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Analysis of the surface water quality in the Szreniawa River catchment area

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Abstract

The intensive agricultural use of the land affects both quantity and quality of river water in the catchment area. Such impact is visible also in the Szreniawa River catchment in the Małopolskie Voivodeship. The combination of intensive plowing and soil susceptibility to water erosion are the main causes of soil and nutrients depletion during the heavy rainfall. The aim of the study is to determine changes in the water quality in the Szreniawa River catchment compared to the agriculture use and precipitation level.

The quality of surface water has been analysed in the river catchment area in three sampling points. The concentration of the total suspended soils in the samples collected after heavy rainfall in August 2017 reached a value of 837 mg·dm^{-3}. The average concentrations of N-NO_3 in the years of 2016–2019 ranged from 0.16 to 13.46 mg·dm^{-3}, with the highest values in the summer (up to 13.46 mg·dm^{-3}). The concentration of N-NH_4 and P-PO_4 in the Szreniawa water was affected by precipitation. The highest value of average concentration of N-NH_4 3.00 mg·dm^{-3} was recorded in the autumn of 2019 in the middle section of the river. The highest value of P-PO_4 0.90 mg·dm^{-3} was recorded in the autumn of 2019 mostly due to water erosion of the loess areas. Erosion has been caused by the short-term heavy rainfall. As a result, suspended solids, soluble and insoluble phosphorus compounds leaked to the river.

Key words: *composition of agricultural crops, nitrogen concentration, phosphorus concentration nitrogen load, phosphorus load, precipitation, total suspended solids*

INTRODUCTION

The agricultural use of the land affects both the quality and quantity of surface water in the river catchment. Surface waters are often used for the irrigation of the fields. In the EU, 44% of total freshwater is used for agricultural purposes, mainly for irrigation. However, the percentage varies from very small values in some northern European countries to 80% in the dry southern regions of Europe [ENRD 2018].

In Poland, the percentage of the total water consumption (groundwater and surface water) for agricultural purposes accounts for 10% of total freshwater. It is a relatively low value in comparison to the EU average [Eurostat 2018]. The water consumption for the agriculture purposes was approximately 1100 hm^3 per year over the period 2008–2010 [MRiRW 2019]. In 2017 water consumption for irrigation of farmland and forest amounted to 8100 m^3 and which represents 4% decrease in comparison to year 2016 [GUS 2018]. Up to date data regarding water consumption for irrigation will be provided by the National Agricultural Census 2020. The water consumption values are expected to double.

Irrigation has become a necessity in some regions of the country over the past decade due to the shortage of precipitation and the lack of the sufficient water retention and storage infrastructure.

The national legislation may also significantly increase water use for irrigation. The legislation aims at facilitating the legal use of water, mainly groundwater. However, the effects of more intense groundwater consumption will be also visible in the river watercourses as they are connected through aquifers with groundwater sources.

Water erosion leads to the degradation of soil and leaching of organic matter from the topsoil, leading to decrease in fertility. It can result in reduced yield and in the worst case scenario, may even destroy crops and rural infrastructure [DRUŻKOWSKI 2004; LIPSKI, KOSTUCH 2005].

Susceptibility to erosion is related to the physical properties of the soil. Conservation practices (mulching and preservation of the plant cover) ensure better protection of the topsoil from leaching and provide higher stability of soil in comparison to conventional tillage [MONTGOMERY 2007; ŻYŁOWSKI 2017]. KRASOWICZ *et al*. [2011] indicated that 29% of land in Poland, including 21% of utilized agricultural area, mainly arable land and 8% of forest area are susceptible to water erosion. Surface water erosion is the main threat to the arable lands of the Małopolskie Voivodeship. Approximately, 28.63% of arable area is exposed to medium or significant erosion. It may result in permanent degradation of the soil profile [WĘŻYK *et al*. 2012].

The main factors affecting agricultural catchments surface water quality are the use of mineral and organic fertilizers, the selection of crops in the crop rotation and agrotechnical treatments affecting the assimilation of nutrients by crops.

Root crops, including vegetables, compared to cereals are characterized by high water demand and low utilization of fertilizer, particularly nitrogen [ILNICKI 2004; HARTZ 2006; NETT 2012]. Regions of intensive vegetable cultivation require extensive fertilization and hence the eutrophication of surface water [ADAMCZYK, JACHIMOWSKI 2013]. Intensive farming, where productivity is the main goal often happens at the expense of renewable natural resources. Such process results in the reduction of biodiversity and landscape transformation [KORNERT *et al*. 1999].

One of the main challenges in the river catchment area is finding the right balance between quality of the surface water and the intensity of agricultural production. The aim of this research is to establish concentrations of the biogenic components: $N\text{-}NO_3$, $N\text{-}NH_4$, $P\text{-}PO_4$ and soils suspension in the river water during spring, summer, and autumn. Furthermore the link between rainfall, type of farming activity and the aforementioned compounds is explored and evaluated.

MATERIAL AND METHODS

The Szreniawa River catchment (20° 34' 24,208" E, 50° 9' 51,174" N; 19° 52' 11,276" E, 50° 22' 34,104" N) with an area of 712 km^2 is located in the Olkusz and Miechowska Upland and Proszowice Plateau (Fig. 1). The Szreniawa River has a length of approximately 80 km and it is a left-bank tributary of the Vistula River [SMOROŃ, KOWALCZYK 2014]. Szreniawa (in Koszyce) contains water of poor ecological status. In 2017 five parameters exceeded limit values of good water status, i.e. nitrate nitrogen, nitrite nitrogen, total nitrogen, phosphates (V) and total phosphorus [WIOŚ 2017].

The land use in the Szreniawa River catchment clearly indicates its typical agricultural character dominated by farmlands (arable land – 81%, meadows and pastures – 6%).

About 68% of arable land in the catchment area is covered by cereals, 10% of this land is used for potato production and 20% is designated for the vegetable crops (Fig. 2). The area of farmland designated for vegetable crops is relatively small, however the intensive nature of its exploitation has adverse effects on the surface water.

The area of the Szreniawa catchment is threatened by water erosion, which is typical for pleated loess areas [SMOROŃ 2012; SMOROŃ, KOWALCZYK 2014]. There are very fertile silts soils formed from loess, belonging to the

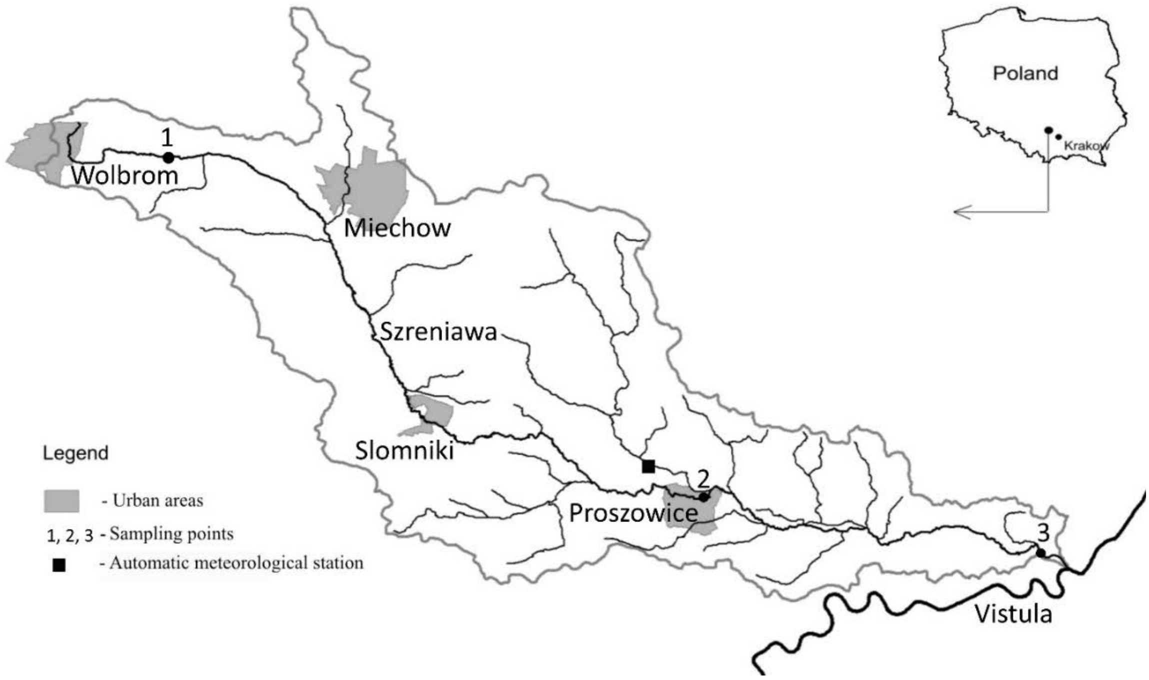

Fig. 1. Location of the research area and sampling points in the region of the upper Vistula River; source: own elaboration

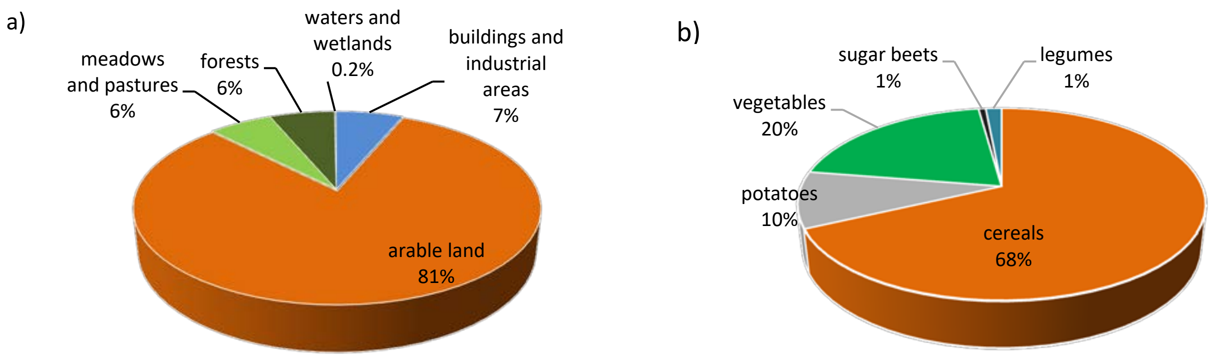

Fig. 2. Share of the land use: a) land classes, b) crops share; source: own elaboration based on CSO [GUS 2018]

type of proper and degraded chernozems and proper brown soils, in case of the river valleys to the alluvial soils. Their value in use is high (I–IIb bonitation class) with a predominance of very good wheat and good wheat agricultural rye complex.

Crops yields in Szreniawa catchment area good and exceed the Polish average e.g. winter wheat crops in good precipitation conditions yield from 8 to 9 $Mg \cdot ha^{-1}$, other cereals 6–8, potatoes 25, and beetroot 50 $Mg \cdot ha^{-1}$.

The makeup of livestock in the catchment area includes mostly dairy cattle and poultry. The livestock production in the Szreniawa catchment amounts for 1.28 LU (livestock unit) per ha of farmland. This value does not exceed the livestock density per 1 ha of farmland specified in the Directive 91/676/EWG (1.5 LU). Values higher than 1.5 LU increase the risk of nitrogen pollution in soil and water. Livestock density is at average level compared to the national average (0.5 $LU \cdot ha^{-1}$) [IUNG-PIB 2019; KOŁODZIEJCZAK 2015].

The study was conducted between 2016 and 2019 at three sampling points located in the Szreniawa River catchment, i.e. in the upper (point 1), middle (point 2) and lower (point 3) river course. Analysis of the water samples were performed in the Laboratory of the Malopolska Research Center ITP (Małopolski Ośrodek Badawczy).

The concentration of $N\text{-}NO_3$, $N\text{-}NH_4$ and $P\text{-}PO_4$ were determined by SLANDI photometer using powder reagents. The amount of biogenic pollutants load discharged from the catchment area, i.e. phosphate phosphorus $P\text{-}PO_4$, nitrate nitrogen $N\text{-}NO_3$ and ammonium nitrogen $N\text{-}NH_4$ was determined based on the measurements of pollutants concentrations in the Szreniawa River for all three points. Moreover, at point 3 located in the estuary part of the river, the value of biogenic pollutants load was compared with the hydrological data obtained from the Polish Institute of Meteorology and Water Management – National Research Institute (Pol. Instytut Meteorologii i Gospodarki Wodnej – Państwowy Instytut Badawczy – IMiGW-PIB). In addition, for all measurement points, the analysis of the total suspended solids in the river was conducted using the gravimetric method.

Pearson's correlation has been used to explore the relationship between rainfall and concentration of various organic compounds as well as total suspended soils in the water. Further, *p* value and standard deviation (*SD*) was used to test the statistical significance of said relationships.

RESULTS

The concentration of $N\text{-}NO_3$, $N\text{-}NH_4$ and $P\text{-}PO_4$ compared to the amount of precipitation was investigated (see Fig. 3).

All analysed samples exceeded the limits of classes I (0.001 mg $P\text{-}PO_4 \cdot dm^{-3}$) and II (0.1 mg $P\text{-}PO_4 \cdot dm^{-3}$). Precipitation had the greatest impact on the concentration of $P\text{-}PO_4$. The highest value of the average concentration of $P\text{-}PO_4$ 0.898 $mg \cdot dm^{-3}$ was recorded in 2019 in the sampling point 2 after heavy rainfall. The lowest values, regardless of the season, were recorded in dry periods (not preceded by rainfall). Lack of continuous relationship in concentration of $P\text{-}PO_4$ between the sampling points was observed.

Standard deviation (*SD*) in spring, summer and autumn was: 0.07, 0.12, 0.22 respectively. Very weak correlation between concentration of $P\text{-}PO_4$ in the same points and rainfall was noted in spring, summer and autumn 0.15, 0.16 and –0.13 respectively, for $p = 0.01$.

Similarly, to $P\text{-}PO_4$ the precipitation affected concentration of $N\text{-}NH_4$ in the Szreniawa River. The highest value of the $N\text{-}NH_4$ average concentrations 3.003 $mg \cdot dm^{-3}$ was recorded in the autumn 2019 in the sampling point 2. The lowest values were observed in the summer. All analysed samples exceeded the limits of classes I (0.04 mg $N\text{-}NH_4 \cdot dm^{-3}$) and II (0.326 mg $N\text{-}NH_4 \cdot dm^{-3}$).

Standard deviation (*SD*) in spring, summer and autumn was: 0.11, 0.37, 0.81, respectively. Very weak correlation between concentration of $N\text{-}NH_4$ in the same points and rainfall was noted in spring, summer and autumn 0.23; 0.53 and –0.12 respectively for $p = 0.01$.

Average concentrations of $N\text{-}NO_3$ between the years of 2016 and 2019 ranged from 0.16 to 13.46 $mg \cdot dm^{-3}$. In the summer the average concentration ranged from 1.328 to 13.460 $mg \cdot dm^{-3}$, in autumn concentration of $N\text{-}NO_3$ ranged from 0.155 to 4.750 $mg \cdot dm^{-3}$. In the spring recorded values varied from 1.370 to 2.960 $mg \cdot dm^{-3}$. The lowest values were noted in the summer in sampling point 3, i.e. 13.160 $mg \cdot dm^{-3}$. The limit values for class I (0.5 mg $N\text{-}NO_3 \cdot dm^{-3}$) and class II (0.8 mg $N\text{-}NO_3 \cdot dm^{-3}$) were exceeded in spring and summer, whereas in the autumn of 2018 these values did not exceed class II.

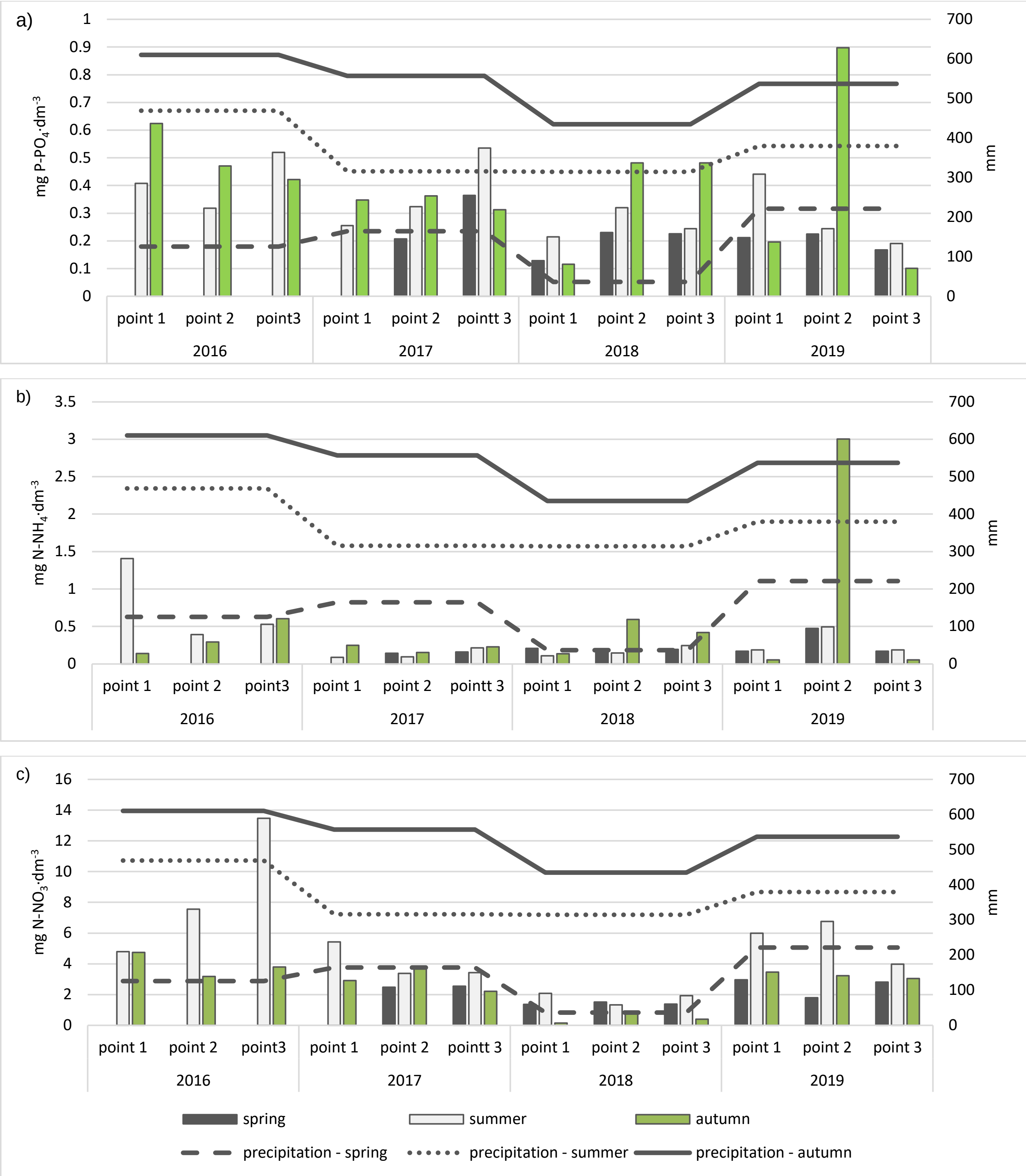

Fig. 3. The average concentration of fertilizer compounds vs. precipitation (spring, summer, autumn): a) $P\text{-}PO_4$, b) $N\text{-}NH_4$, c) $N\text{-}NO_3$; source: own study

Standard deviation (*SD*) in spring, summer and autumn was: 0.66, 3.30, 1.44 respectively. Strong correlation between concentration of $N\text{-}NO_3$ and rainfall was noted in spring 0.83 (but only at some sampling points), and a weak correlation in summer and autumn was observed: 0.28 and 0.33 for $p = 0.01$.

Figure 4 demonstrates the values of total suspension ranged from ca. 12 mg·dm^{-3} to ca. 451 mg·dm^{-3}. The highest values in the range of 198–451 mg·dm^{-3} were recorded in the autumn of 2016 while the lowest values were recorded in the summer of 2018. The total suspended solids analyzed by VIEP in Kraków in the years 2016–2019 at the Szreniawa-Koszyce point ranged from 54.3 mg·dm^{-3} (average annual 2016) to 72.8 mg·dm^{-3} (average annual 2017).

Standard deviation (*SD*) is high at all sampling points: 61.47, 118.75, 157.52. Significant variation in suspended solids concentration in all samples has been recorded in comparison to average which is respectively: 110.94, 130.96, 148.63 mg·dm^{-3}.

The total suspended solids in the rivers depends on many factors, of which precipitation, particularly the precipitation intensity plays a significant role. Figure 5 indicates relationship between precipitation and total suspended solids in the river water for point 3. During the research period, the concentration of total suspension, measured at the time of water sampling, ranged from slightly above zero in 2016 to 837 mg·dm^{-3} in August 2017.

The total suspended soils concentration ranged from 50 to 400 mg·dm^{-3}. In most samples the highest content of total suspended solids in the Szreniawa River was observed after heavy rainfall. The high concentration of the total suspended solids observed in some periods, e.g. 29.06.2017 – 318 mg·dm^{-3} (low precipitation – 3.6 mm), was most likely caused by other factors. However, during periods without rainfall or with daily precipitation not exceeding 5 mm, the concentration of total suspended solids was low and did not exceed 40 mg·dm^{-3}.

According the Figure 6 the average flow in the analysed period was 2.67 m^3·s^{-1}. It is a result similar to the average flow (*SSQ*) for the years 1980–2000: 2.56 m^3·s^{-1} [SMOROŃ 2012]. From June 2016 to May 2017 an increase in the average monthly flow occurred, whereas the loads of P-PO_4 and N-NO_3 were 2.2–5.7 Mg and 1.7–109.6 Mg, respectively (Fig. 8). From October 2017, a decrease in the average flow occurred, which resulted in a decrease in the load of P-PO_4 that ranged from 0.4 to 3.0 Mg. Lower values of the N-NO_3 loads from 0.6 to 20.4 Mg were also noted during this time.

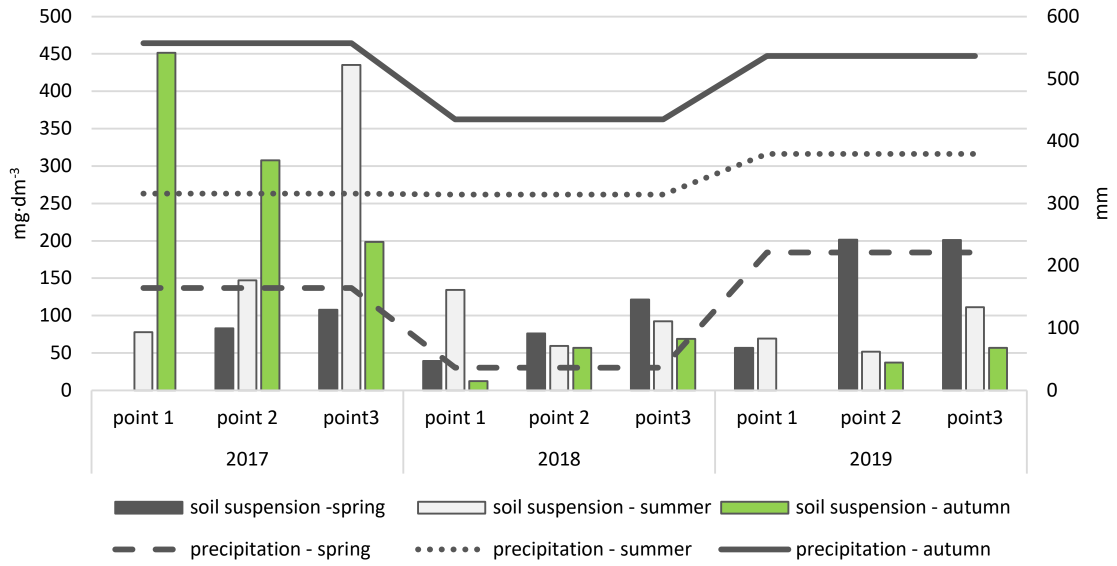

Fig. 4. The average value of total suspension compared to precipitation (spring, summer, autumn); source: own study

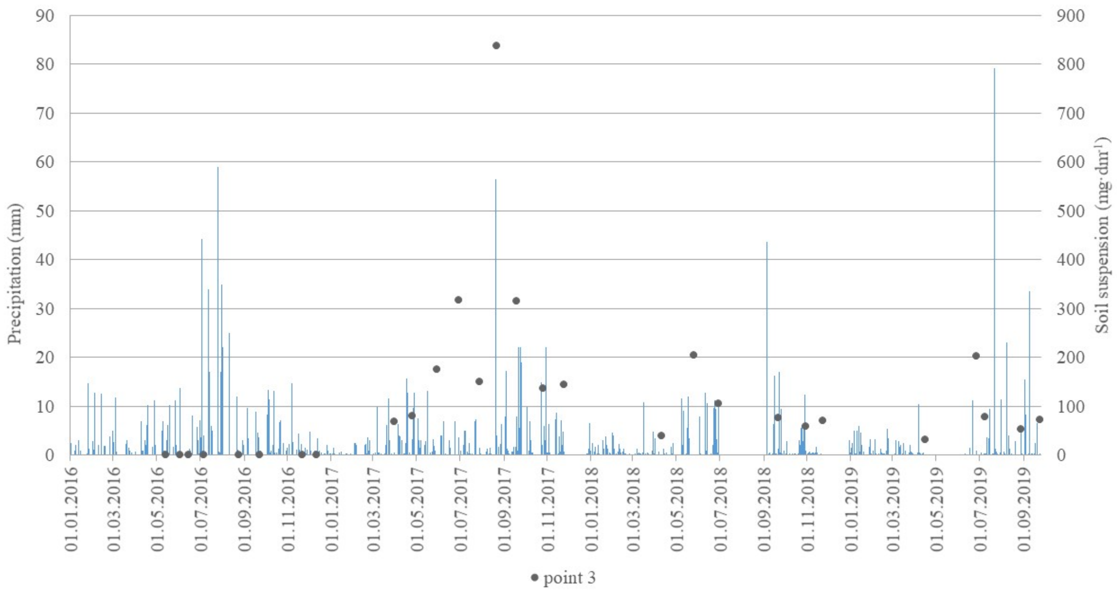

Fig. 5. The relationship between precipitation and total suspended solids for point 3; source: own study

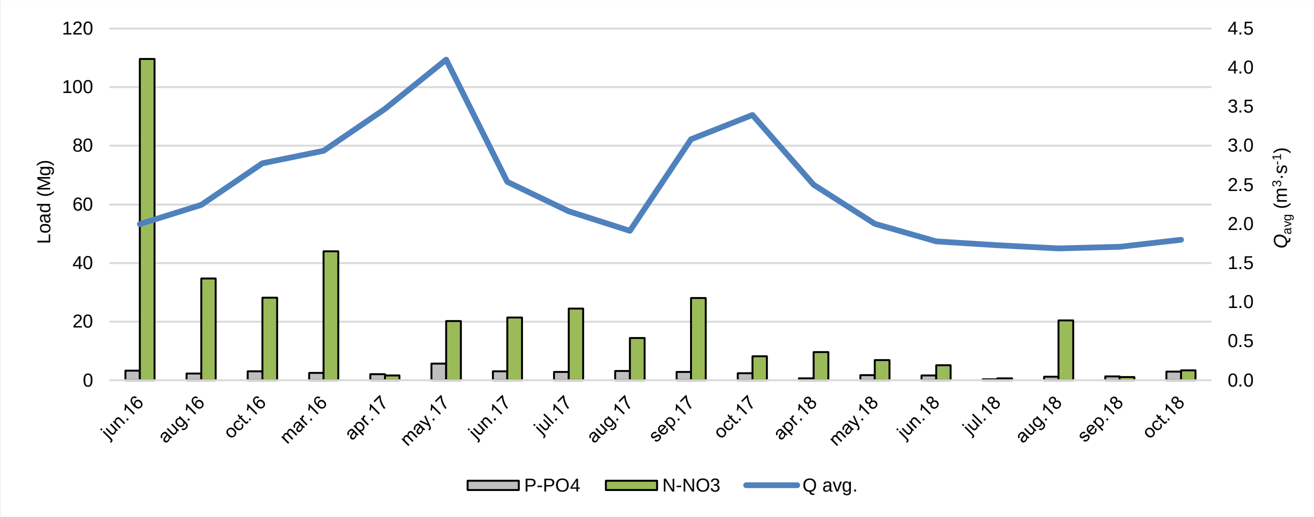

Fig. 6. The chart of the P-PO_4 and N-NO_3 loads for sampling point 3 compared to the average monthly flow Q_{avg}; source: own study

DISCUSSION

The conducted research allowed to examine the qualitative and quantitative state of surface waters in the Szreniawa River catchment, against agricultural activity. The conducted research demonstrated the quality of flowing waters of the Szreniawa River exceeding norms for classes I and II. The average concentration of N-NH_4 exceeded the limit values for class I in all analyzed points. Average concentration of N-NO_3 did not exceed norms in class II only in two cases in 2018. In other cases, the water of the Szreniawa River exceeded the norms in class II for N-NO_3. The structure of the catchment causes the lack of precipitation and limits its amount when it does occur. It also restricts the surface runoffs in the Szreniawa catchment leading to high loss of soil material after heavy rainfall. The high values of the average concentration of P-PO_4, exceeding class II norms, are particularly noteworthy. The highest values of P-PO_4 (0.898 mg dm^{-3}) were noted in autumn 2019 – as a result of water erosion in these loess areas caused by short-term, very intense precipitation. As a consequence, soluble and insoluble phosphorus compounds got into the Szreniawa River together with the soil suspension.

Similar studies, exploring the sources of pollution of rivers including agricultural factors have led to discovery of three principal elements affecting the surface water quality: intensity of rainfall, soil type and susceptibility to erosion and the scale of agricultural production [BORMANN *et al*. 2007; BROAD, CORKREY 2011; CARLYLE, HILL 2001; LEE *et al*. 2005; MA *et al*. 2009; SCHEREN *et al*. 2000; TONG, CHEN 2002]. Further, other research has also concluded that soil erosion occurs during increased depletion of biogenic compounds, in particular phosphorus [BECHMANN *et al*. 2008; 2009; MARTIN *et al*. 1999]

The agricultural pollution, from arable land transfers to surface and ground waters. This process is magnified by the incorrect use of fertilizes. Amplified fertilizer use leads to increase biogenic substances presence in the aquatic environment. Leaching from the agricultural land to the surface water accounts for 220,000 Mg of nitrogen. Bearing in mind that the total amount of the agricultural nitrogen input is 1,830,000 Mg the nitrogen losses to surface water equal 12% [IZYDORCZYK *et al*. 2015].

Erosion prevention practices result in a decrease in the outflow speed and, consequently, in an increase in the retention capacity of agricultural land. This method include appropriate cultivation methods, for example reducing tilling or exclusion plowing across the slope. Other anti-erosive method can be used, such as the creation of plant protection strips, e.g. clumps of trees and shrubs. It also serves to increase the retention capacity [WĘŻYK *et al*. 2012]. The mosaic nature of agricultural areas and the interaction between habitats, make protective plant strips useful to protect populations of wild organisms [MIODUSZEWSKI, OKRUSZKO (eds.) 2016].

CONCLUSIONS

1. The quality of the surface water in the river catchment area with predominantly agricultural lands is affected by the size, shape, and location of the arable area.
2. The intensity of the rainfall has a strong bearing on the amount of nutrients and suspended solids washed out from the arable land.
3. Crops rotation and location and their suitability for local environmental conditions should be taken into consideration to protect surface water from agricultural contamination.

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