale freshets, appearing after several calmer years, the increase in the size of transport of suspended matter faster than the growth of flow was observed, caused by high turbidity, which, however, declined rapidly in subsequent years. In total, during the year, Wieprz River transports $10.5 \cdot 10^3$ tons of dissolved substances and over 660 tons of suspensions through the profile in Gucιów. Calculated on the basis of the amount of discharged substances, annual rates of chemical and mechanical denudation in the Upper Wieprz River catchment were respectively: $36.1\ t \cdot km^{-2}$ and $2.4\ t \cdot km^{-2}$. Similar values of these indicators occur in the lowland areas of central Poland (Ciupa et al. 2017), while in comparison with river catchments of the neighbouring Lublin Upland, similar in terms of size and use, for instance, Bystrzyca and Uherka, these values are low, as the chemical denudation rate can be twice higher there, and mechanical denudation can be even 3–6 times higher than in the Wieprz River catchment in the Roztocze area (Maruszczak et al. 1992).

The years 1996–2016 in central Roztocze region were characterized by varied and changing climatic conditions, with the expected tendency to increase air temperature and precipitation sums. Based on these forecasts, the flow patterns of energy and matter suggested a gradual increase in runoff, and acceleration of denudation processes in the Roztocze area (Michalczyk and Paszczyk 2004). The conducted monitoring of runoff and fluvial transport in the Wieprz River sub-catchment does not confirm this scenario. Average flows (SQ) and low flows (SNQ and NNQ) as well as runoff volume in the upper Wieprz River catchment, in the analysed multi-year period, remained virtually unchanged, whereas fluvial transport, especially of suspensions, even tended to decrease slightly. In addition, the growing trend of high flows (WWQ and SWQ), which had been observed in the Wieprz River part located within the Roztocze area since mid-20th century, was stopped (Michalczyk et al. 2004). This is not related to the increase in the area of small retention, mainly through the construction of the Jacynka reservoir and the expansion of the reservoir in Krasnobród, because the Jacynka's share in the supply of Wieprz River is insignificant, whereas the reservoir in Krasnobród is not a flow reservoir; and despite the expansion, it did not significantly enlarge its volume, and in part, the already pre-existing fish ponds had been included in it. The discrepancy between the obtained results and earlier forecasts can be explained by the greater than assumed stability of this geo-ecosystem, or by too short a time of the analysis, which does not adequately reflect the direction of changes. However, if we were to assume that the increase in the amount of fluvial transport, both in the form of solutions and suspensions, often results from environmental contamination (Moniewski 2015, Mosiej et al. 2007), and from the intensity of anthropogenic pressure (Kostrzewski 1994, Świeca 1998, Natkaniec and Możdżeń 2013), the current opposite trend may indicate a decrease in the economic and settlement-related pressure on this area. After a documented, significant reduction in the aeolian transport intensity, and the changes in the structure of aeolian rainfall near Guciów (Demczuk et al. 2015), this would be another proof of the progressive re-naturalization of at least some part of the upper Wieprz River catchment (Furtak et al. 2000). This process, manifesting itself in practice as an increase in the share of set-aside fields and forests (Grądziel et al. 2006), especially on steep slopes (Someya and Furtak 1996), reduces surface runoff, thus limiting soil erosion (Stępniewski 2008, Stępniewski et al. 2010). In turn, this helps to compensate for the runoff and the reduction of fluvial transport, mainly of suspensions, despite significant relief of the terrain. In conjunction with an increase in air temperature, progressive restoration (re-naturalization) may contribute to increased transpiration, and to an increase in the proportion of evaporation in the catchment's water balance.

CONCLUSIONS

The upland sub-zone of Wieprz River catchment, in terms of morphometric parameters, is characterized by low, seasonal and long-term variability of runoff and fluvial transport, the size of which, especially of suspensions, is lower compared to similar rivers of the Lublin Upland. The significant share of protected areas, and the related forest cover of the catchment, as well as the large share of meadows in agricultural lands, lead to low denudation rates calculated for the Wieprz River catchment, and make it similar to the lowland river catchments of central Poland.

The growing trend of annual sums of atmospheric precipitation over a multi-year period has not translated into the forecasted increase ion the runoff from the catchment – on the contrary, there has been equalization and of the runoff that even before had been slight, accompanied by the reduction of the amount of material transported by the Wieprz River, particularly of the suspended load, linked to the progressive restoration of the catchment to its natural state.

Conducting multi-year, longitudinal monitoring research makes it possible to verify the projections concerning the functioning of the natural environment, particularly with the low predictability of the direction and volume of the changes occurring therein.

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WIELOLETNIA ZMIENNOŚĆ ODPŁYWU WODY I TRANSPORTU FLUWIALNEGO GÓRNEGO WIEPRZA (ROZTOCZE ŚRODKOWE)

ABSTRAKT

Zmienność odpływu wody i transportu fluwialnego w zlewni górnego Wieprza (300,3 km^2) na Roztoczu Środkowym (Tomaszowskim) przedstawiono w oparciu o wyniki codziennych pomiarów w Guciowie z lat 1996–2016. Okres badań charakteryzował się dużą zmiennością rocznych sum opadów – od 563,2 mm (2003) do 932,9 mm (2010), przy średniej rocznej 735 mm. Średni roczny przepływ Wieprza zmieniał się od 0,91 $m^3 \cdot s^{-1}$ (1996) do 2,27 $m^3 \cdot s^{-1}$ (2010), zaś skrajne wielkości przepływu zawarły się w przedziale od 0,5 $m^3 \cdot s^{-1}$ (1996) do 13,1 $m^3 \cdot s^{-1}$ (2005). Zmienność przepływów rocznych, miesięcznych i skrajnych nie była duża. Wskaźnik odpływu jednostkowego wyniósł 4,5 $dm^3 \cdot s^{-1} \cdot km^{-2}$ i zmieniał się od 3,0 $dm^3 \cdot s^{-1} \cdot km^{-2}$ do 7,6 $dm^3 \cdot s^{-1} \cdot km^{-2}$, a całkowity średni odpływ roczny Wieprza w Guciowie wyniósł 142 mm, przy zmienności 95–239 mm. Reżim odpływu miał cechy typu niwalnego, średnio wykształconego. Dynamika transportu roztworów i zawiesin nawiązywała do sezonowych i rocznych zmian odpływu Wieprza. Średni roczny transport fluwialny zmieniał się od $7,8 \cdot 10^3$ t (lata 1996 i 2004) do $18,0 \cdot 10^3$ t (2010), przy czym transport roztworów stanowił 89–97% całkowitej ilości unosin. Obliczone dla zlewni wskaźniki denudacji mechanicznej i chemicznej wyniosły odpowiednio 2,4 i 36,1 $t \cdot km^{-2}$ na rok. Mimo wyraźnego trendu wzrostu rocznych sum opadów atmosferycznych, odpływ wody nie zwiększył się, wbrew prognozom, a transport fluwialny, zwłaszcza zawiesin, miał tendencję do nieznacznego spadku.

Słowa kluczowe: Wieprz, przepływy charakterystyczne, odpływ całkowity, transport fluwialny