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Research Article

SEASONAL CHANGES IN PHOSPHORUS LOAD FLOWING OUT OF SMALL AGRICULTURAL CATCHMENTS

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ABSTRACT
In this article distribution of monthly phosphorus loads flowing out of two agricultural catchments which are located in different physiographic conditions of Lower Silesia was analysed. Loads of phosphorus runoff from the catchment located in the piedmont part of Lower Silesia in each month rarely exceed 0.10 kg P · ha^{-1}. The size of annual load is determined by loads obtained in two months of early spring. Much lower loads obtained for lowland catchment, located near Wroclaw. Values calculated for each month rarely exceed the value of 0.01 kg P · ha^{-1}. Culmination of loads bringing away is a bit more extended in a time compared to the catchment located on Sudety Mts. Foreland. Much higher loads are observed during the period from January to April – this period has a major impact on the size of phosphorus load that flows out from this catchment during whole hydrological year.
The obtained results clearly indicate that the threat of watercourses and water reservoirs supply in phosphorus compounds from agricultural land is periodic and it is particularly high during early spring. Phosphorus load flowing out from the analyzed catchments is very diverse. From facility located on Sudety Foothill in hydrological year, during research period, flowed away average 0.81 kg P · ha^{-1}. Significantly lower values were obtained for second facility and it was average 0.15 kg P · ha^{-1} during a year. The size of load discharged during a year is largely determined by amount of phosphorus load flowing out during winter half of the year (from XI to IV). In case of foothill catchment in this period flowed out average 0.56 kg P · ha^{-1}, which presents 69% of annual load and in lowland catchment this percentage was even slightly higher and was 73%.

Keywords: water, catchment, season, load, phosphorus.

INSTRODUCTION

Phosphorus compounds flowing into surface water pose a significant risk of eutrophication, and thus contribute to the degradation of these resources. This significantly limited the usefulness of this kind of water to be used for various purposes like water supply of population and industry, recreation, etc. Supply of phosphorus to surface water as a limiting element of primary production should be subject to special control and restriction. Currently, much more attention is paid to reducing the flow of nitrogen into surface waters, especially in the nitrate form, which reduces their suitability for the use for purposes connected with supply of the population with drinking water.

One of the sources of phosphorus contaminating surface water is agricultural land [Pulikowski 2004; Sojka et al. 2008; Czaban 2009;]. Phosphorus compounds used as fertilizers are adsorbed on soil particles and hardly dissolve in the soil. Phosphates enter into surface water with suspensions, mainly as a result of erosion. It is estimated that the loss of phosphorus during fields fertilization ranges from 0.1 to 5.0 % and is a significant source of phosphorus in surface water [Dojlido 1995]. In breeding farms plants needs of phosphorus can be fully covered by natural fertilizers. Reduction of mineral fertilization ensures the reduction of excess of this component in the soil, which poses a threat to groundwater, while not significantly affect the yield increase [Pietrzak 2005]. In most cases, a reduction in phosphorus fertilization does not reduce the profits of the farmer, but reduces costs, and it is always beneficial to the environment [Sapek 2008].

The phosphorus content in the water flowing from the small lowland catchments, in contrast to nitrate, has no relationship with the indicator of soils bonitation [Witkowski 1997] and content of phosphorus in the soil [Gardner 2002] but is correlated to the share of crops fields in catchment and inclines [Ekholm et al. 2000] as well as arable lands [Skorbiłowicz 2010]. The concentration of phosphorus also shows a positive (not always significant at $p = 0.05$) correlation with the volume of runoff [Pulikowski 2002], which confirms the high proportion of surface runoff in shaping the size of phosphorus load flowing out from the catchment. Runoff, groundwater and water captured in soil pores from areas located by the river are responsible for moving 98% of orthophosphate outflowing from the catchment [Banaszuk et al. 2009]. The average annual concentration of total phosphorus in lowland rivers may even exceed 2 mg P · dm^{-3} [Dąbrowska, 2008]. In case of catchment with disordered water and wastewater management an important source of phosphorus in surface water may be domestic wastewater discharged in an uncontrolled way [Pulikowski et al. 2011a].

Excess of phosphorus in surface water is a global problem. Phosphorus once introduced into the environment cumulates and can be removed only in the process of remediation [Sapek 2011]. One way to reduce the flow of this component into surface water may be the use of materials absorbing this component in wastewater treatment plants or reservoirs where runs pollutions from small agricultural catchments [Karczmarczyk, Bus 2014]. Another solution is to use on the inlet to the reservoir a small primary reservoir [Dąbrowska et al. 2014].

RESEARCH METHODOLOGY

The study analyzed the results of research carried out in three consecutive hydrological years 1999/2000, 2000/2002 and 2001/2002 at two different facilities located in the lower Silesia. One of them – Stare Bogaczowice – is located on the border of the Bolkow-Walbrzych Foothill and Wałbrzyskie Mountains, in the region of Central Sudetes. The study included ditch catchment with total area of 29 hectares. This catchment is situated 400–500 meters above sea level on the northern and north-eastern slopes. Declines of this area are very large, ranging from 5–8%. The catchment area includes arable fields, partially drained [Pulikowski 2004]. During the study period rainfalls were higher than long-term average value (655 mm). Year 2001/2002 is worth attention because during this period very high annual precipitation, up to 1044 mm, was noted. This was connected to an extremely high rainfall that occurred in August (348 mm) (Table 1). The average annual temperature in each year was higher than the average of the long term and ranged from 8.4 °C to 8.6 °C (Table 2).

The second research facility (Szewce) is located in the Silesian Lowland near Wrocław. The property is situated in the catchment at an altitude of 114–132 m above sea level Declines in the area range from 2.5 to 4.0‰. The study included the catchment area of 100.7 hectares that is an arable land, of which nearly 40% is drained by drainage. On this area occur brown soils with particle size of light and medium loam. There are also heavy clays and small amounts of well decomposed peat [Pulikowski 2004].

During the two years of study rainfalls occurred close to the long-term average of 587 mm.

Table 1. Monthly and annual precipitation totals (mm) at particular experimental object

Meteorological station (object)	Years	Months												Year
		XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	
Szczawno-Zdrój (Stare Bogaczowice)	1999/2000	40	26	66	51	65	17	112	56	175	44	69	17	738
	2000/2001	45	20	34	40	70	77	50	80	201	114	122	21	874
	2001/2002	52	57	29	42	35	34	100	64	160	348	65	58	1044
	2001/2002	32	21	21	40	16	27	28	40	63	108	50	48	494
Ligota Piękna (Szewce)	1999/2000	43	31	50	40	94	11	64	25	127	41	28	8	562
	2000/2001	42	33	16	21	79	30	53	85	170	44	107	34	714
	2001/2002	29	32	27	68	37	46	48	48	49	107	36	59	586

Table 2. Mean monthly and annual air temperatures (°C) at particular experimental object

Meteorological station (object)	Years	Months												Year
		XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	
Szczawno-Zdrój (Stare Bogaczowice)	1999/2000	1.7	0.2	-2.0	1.8	2.9	10.7	14.0	16.7	15.0	17.0	11.9	11.3	8.4
	2000/2001	6.3	1.4	-0.6	0.3	2.5	6.7	13.4	13.8	17.9	18.1	11.0	11.9	8.6
	2001/2002	1.7	-3.7	-0.8	4.4	4.1	7.5	15.6	16.8	18.3	18.6	11.4	7.0	8.4
Wrocław-Strachowice (Szewce)	1999/2000	3.0	1.9	-0.3	3.8	5.0	12.1	15.7	17.9	16.5	19.0	13.4	12.5	10.0
	2000/2001	6.8	2.5	0.6	1.1	3.5	8.0	14.8	15.1	19.2	19.3	12.5	12.7	9.7
	2001/2002	3.4	-1.7	0.6	4.9	5.3	9.0	17.0	18.2	20.1	20.6	13.6	8.2	9.9

Year 2000/2001 in which there was a high annual precipitation of 714 mm is noteworthy. It was the result of, among others, high rainfall that occurred in July (170 mm) (Table 1). The average annual temperature in each year was higher than the average of the long term and ranged from 9.7 °C to 10.0 °C (Table. 2).

Measurements were taken in measurement cross-sections equipped with triangular Thomson's overflow, staff gauge and limnigraph. Water samples for determination of phosphorus were taken 1–2 times a month.

The calculation of the phosphorus load flowing out from the catchment were based on daily measurements of runoff and periodic analyzes of the composition of the outflowing water. For periods between successive terms of chemical analyzes, phosphorus concentration was determined by linear interpolation:

$$Ł = \sum_{t=1}^{t=T} (\overline{Q}_t \cdot C_t^{\,I})$$

where: Ł – load of contaminants outflowing from catchment during a month, $kg \cdot ha^{-1}$,

$C_t^{\,I}$ – determined the average daily value of the concentration of the examined component, for the days of the period between the execution of two consecutive analyzes determined by linear interpolation, $kg \cdot m^{-3}$,

$\overline{Q}_t$ – average daily volume of unit outflow, $m^3 \cdot ha^{-1}$,

t – next days in the month.

RESULTS AND DISCUSSION

The load is an objective parameter in order to compare the share of different sources, e.g. point and surface in water pollution of the river or reservoir. The most common calculation period is a year, less common - a day, and in the case of area sources, unit load referenced in addition to the catchment area is in use. While in the case of point sources, for example outflow of the treated wastewater from wastewater treatment plant load is not subject to significant fluctuations over the year, whereas in the case of area sources this variability is very important. Accordingly, the phosphorus load variability was analyzed in subsequent months over 3 consecutive hydrological years.

Loads of phosphorus runoff from the catchment located in the piedmont part of Lower Silesia in each month rarely exceed 0.10 kg P $\cdot$ ha^{-1} (Figure 1.). About size of the annual load decide loads obtained in one or two months. In the first two years there are months of February and March, a period in which the early spring thaw begins, time of intense flow of water from the catchment. During this period, the monthly load exceeds even 0.40 kg P $\cdot$ ha^{-1} (Figure 1). A slightly different situation was found in 2001/2002, the maximum monthly charge was obtained for August, which is directly related to the extremely high rainfall that was recorded in this month (Table 1).

Much lower loads were determined for lowland catchment, located near Wroclaw. The values calculated for each month rarely exceeded the value of 0.01 kg P $\cdot$ ha^{-1}. The culmination of load flowing out is a bit more spread in time comparing to catchment located on Sudety Foothill. Much higher loads were observed during the period from January to April. This period has a major impact on the size of phosphorus load, which flows under these conditions throughout the hydrological year. Seasonal nature of phosphorus runoff from catchment is closely related to volatility of the water volume discharged by the river which decides about its size, while the maximum concentration of phosphorus was found in the summertime [Skorbiłowicz, Ofman 2014]. A similar seasonal distribution of loads is obtained for example for nitrogen [Pulikowski et al. 2011b].

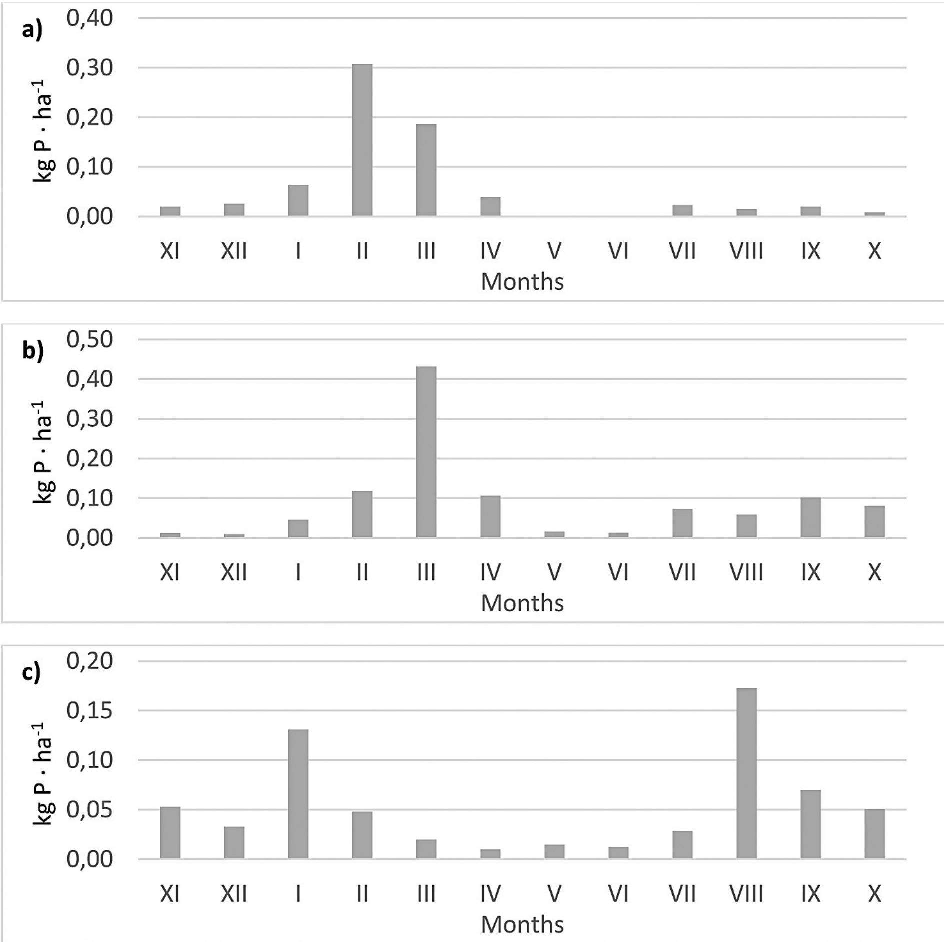

Figure 1. Monthly loads of phosphorus runoff from one hectare of agricultural land in the Sudeten Foreland (Stare Bogaczowice) in the hydrological years: a – 1999/2000, b – 2000/2001, c – 2001–2002

The results clearly indicate that the threat of supply watercourses and water reservoirs in phosphorus compounds from agricultural land, is periodic and is particularly high during early spring.

Phosphorus load flowing out from the analyzed catchment is very diverse (Table 3). In the case of a facility located in the Sudety Foothill in the hydrological year 2000/2001 float away even more than 1 kg P · ha^{-1}, during study period flowed away average 0.81 kg P · ha^{-1}. Significantly lower values were obtained for the second object, averaged over the year flowed 0.15 kg P · ha^{-1}, and the range of variation was small – from 0.12 to 0.18 kg P · ha^{-1}. A similar value (0.13 kg P · ha^{-1}) was obtained by Witkowski [1997b]. Such large differences in loads between these objects is likely due to the varying amount of rainfall, and thus a greater unit outflow in piedmont catchment.

The size of load discharged during the year is largely determined by the amount of phosphorus flowing out in the winter (XI and IV). In case of piedmont catchment at this time flowed away on

Table 3. Periodic and annual loads of phosphorus outflow from the catchment area of agricultural. kg P · ha^{-1}

Object	Years	Winter half-year	Summer half-year	Year
Stare Bogaczowice	1999/2000	0.64	0.07	0.71
	2000/2001	0.73	0.34	1.07
	2001/2002	0.35	0.30	0.65
	Mean	**0.56**	**0.25**	**0.81**
Szewce	1999/2000	0.09	0.03	0.12
	2000/2001	0.13	0.05	0.18
	2001/2002	0.13	0.03	0.16
	Mean	**0.11**	**0.04**	**0.15**

average 0.56 kg P · ha^{-1} (Table 3), which represents 69% of annual load, in the case of lowland catchment, this percentage was slightly higher and amounted to 73%. Studies in Canada have shown that in the same period of melting snow, flows 20% of the annual phosphorus load [Su et al. 2011].

CONCLUSION

Loads of phosphorus runoff from the catchment located in the piedmont part of Lower Silesia in each month rarely exceed 0.10 kg P · ha^{-1}. The size of the annual load is determined by the loads obtained in the two months of early-spring. Much lower loads were determined for lowland catchment, located near Wroclaw. The values calculated for each month rarely exceed the value of 0.01 kg P · ha^{-1}. The culmination of loads outflowing is a bit more spread in time compared with the object located at the foothills of the Sudety. Much higher loads were observed during the period from January to April. This period has a major impact on the size of the phosphorus load, which flows under these conditions throughout hydrological year.

The results clearly indicate that the threat of supply watercourses and water reservoirs in phosphorus compounds from agricultural land, is periodic and is particularly high during the early spring.

Phosphorus load flowing out from the analyzed catchment is very diverse. From a facility located in the foothills of the Sudety during hydrological year, average in the study period flowed 0.81 kg P · ha^{-1}, significantly lower values were obtained for the second object, on average, in the year flowed 0.15 kg P · ha^{-1}. About the size of load discharged during the year largely determines the amount of phosphorus flowing out in the winter (XI and IV). In case of piedmont catchment at this time flowed away on average 0.56 kg P · ha-1 (Table 3), which represents 69% of annual load, in the case of lowland catchment, this percentage was slightly higher and amounted to 73%.

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