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SHARE OF DIFFERENT TYPES OF CATCHMENTS IN THE SOLINA RESERVOIR LOADING WITH BIOGENIC ELEMENTS

The results of experiments carried out in 1999–2001 on the Solina reservoir ecosystem are given. The run-off of the nitrogen and phosphorus derivatives from the catchments of particular tributaries was estimated. It was found that loads of both nitrogen and phosphorus ranged between 4.9–24.9 kg N ha^{-1} $year^{-1}$ and 0.2–1.1 kg P ha^{-1} $year^{-1}$, respectively, and that their values detected were higher than the values expected for woodland catchments. The highest values of both elements were observed in the Daszówka stream water, which was attributed to the effect of point sources of the biogens. No clear correlations between particular types of catchment and biogen loads were found. The highest correlation was found for the load of nitrate-nitrogen and the share of meadows in a total catchment [%] (R = 0.78). The variations of both nitrogen and phosphorus loads did not depend on the season.

1. INTRODUCTION

Over the last decades a rapid acceleration of eutrophication of lakes, reservoirs and other water bodies has been observed. This process is encouraged by economic growth and development being responsible for an increase in the loads of biogens. Geomorphological and paleolimnological studies have proved that both nitrogen and phosphorus loads discharged into seas and oceans have increased by 2500% over last 3000 years (JICKELLS et al. [1]) which means 0.8% progress in eutrophication per year. Moreover, ZHOU et al. [8] have informed that loading of Irish lakes with biogen compounds have been increasing by 200% during the time span of 1990–2000 (20% per one year!). A decrease in both nitrogen and phosphorus loads by building modern sewage-treatment plants is not sufficient yet. Sustainable development, global view and recognition of all sources of biogenic elements are necessary.

Besides the point sources of biogens connected with sewage disposal, both precipitation (important in the case of oligotrophic lakes with considerable areas) and

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surface run-off should be considered in the overall balance of biogens. The latter parameter depends on the catchment characteristics. Loads from forests, meadows and pastures or arable and idle areas are strongly diversified (KAJAK [3]). Moreover, geology of catchment and soil erosion can be important factors influencing the magnitude of loads supplied by inland waters (JØRGENSEN and BENDORICCHIO [2]). Diversification of nutrient loadings collected by KAJAK [2] and JØRGENSEN and BENDORICCHIO [3] is shown in table 1. Though both sources are independent, their similarity is distinct. The lowest and the highest values of surface run-off are observed for forests and arable areas, respectively.

Table 1

Run-off of total nitrogen and phosphorus from catchment to inland waters

According to KAJAK [3]			According to JØRGENSEN and BENDORICCHIO [2]				
Character of catchment	Mean (max) load, kg ha^{-1} year^{-1}		Character of catchment	Range (mean) of loads kg N ha^{-1} year^{-1}		kg P ha^{-1} year^{-1}	
	Nitrogen	Phosphorus	Geology →	Igneous	Sedimentary	Igneous	Sedimentary
Forests	<10 (13–335)	0.04–0.2 (0.4; 0.9)	Forests	1.3–3.0 [2.0]	1.5–5.0 [3.4]	0.007–0.09 [0.05]	0.07–0.18 [0.12]
Meadows and pastures	<10 (24–60)	0.05–0.17 (2.6–10)	Forest and pasture	2.0–6.0 [4.0]	3.0–8.0 [6.0]	0.06–0.12 [0.11]	0.11–0.37 [0.23]
Arable areas	2.6–26.7 (120; 153)	0.06–2.9 (4.4; 54.0)	Orchards and gardens		22.4	0.18	
Idle areas	33–185	0.56–2.9	Pastures		1.0–8.5	0.15–0.75	
Run-off from estate	4.1–9.3	1.0–5.3	Cropland		5.0–12.0	0.22–1.0	

2. AREA OF INVESTIGATION

The Solina reservoir (figure 1) came into existence in 1968 as a result of damming the San River by a concrete dam being constructed at a distance of 325.4 km from the river spring. It is the biggest dam reservoir in Poland in terms of its volume (502 mln m^3) and also the deepest one (max 60 m, 22 m on an average). The reservoir occupies the area of approximately 22 km^2. The basin tributaries are natural water races – rivers and streams. All of them are mountainous rivers characterized by large slope and high erosion rate. The tributaries as typical mountainous streams have sudden freshet after heavy rains. Strong washing of pollutants and soil material out of drainage basin takes place during freshets. The tributaries differ one from another in their lengths, areas of percolation and mean flows.

Overall drainage basin occupies the area of 1174.5 km. A basic part of the basin is occupied by forests, and a lesser, by meadows and pastures. Croplands constitute only a little fraction of the area. The drainage basin is sparsely populated. An economic

activity is concentrated mainly in valleys near rivers and streams estuaries. What the area lacks are industrial plants. Most of the resorts with their leisure centers and bungalows have a recreational character.

Table 2

Some of hydrological, geographical and economical parameters of water-courses and catchments

Parameters	The San	The Solinka	The Czarny	The Pani-szczówka	The Buko-wiecki	The Wołko-wyjka	The Daszówka
Length of river (stream) [km]	92.4	41.3	18.2	6.5	6.9	9.6	8.3
Slope [%]	4.55	12.7	9.78	16.96	25.32	22.08	21.2
Long-term mean flow [m^3/s]	10.04	5.54	1.88	0.37	0.06	0.65	0.53
Catchment area [km^2]	603.7	307.6	89.9	16.7	19.1	29.94	24.5
Mean height [m a.s.l.]	741.0	750.5	593.8	528.5	520.0	586.5	538.5
Population [persons/km^2]	5.5	7.2	21.3	0.0	28.7	32.4	32.2
Cropland [%]	2.8	3.3	4.4	2.1	26.5	2.9	19.6
Meadow, pasture [%]	15.3	7.9	21.3	31.5	19.2	14.8	22.5
Forests [%]	80.0	77.4	64.2	31.7	46.2	56.0	53.9
Idle [%]	1.5	12.1	9.8	34.2	8.1	25.6	2.8

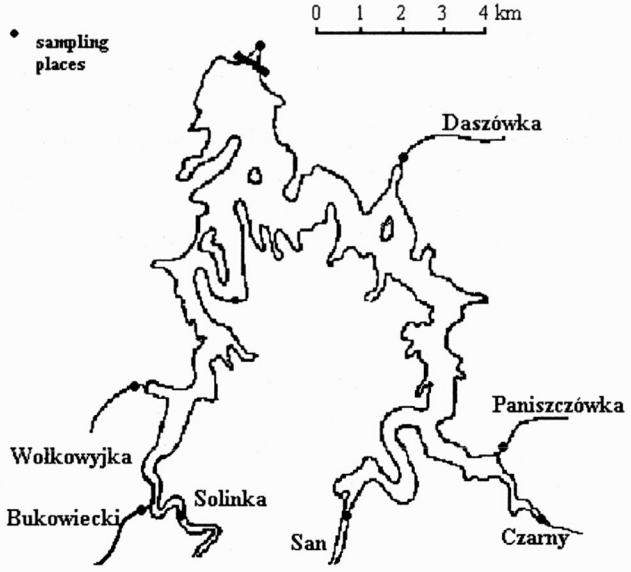

Fig. 1. Location of sampling places and some of physical features of the Solina reservoir: max. volume – 502 mln m^3, planed hydraulic retention time (HRT) – 215 days, actual HRT – 220 days, max. depth – 60 m, mean depth – 22 m, area of the reservoir – 22 km^2, length along the axle of the San River – 26 km, length along the axle of the Solinka River – 14 km

3. METHODS

Mass balance of nutrients was investigated from March 1999 till March 2001 at eight points localized in estuarine sections of seven tributaries and at the outflow of the Solina reservoir. Samples were collected 1–2 times a month (30 times). Nitrogen (nitrate, ammonium and total nitrogen) as well as phosphorus (phosphate and total phosphorus) were analyzed in every sample. Spectroquant® colorimetric standard test methods were used to determine the concentrations of some nutrients in sampled water (Merck Directory [5]). The flow rates (Q) at the inlets necessary for estimating the loads were calculated on the basis of water levels and Q. Discharge was monitored every day by personnel of dam. Annual loads of elements were calculated and expressed in kilogram per hectare.

4. RESULTS AND DISCUSSION

Statistical data for all tributaries of the reservoir obtained during the experimental period are shown in table 3. The mean values of total phosphorus loads for six tributaries were almost similar (0.2–0.6 kg ha^{-1} $year^{-1}$). Moreover, the values calculated are somewhat larger than expected values inherent in the catchment area of such a high percentage of forests and meadows. This phenomenon proves that there exist some point sources of phosphorus, especially households in environs of the Wołkowyjka stream estuarine and charcoal manufacture centers in a lower course of the Paniszczówka stream. The point sources of phosphorus have also been responsible for its load in the Daszówka stream. High values of both mean and maximal loads, respectively, 1.1 and 2.4 kg ha^{-1} $year^{-1}$ can be explained by the fact that the stream flows through two large, not sewered villages, where all domestic sewage has been discharged into the stream. Therefore, this part of the reservoir which is supplied with crude water from the Daszówka stream displayed most apparent eutrophication (KOSZELNIK et al. [4]).

Mean values of total nitrogen were lower or slightly higher (the San River) than 10 kg ha^{-1} $year^{-1}$ in most cases, reflecting the character of the catchment area (see table 1). A considerably higher loads (above 24 kg ha^{-1} $year^{-1}$) were found in the Daszówka and the Paniszczówka. Such a condition of the Daszówka is related to point sources of biogens. In the catchment of the Paniszczówka stream, above 65% of the area are occupied by pastures, meadows and idles. Because they are fertilized, the fertilizer losses might have a significant effect on nitrogen load which is higher in the the Paniszczówka (13.7 kg ha^{-1} $year^{-1}$) than in other streams.

Table 3 contains data referring to both the ammonium ($N–NH_4^+$) and the nitrate ($N–NO_3^-$) nitrogen. In the catchments of particular streams, either the point sources of $N–NH_4^+$ or the areal sources of $N–NO_3^-$ dominate. With the exception of the

Daszówka and the Paniszczówka characterized by the highest values of these nitrogen derivatives, the ammonium and nitrate concentrations in other tributaries were on similar levels, i.e. 0.5–0.8 kg $ha^{-1}year^{-1}$ and 1.8–4.8 kg $ha^{-1}year^{-1}$, respectively. Nevertheless, the loads were still huge and significantly higher compared to other Polish river basins where arable areas have the supremacy over other their types, which should be theoretically characterized by a large biogen run-off (RYBAK [7]). While considerable run-offs of $N–NO_3^-$ (11.2 kg ha^{-1} $year^{-1}$) and $N–NH_4^+$ (1.2 kg ha^{-1} $year^{-1}$) from the catchment area of the Daszówka stream and $N–NO_3^-$ (13.7 kg ha^{-1} $year^{-1}$) from the catchment area of the Paniszczówka stream were not unexpected taking account of the context previously described, the appreciable loads of ammonia from the Paniszczówka catchment (1.1 kg ha^{-1} $year^{-1}$) could be explained by an intensive pasturing during spring–autumn period of both years of investigation. Based on the results obtained it was found that biogens were exported from both terrestrial and point sources. There was not observed very good correlation between some forms of nitrogen and phosphorus and degree of land development. In the case of phosphorus, none of the Pearson correlation coefficients (R) was higher than 0.35. The correlations for nitrogen were slightly higher. As shown in figures 2 and 3, both nitrate and total nitrogen run-offs from meadows were most predictable with $R = 0.78$ and 0.72, respectively. The coefficients are statistically significant at $p < 0.05$. Nevertheless, in the case of forest, the statistics calculated were negative and insignificant, –0.57 (for $N–NO_3^-$) and –0.52 (for N_{tot}), at the probability mentioned. These values testify to the inversely proportional dependence. An increase in the proportion of forest in catchment area favours a decrease in nitrate and in consequence in total nitrogen loads. Taking account of the above, most of nitrate run-offs to the Solina reservoir water came from meadows.

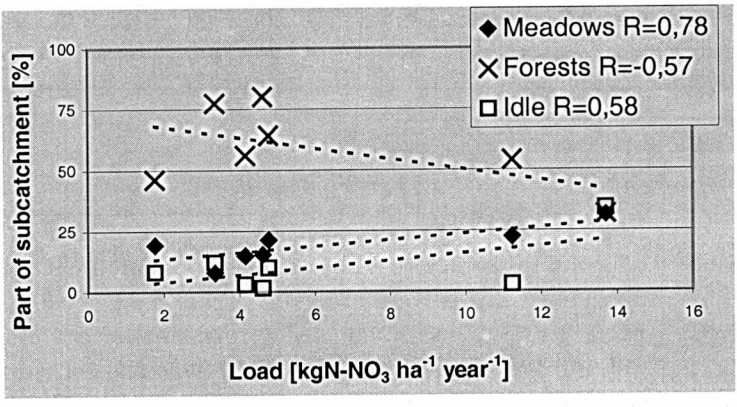

Fig. 2. Load of $N–NO_3^-$ versus the type of catchment

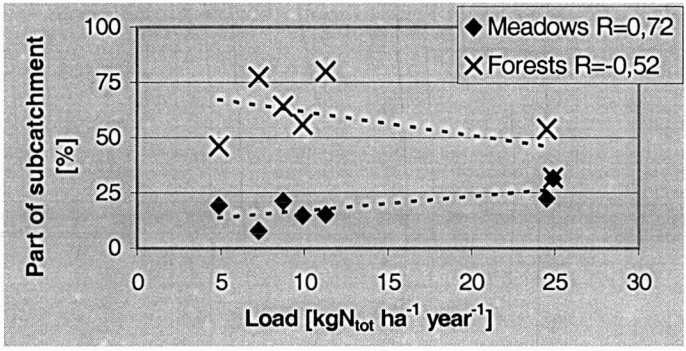

Fig. 3. Load of N_{tot} versus the type of catchment

Table 3

Mean, maximum and minimum values of nitrate, ammonia and total nitrogen and total phosphorus [kg ha^{-1} year^{-1}] in particular catchment areas of the Solina reservoir. SD – standard deviations at $n = 30$

River	Load	P_{tot}	$N\text{–}NO_3^-$	$N\text{–}NH_4^+$	N_{tot}	River	Load	P_{tot}	$N\text{–}NO_3^-$	$N\text{–}NH_4^+$	N_{tot}
The San	Mean	0.4	4.6	0.8	11.3	The Wołkowyjka	Mean	0.6	4.2	0.5	9.9
	Maximum	1.4	8.7	5.6	18.5		Maximum	2.2	8.7	2.2	17.9
	Minimum	0.1	2.0	0.1	5.2		Minimum	0.1	2.3	0.1	6.0
	SD	0.3	1.5	1.0	3.6		SD	0.5	1.6	0.4	3.1
The Solinka	Mean	0.3	3.4	0.7	7.2	The Paniszczówka	Mean	0.6	13.7	1.1	24.9
	Maximum	1.7	8.1	4.8	14.5		Maximum	1.7	33.7	6.7	61.3
	Minimum	0.04	1.6	0.1	2.6		Minimum	0.1	2.5	0.1	6.0
	SD	0.4	1.5	0.9	3.0		SD	0.4	8.2	1.3	12.9
The Czarny	Mean	0.2	4.8	0.5	8.7	The Bukowiecki	Mean	0.2	1.8	0.8	4.9
	Maximum	0.8	18.7	5.0	27.4		Maximum	0.7	4.4	2.5	13.1
	Minimum	0.03	1.3	0.1	2.3		Minimum	0.03	0.6	0.1	1.5
	SD	0.1	3.5	0.9	5.3		SD	0.2	0.9	0.6	2.6
The Daszówka	Mean	1.1	11.2	1.2	24.5						
	Maximum	2.4	33.7	5.1	52.8						
	Minimum	0.1	2.9	0.1	4.7						
	SD	0.7	6.4	1.0	12.2						

The variability of loads is characterized by standard deviation (SD, table 3). Very clear variations of phosphorus loads were observed during the period of experiments. SD ranges from 50% to 100% of mean value of loads. Smaller deviations were observed in the case of nitrogen indicators. Moreover, seasonal variations were not found which confirmed the thesis that beside seasonal areal factors also point, seasonally independent factors have an influence on loads exported from the catchments investigated.

5. SUMMARY

1. The mean loads of phosphorus in all catchments were similar and somewhat higher than these expected in the areas with high per cent of forests and meadows.

2. The mean loads of nitrogen represent a type of catchment with exception of the Daszówka and the Paniszczówka catchments, where the export of biogens was higher than that reported in literature. A significant proportion of point sources of biogens in the catchment is responsible for such a phenomenon.

3. High correlations between land development of a particular catchment and the load of elements tested were not found with the exception of the correlation between nitrate plus total nitrogen and the proportion of meadows in a given catchment. This confirms the thesis that the proportion of meadows in catchment and the load of N_{tot} and $N\text{–}NO_3^-$ are represented by a direct and proportional relationship.

4. The variabilities of the phosphorus loads exported from the catchments were considerably larger than these of nitrogen loads, but in both cases they were seasonally independent.

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UDZIAŁ RÓŻNYCH TYPÓW ZLEWNI W ZASILANIU ZBIORNIKA SOLIŃSKIEGO PIERWIASTKAMI BIOGENNYMI

Przedstawiono wyniki badań prowadzonych w latach 1999–2001 w ekosystemie Zbiornika Solińskiego. Oszacowano ładunki związków azotu i fosforu, jakie ze zlewni poszczególnych dopływów spływają do zbiornika. Stwierdzono, że ładunki zarówno azotu, jak i fosforu wynoszące odpowiednio

4,9–24,9 kg N ha^{-1} rok^{-1} oraz 0,2–1,1 kg P $ha^{-1}rok^{-1}$ były nieco wyższe, niż można się było spodziewać w zlewniach o dużej przewadze lasów. Najwyższymi ładunkami obydwu pierwiastków charakteryzował się potok Daszówka, co przypisano wpływowi punktowych źródeł zanieczyszczeń biogenami. Nie zaobserwowano wyraźnych korelacji między poszczególnymi rodzajami zlewni a analizowanymi ładunkami. Najlepiej skorelowany był ładunek $N–NO_3$ z udziałem łąk w całkowitej powierzchni zlewni [%] (R^2 = 0,78). Obserwowana zmienność ładunków obydwu pierwiastków nie miała charakteru sezonowego.