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Influence of runoff of suspended solids on quality of surface water: Case study of the Szreniawa River

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Abstract

Research was conducted in selected points of the Szreniawa River basin (area 712 km²) located in the Miechowska Upland and the Proszowice Plateau. In the years 2016–2017 water samples from the Szreniawa River were taken monthly and the concentration of suspended solids was determined by filtration. The concentration of biogenic components NO₃-N, NH₄-N and PO₄-P was determined by a colorimetric method, using an automatic flow analyser. The average concentration of suspended solids ranged from 192 to 390 mg·dm⁻³ (with minimum values of 5–20 mg·dm⁻³ and maximum 837–3937 mg·dm⁻³) at individual points. There was an upward trend between the content of suspended solids and the concentration of biogenic components. An extremely high concentration of suspended solids happened during storm-like precipitation at the end of June 2017 and amounted to 3937.2 mg·dm⁻³. The concentration of biogenic components was also highest in this period and amounted to 2.50 mg·dm⁻³ of NO₃-N, 0.49 mg·dm⁻³ of NH₄-N and 1.18 mg·dm⁻³ of PO₄-P. At low precipitation the concentration of suspended solids was also low (5.0 mg·dm⁻³). A similar pattern was observed for the concentration of biogenic components which was 0.39 mg·dm⁻³ of NO₃-N, 0.17 mg·dm⁻³ of PO₄-P and 0.08 mg·dm⁻³ of NH₄-N.

Key words: *cambisols, chernozems, concentration of NO₃-N, NH₄-N, PO₄-P, dusty soils, loess, suspended solids*

INTRODUCTION

Losing soil particles from the agricultural fields causes destruction of the soil cover, reducing its thickness and depleting its richness of fertile components and thus contributing to the deterioration of agricultural production efficiency [CHADWICK, CHEN 2002; HALIMI *et al.* 2018; HEJDUK *et al.* 2017; KOWALCZYK *et al.* 2014; NEARING *et al.* 2005; PÄRN, MANDER 2007; QUINTON *et al.* 1999; SMOROŃ, KOWALCZYK 2012; VAGSTAD *et al.* 2001]. This phenomenon, especially in undulating loess areas, presents a significant economic problem and causes high environ-

mental degradation. Along with the surface runoff on the slope that is caused by precipitation, chemical components of biogenic nature are also removed from the most fertile upper soil layer [BORDA *et al.* 2011; ILNICKI 2004; MANDER *et al.* 2000; NEARING *et al.* 2005; SMOROŃ *et al.* 2011; SMOROŃ, KOWALCZYK 2014b; SOSZKA 2009; WRÓBEL 1991].

In the South of Poland, the region most endangered by this phenomenon is the voivodship of Małopolska, in particular its northern part with intensively used agricultural areas [FATYGA 1978, KORELESKI 2008; Rozporządzenie... 2015].

The aim of this study was to determine both the changes in the content of suspended solids in the Szreniawa River caused by variable precipitation and the concentration of biogenic components $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$.

Research was carried out in the Szreniawa River basin with an area of 712.8 km² and its location at 50°08'N~50°26'N and 19°46'E~20°35'E. Geomorphologically, the research area of the Szreniawa River basin is located in the macroregion of the Nidziańska Syncline. It covers the mesoregion of the Miechowska Upland and the Proszowice Plateau [KONDRACKI 2000; TŁUSZCZ 2007]. The Nidziańska Syncline mainly is composed of rocks of Middle and Upper Cretaceous age as well as of Miocene age in the South [ALEKSANDROWICZ 1999; WĘCŁAWIK 1991].

Geographically, the Szreniawa River basin covers the territory of the Olkuska Upland, the Miechowska Upland and the Proszowice Plateau [TŁUSZCZ 2007]. The Szreniawa River is about 80 km in length and constitutes the left-bank tributary of the Vistula River. The river originates in the peat land with its springs located near Wolbrom (about 380 m a.s.l.), in the region of the Olkuska Upland. It runs in the south-eastern direction and joins the Vistula River in Koszyce (178 m a.s.l.). The Szreniawa River is classified as a sub-hydrologic transition type (coefficient $k = 0.77$).

The landform in the Szreniawa River basin is made of wide and short hummocks composed of Neogene clay and sand sediments. This landform refers back to Tertiary surfaces which fragments have been preserved at the altitude of 230–250 m a.s.l. and 215–230 m a.s.l. Neogene formations have been over-built with a dusty top layer, in places also with glacial clay and fluvioglacial sediments [IZMAIŁOW, MICHNO 2009; ROMMENS *et al.* 2005].

In the upper part of the Szreniawa River basin, the soils were formed from loess located on the Jurassic limestone and chalk marl, whereas in the lower part, from loess located on the Cracovian clays. These soils run the highest risk of losing the surface soil particles [JÓZEFACIUK, JÓZEFACIUK 1992]. These soils belong to the following groups: chernozems, retisols, cambisols and fluvisols in the river valleys. They are also of very high fertility and usable value – placed in I–IIIb bonitation class which promotes intensive agricultural production. The value of the overall quality index of the agricultural production in the Szreniawa River basin stands at 95.8 and in some districts from 81.5 to even 101.1 [WITEK *et al.* 1994].

For many years the annual air temperature has been high with its average value of 7.0°C in the upper part of the basin and 8.0°C in its lower parts. Average annual precipitation in those regions are 650 and 600 mm respectively [NIEDŹWIEDŹ, OBREŃSKA-STARKŁOWA 1991]. On average, in the Szreniawa River basin, an agricultural land accounted for 83.5% of the total area, forests – 6.0% and other land forms – 10.5% [SMOROŃ *et al.* 2009]. The agricultural land was dominated by an arable land and occupied 91.3% of the area, meadows and pastures 6.6% and 1.1% respectively and orchards 1.0%. Crops that require high fertilisation such as vegetables, wheat, barley, root crops and industrial crops are mainly grown there. The mineral fertili-

sation of field crops is high and ranges from 113.0 to 142.5 kg NPK·ha⁻¹ of agricultural land [SMOROŃ 2012].

METHODS

Three water sampling points were established in the Szreniawa River (area 712 km²) to implement the stated research objective. Point No. 1 (coordinates 50.163463 N; 20.574772 E) was located in Koszyce near the place where Szreniawa River flows into the Vistula River. Point No. 2 (coordinates 50.315131 N; 20.011785 E) was located in Jaksice at about 2/3 of the river length. Point No. 3 was situated in the initial run of the river (in the town of Szreniawa, coordinates 50.375952 N; 19.867233 E).

Data on precipitation were obtained from the automatic meteorological station located in Opatkowice (coordinates 50.210664 N, 20.286427 E, at an altitude of 212 m a.s.l., at about 1/3 of the Szreniawa River length starting from its confluence with the Vistula River. Distances from the station to the measurement points ranged from approximately from 10 to 30 km.

From three measurement points (Fig. 1) water samples were taken monthly in two periods: first – from June to October 2016 and second – from March to October 2017. In each sample, the concentration of suspended solids and biogenic components $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ were determined. The data on concentration of chemical components during the research period enabled the assessment of water quality in the Szreniawa River, according to the surface water classes [Rozporządzenie... 2002; 2016].

The content of suspended solids in the soil water at sampling points was determined by filtration in accordance with PN-EN 872:2007/Ap1. The concentration of $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ was determined by a colorimetric method, using an automatic flow analyser. In order to indicate a relation between the content of suspended solids and the concentrations of individual biogenic components, linear regression equations were calculated together with the values of the determination coefficient R^2 . The Pearson's r correlation coefficient was also determined together with the materiality level (p) and standard deviation (SD) for the concentration of biogenic nutrients and the content of suspended solids.

RESULTS

During the study period, high variability of precipitation was observed (Fig. 2). The heaviest rainfall was recorded in July 2016. Also, October 2016, August and September 2017 were the months with heavy rain. The lowest precipitation was recorded in December 2016 and January 2017. Total precipitation was 556.5 mm from May to the end of December 2016 and 535.7 from January to the end of October 2017 (Fig. 2).

The content of suspended solids in the Szreniawa River was determined at the time of sample collections (Fig. 2). Its value was highly diversified between individual sampling points. The highest content of suspended solids was recorded on 29 June 2017. However, it usually ranged

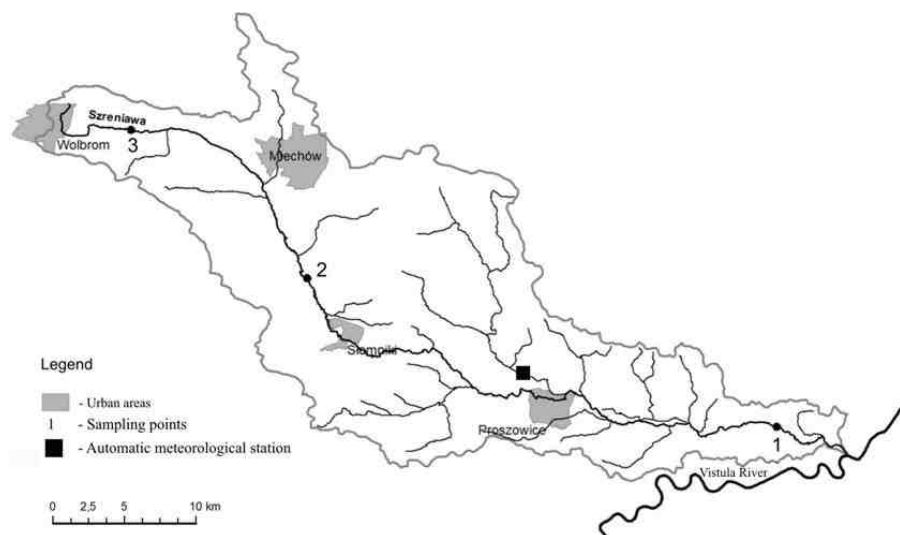


Fig. 1. Location of the study area with sampling points and the automatic meteorological station; source: own elaboration

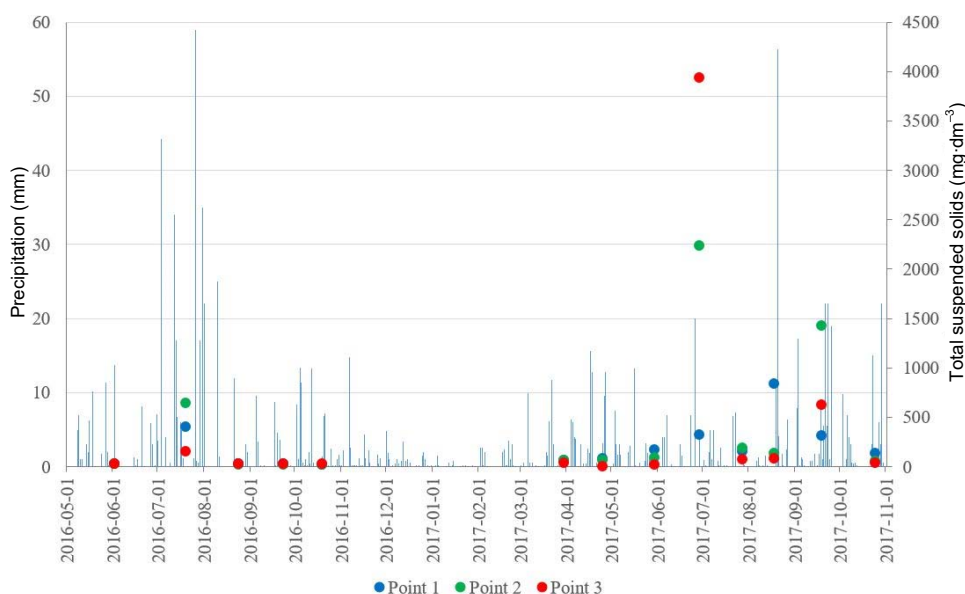


Fig. 2. Precipitation and total suspended solids at the sampling points; source: own elaboration

from 30 to 400 mg·dm⁻³. Higher content of total suspended solids was recorded more frequently after local heavy precipitation. Its significant values were recorded also in July 2016, June, August and September 2017. On the other hand, the suspended solids content was low and didn't exceed 20 mg·dm⁻³ in periods without precipitation or with low daily rainfall. The suspended solids in the Szreniawa River, which occurred during precipitation-free periods is probably the result of the anthropogenic pressure exerted on the area by the local community. In this region, only 23.9% of permanent residents have an access to the water treatment plant. Probably yet another contributing factor is an unfavourable proportion of the sewage – water supply networks length which amounts to 0.2 [SMOROŃ, KOWALCZYK 2014a]. This means that some of domestic effluents carrying suspended solids can be discharged into the aquatic environment in an uncontrolled manner. In this context, it can be assumed that in the Szreniawa River the

content of suspended solids above 20 mg·dm⁻³ is caused by the loss of soil particles from arable fields.

During the study period, the highest average values of suspended solids were recorded in the sampling points No. 2 and No. 3 and amounted to more than 380 mg·dm⁻³ (Tab. 1). It is due to greater inclination of slopes in this area, which stimulates the intensity of the loss of surface soil material.

Table 1. Content of suspended solids (mg·dm⁻³) at individual sampling points

Sampling point No.	Content at		
	point 1	point 2	point 3
Min.	20.0	16.0	5.0
Max	837.0	2238.0	3937.0
Average	199.2	384.5	390.8
SD	229.7	683.1	1078.0

Source: own study.

Table 2. Concentration of biogenic components in surface waters in the Szreniawa River

Sampling point No.	Concentration of biogenic components (mg·dm ⁻³)								
	point 1			point 2			point 3		
	NO ₃ -N	NH ₄ -N	PO ₄ -P	NO ₃ -N	NH ₄ -N	PO ₄ -P	NO ₃ -N	NH ₄ -N	PO ₄ -P
Min.	0.19	0.02	0.17	0.28	0.02	0.08	0.39	0.04	0.11
Max	6.22	0.53	0.63	6.20	1.81	0.62	12.50	0.49	1.18
Average	3.07	0.19	0.36	2.97	0.36	0.28	4.29	0.13	0.31
SD	1.75	0.13	0.16	1.88	0.55	0.14	3.41	0.13	0.28

Source: own study.

However, the average content of suspended solids at point No. 1, which was situated close to the estuary of the Szreniawa River was about half the value at points No. 2 and No. 3. Probably, it is due to a smooth landform features that promotes less intense soil loss. The value of standard deviation (*SD*) stands at all points at the high level, which indicates a large differentiation, around the average value, of the content of suspended solids in the water samples for individual sampling periods (Tab. 1).

The concentration of biogenic nutrients for individual sampling points was listed in Table 2. Among the analysed components, the highest concentration revealed NO₃-N, in particular at No. 3 sampling point. In relation to the other points, the concentration of NO₃-N was higher by about 1.2 mg·dm⁻³. It is worth noticing that maximum values of concentration at, for example, point No. 3, exceed several times the mean value. The minimum concentration of NO₃-N at each point was at lower level and amounted to less than 0.39 mg·dm⁻³.

The average concentration of NH₄-N and PO₄-P are much lower than NO₃-N. The minimum concentration of these components did not exceed 0.17 mg·dm⁻³ and the maximum concentration was lower than 1.81 mg·dm⁻³. The values of standard deviation (*SD*) stayed at relatively high level at individual points. This indicates a significant dispersion of NH₄-N and PO₄-P concentration around the average in individual sampling periods.

Figures 3, 4 and 5 present graphically the relationship between the content of suspended solids and the concentration of individual biogenic components at each sampling point. At all points this relationship reveals an upward trend, which means that the higher the content of suspended solids in the Szreniawa River, the higher the concentration of the analysed components.

The best matching of the model for PO₄-P occurred for all sampling points. The value of the determination coefficient *R*² indicates relatively strong linear correlation between data (Fig. 3, 4, 5). The concentration of PO₄-P is strongly correlated with the content of suspended solids (correlation coefficient *r* = 0.90; significance level *p* = 0.01). In the case of NO₃-N, the determination coefficient *R*² was of very low values for points No. 1 and No. 2. This indicates an unsatisfactory model adjustment, which translates into the irrelevant relationship between these features. The concentration of NO₃-N in these points is poorly correlated with the content of suspended solids (correlation coefficient *r* = 0.22 at point No. 1 and *r* = 0.17 at point No. 2; significance level *p* = 0.01).

In the case of NH₄-N, the values of the determination coefficient *R*² were low at points No. 1 and No. 2. (correlation coefficient *r* = 0.6; significance level *p* = 0.01). This also means that the model adjustment is not satisfactory, but it is still slightly better than in the case of NO₃-N. However, at point No. 3 the model fits satisfactorily for NH₄-N (correlation coefficient *r* = 0.79; significance level *p* = 0.01) and also for NO₃-N (correlation coefficient *r* = 0.72; significance level *p* = 0.01).

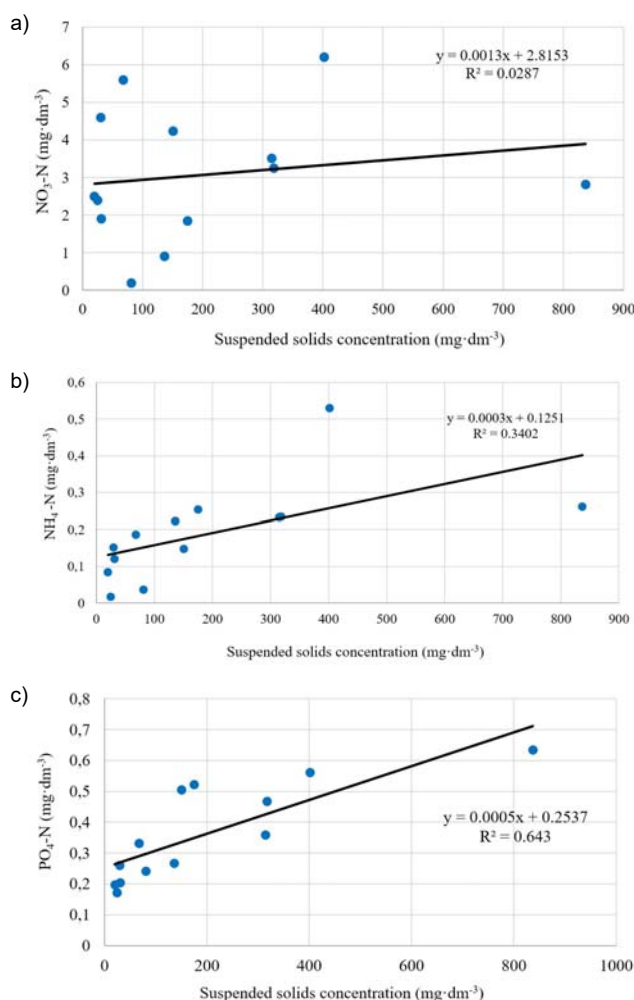


Fig. 3. Relationship between the concentration of biogenic components and the content of suspended solids at sampling point No. 1; for 13 comparable pairs and significance level *p* = 0.01; *R*² = determination coefficient; source: own elaboration

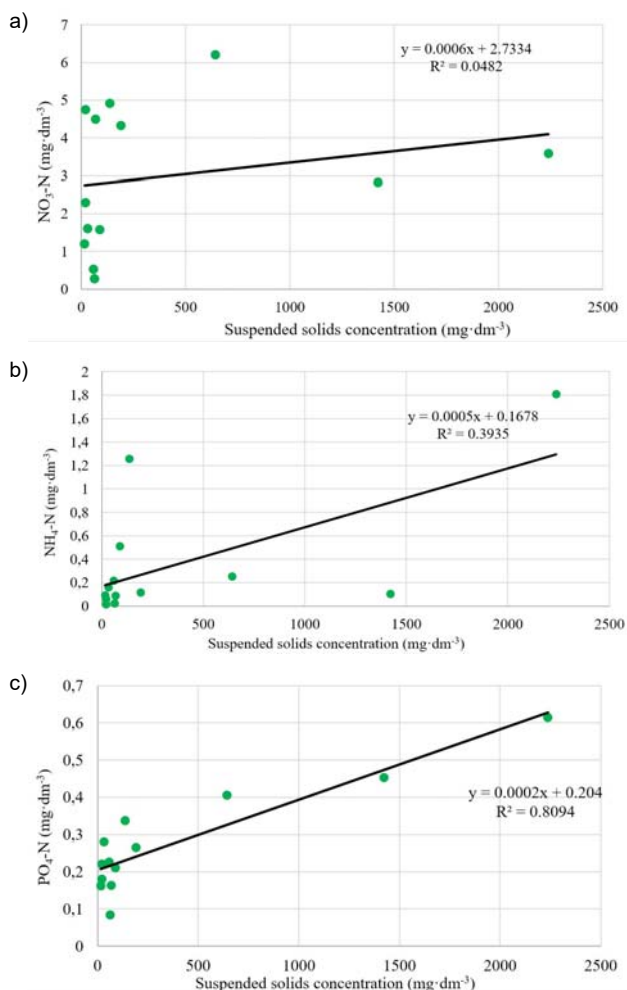


Fig. 4. Relationship between the concentration of biogenic components and the content of suspended solids at sampling point No. 2; for 13 comparable pairs and significance level $p = 0.01$; R^2 = determination coefficient; source: own elaboration

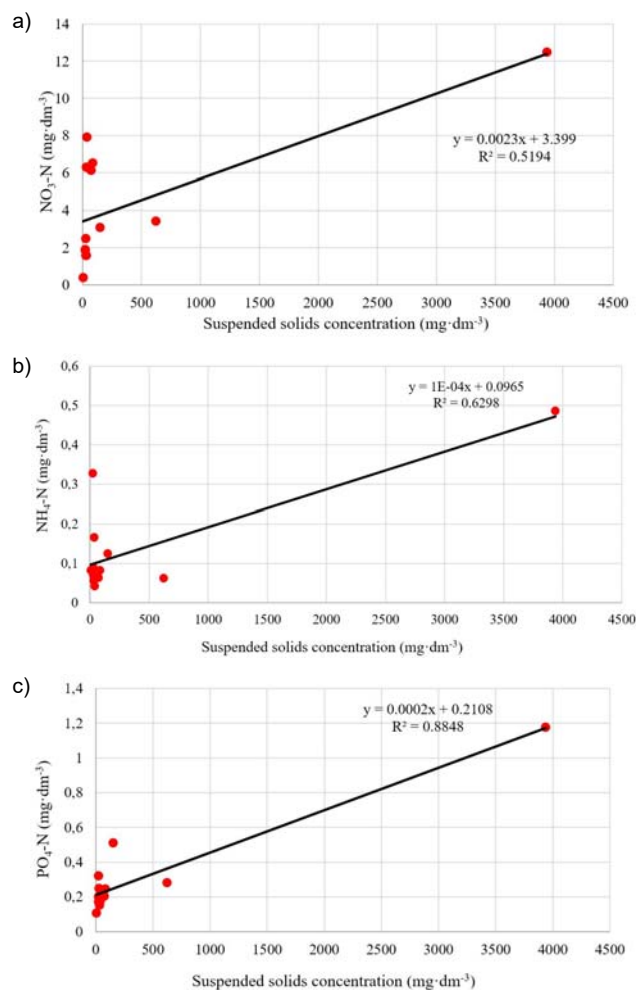


Fig. 5. Relationship between the concentration of biogenic components on the content of suspended solids at sampling point No. 3; for 13 comparable pairs and significance level $p = 0.01$; R^2 = determination coefficient; source: own elaboration

DISCUSSION

The obtained results of this study allowed to determine the value of concentration of suspended solids that are carried by variable precipitation from undulating agricultural areas into the Szreniawa River. Also, the concentration of selected biogenic components, which together with suspended soils were carried away from the surface of arable fields, was analysed in the surface waters of the Szreniawa River basin. At three selected sampling points water samples were collected for analysis and the concentration of $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$ were determined therein.

The research enabled to determine the impact of suspended solids together with biogenic components $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$ being carried away into waters draining the Szreniawa River basin. It was observed that with the increase of suspended solids in surface waters caused by intense precipitation, the concentration of biogenic components also increases.

This has been indicated by the upward trend between these factors in the Szreniawa River. This relationship is clearly visible in the case of $\text{PO}_4\text{-P}$, where the value of the determination coefficient R^2 for individual sampling points

was the highest. To a lesser extent this relationship was evident for $\text{NH}_4\text{-N}$. The weakest and most irrelevant relationship in the case of $\text{NO}_3\text{-N}$ was found at sampling points No. 1 and No. 2.

An example confirming the relationship between the content of suspended solids and the concentration of biogenic components are the results of water sampling obtained in April 2017. During this period, the loss of suspended solids from arable fields was effectively non-existent due to low precipitation. Especially at point No. 3, the content of suspended solids in the water sample was the lowest by comparison to the other sampling periods at this point and was $5.0 \text{ mg}\cdot\text{dm}^{-3}$. Similarly, the concentrations of $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ were then very low and amounted to 0.39, 0.08 and $0.11 \text{ mg}\cdot\text{dm}^{-3}$ respectively. The water at this sampling point was also of high quality and, according to the criteria of surface waters, was classified 1st class [Rozporządzenie... 2016].

However, the situation changed drastically during short-term heavy storms, which were causing rapid loss of suspended solids into the Szreniawa River. Such situation occurred at the end of June 2017. The content of suspended solids at the sampling point (No. 3) mentioned above was

as high as $4000 \text{ mg}\cdot\text{dm}^{-3}$. This resulted in a significant increase of the concentration of $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ in water from this sampling point and amounted to 12.5, 0.49 and $1.18 \text{ mg}\cdot\text{dm}^{-3}$ respectively. As a result of the loss of suspended solids the water quality in the river significantly deteriorated, which on average during the research period remained, in terms of quality, beyond the surface water classification. This particular occurrence provided a unique opportunity to record such a high value of suspended solids and biogenic components. However, it should be emphasized that during growing season such cases have occurred quite frequently in the Szreniawa River basin.

The issue of suspended solids infiltrating into running waters is worth discussing in the context of environment. The average concentration of $\text{NO}_3\text{-N}$ in water from individual sampling points exceeded $2.2 \text{ mg}\cdot\text{dm}^{-3}$ and $0.25 \text{ mg}\cdot\text{dm}^{-3}$ in the case of $\text{PO}_4\text{-P}$. Yet, the water from the water samples taken at the sampling point (No. 3) in April 2017 was very clean. While analysing the problem of losing soil particles within rainwater, which has a negative impact on the fertility of agricultural land, our attention should be focused on its significant contribution to the migration into surface waters of various chemicals, including biogenic components. It is confirmed by KUREK [1990], who conducted research on the soil material carried into the Dobczyce Reservoir. According to the author, the content of chemical components carried with the soil material was significantly higher than the concentration of these components in surface waters. In this area, about 50 g of phosphorus and total nitrogen migrated with 1 m^3 of suspended solids from agricultural areas into running waters.

Also the research results of other authors indicate that together with the soil material significant amounts of biogenic components (phosphorus in particular) are carried into surface waters [BECHMANN *et al.* 2008; 2009; HEJDUK 2011; MARTIN *et al.* 1999].

The phenomena of the migration of suspended solids from the sculptured agricultural loess areas constitute a serious threat to the natural environment. According to KORELESKI [2005], the processes of the loss of soil particles within rainwater has the largest share in the degradation of edaphic formations. In particular, the consequences of this phenomenon negatively affect agriculture (agrosystems) and water management, but also contribute to the transformation of the landscape. Environmental aspects of the migration of suspended solids together with biogenic components into surface waters during intense precipitation, are part of the European Union regulations regarding the quality of natural environment, especially the water environment [Directive 2000/60/EC]. This directive organises and coordinates existing European water legislation to protect water against pollution at its origin.

SUMMARY AND CONCLUSION

The phenomena of surface runoff in agricultural areas located on the Miechowska Upland and the Proszowice Plateau in northern part of the Małopolska voivodship constitute a significant threat to protection of soil environment. Due to the undulating terrain, and also in view of the sus-

ceptibility to washing loess soils present here, this area was classified as endangered by water erosion. About 58% of the area of agricultural land of the Szreniawa River basin is also threatened with rill erosion in the range from 3 to 5, which classifies this area to the first level of urgency of managing gullies.

However, it should be emphasized that not only steepness of slopes and the intensity of precipitation affect the size of surface runoff of soil particles. An important factor is also the structure of agricultural land use, that is inappropriate for the protection of soil and water quality. Values of turf-forest coefficient (0.12) and grassland coefficient (0.07) in the Szreniawa River basin are very small. This means that only a small area of the Szreniawa River basin is permanently covered with turf-forest vegetation and used as meadows or pastures. Over 80% of agricultural land is cultivated in plow, and thus the soil is not permanently protected against surface runoff. As a result, suspended solids of soil easily migrate to surface water, simultaneously enriching it with nutrients.

The research results show significant differences in the content of soil suspended solids in surface water. It depends on various parameters, including: land cover, steepness of slopes and intensity of weather phenomena. In considered area, the organization of site should allow for the discharge of excess rainwater so as to avoid the formation of intense runoff spots and enable the effective implementation of entire complex of measures to protect the soil.

Based on the conducted research, the following conclusions can be formulated.

1. Intensive precipitation occurring on the undulating agricultural loess areas of the Szreniawa River basin, intensified the processes of suspended solids being washed into surface waters. The coefficient of soil suspended solids at individual measurement points in the Szreniawa River basin ranged from 5 to $3937 \text{ mg}\cdot\text{dm}^{-3}$.

2. It was shown that together with an increase of suspended solids in the Szreniawa River, the concentration of biogenic components was also increased. The maximum content of nitrate nitrogen in surface water sometimes reached $12.5 \text{ mg NO}_3\text{-N mg}\cdot\text{dm}^{-3}$.

3. It resulted in the deterioration of water quality in the Szreniawa River, which most often remained outside the limits of classes for surface waters.

4. Among the studied components, the concentration of phosphate phosphorus ($\text{PO}_4\text{-P}$) in the Szreniawa River showed the strongest correlation with the content of suspended solids.

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Wpływ zawiesiny glebowej wymywanej ze zlewni Szreniawy na jakość wód powierzchniowych

STRESZCZENIE

Badania prowadzono w wybranych punktach na terenie zlewni Szreniawy (o powierzchni 712 km²), położonej na wyżynie Miechowskiej i Płaskowyżu Proszowickim. W latach 2016–2017 pobierano w cyklu miesięcznym próbki wody z rzeki Szreniawy i oznaczano w nich ilości zawiesiny glebowej (metodą filtracji) oraz stężenie N-NO₃, N-NH₄ i P-PO₄ – metodą kolorymetryczną, za pomocą automatycznego analizatora przepływowego. Średnia zawartość zawiesiny glebowej wynosiła od 192 do 390 mg·dm⁻³ (min. 5–20, max 837–3937). Stwierdzono rosnący trend zależności między zawartością zawiesiny glebowej a stężeniem składników biogennych. Przykładem ekstremalnie dużej zawartości zawiesiny glebowej był koniec czerwca 2017 r., gdy po opadach o charakterze nawałnicowym wynosiła ona aż 3937,2 mg·dm⁻³. Wtedy też stężenie składników biogennych było największe i kształtowało się na poziomie 12,50 mg·dm⁻³ N-NO₃, 0,49 mg·dm⁻³ N-NH₄ oraz 1,18 mg·dm⁻³ P-PO₄. W przypadku niewielkich opadów zawartość zawiesiny glebowej była mała i wynosiła 5,0 mg·dm⁻³, a stężenie N-NO₃ wynosiło 0,39 mg·dm⁻³, P-PO₄ – 0,17 mg·dm⁻³ i N-NH₄ – 0,08 mg·dm⁻³.

Słowa kluczowe: czarnoziemy, gleby brunatne, gleby pyłowe, lessy, stężenie N-NO₃, N-NH₄, P-PO₄, zawiesina glebowa