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RUN-OFF OF NUTRIENTS FROM RIVER WATERSHEDS USED FOR AGRICULTURAL PURPOSES

The paper synthetizes the results of investigations aimed at determining the influence of soil pollution on the quality of surface waters. Within 9-river watersheds, subject to investigations performed in two-year cycles, 21 partial catchment areas have been separated. The latter differed in the degree of agricultural use of land. Farming land covered from 18.6 to 100% of their areas, 11.2–91% of which were made up by arable land. The unit discharge loads of phosphorus and nitrogen and the relationship between these loads and the percentage of farming land in the watersheds have been determined.

1. INTRODUCTION

Nutrients transferred by rivers from farming lands to water basins are considered to be the one of the main factors intensifying the process of eutrophication. Hence, the papers concerned with this problem are more and more numerous. The so far undertaken investigations of this problem were chiefly intended to determine the magnitude of the nutrients discharged from watersheds used for agricultural purposes. From the available data it follows that the unit discharge loads varied within a wide range, even if the characteristics of the watersheds were similar (see tab. 1).

The transfer and transformation processes of nutrients in soil and water are influenced by so many and different factors, affected, in turn, by the given conditions that the construction of a generally binding mathematical model is much difficult or even impossible. Thus, forecasting the magnitude of agricultural non-point land

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Table 1

Unit discharge of nutrients from the catchment areas of different characteristics

Country	Characteristics of catchment area	Unit discharge, kg/ha·year		
		N	P	K
1	2	3	4	5
Poland	Piedmont	3.3–4.7	0.06–0.50	1.8–11.2
Poland, Szczecin Lowland [2]	55% of arable land, heavy soil	7.1–16.3	0.20–0.44	25.7–33.2
	48% of arable land, medium heavy soil	5.5–12.2	0.18–0.22	12.5–16.6
	30% of arable land, 50% of forest, light soil	3.9–6.0	0.09–0.18	9.1–15.8
Poland, rivers in Pommerania [18]	55–75% of arable land (light soil) 15–32% of forest	1.0–1.3	0.09–0.11	
Poland,	18–25% of arable land, 43–45% of forest	7.1–23.3	0.11–0.33	
mountain	1.4–3.2% of arable land, 30–75% of forest	16.6–23.6	0.27–0.44	
watersheds [7]	95% of forest	10.9–30.2	0.28–0.40	
USSR [12]	Drained fields	1.4–80	0.00–3	0.3–60
GDR [17]	Meadows	3.63	0.36	
	Forest–meadow watersheds	3.86	0.33	
	Coniferous forest	5.05	0.21	
	Muds	11.83	0.70	
	Pastures (170 kg NK/ha)	26.03	1.10	
FRG [14]	Agricultural watersheds	10.2–17.3	0.33–0.64	
	Forest watersheds	1.6–16.0	0.19–0.63	
FRG [1]	51% of arable land, 28% of forest	14.5–29.2	0.5–0.85	
	91% of forest	4.1–7.0	0.026–0.06	
Finland [9]	Agricultural watersheds	1.8–5.6	0.06–0.10	
	Undeveloped land	0.79–1.8	0.04–0.06	
The Netherlands [11]	Loamy soil, agricultural watershed (300 kg NPK/ha)	> 20	mean 0.065	
Denmark [3], [6]	Sandy soil, agricultural watershed (300 kg NPK/ha)	up to 50 13–15	0.35–1.0	
Switzerland [8]	Agricultural watershed	16–21	0.35–0.69	0.46–1.68
Switzerland [19]	Woodland	8.4	0.04	
	Unfertilized pastures (pre-Alpine land)	16.5	0.74	
	Fertilized meadows (pre-Alpine land)	19.4	1.02	
USA [13]	Intensely used agricultural land	over 80	over 2	
	Low developed agricultural land	0.59	0.023	
USA [19]	Woodland	1.43–3.57	0.26–1.07	

1	2	3	4	5
USA [5]	Woodland, volcanic bed-rock		0.026–1.07	
	Woodland, sedimentary bed-rock		0.067–0.145	
	Woodland + pastures, volcanic bed-rock		0.081–0.160	
	Woodland + pastures, sedimentary bed-rock		0.205–0.370	
	Agricultural–woodland, volcanic bed-rock		0.059–0.50	
	Agricultural land, sedimentary bed-rock		0.11–1.13	
USA [15]	Young moraine (rocks)		0.006	
	Old moraine		0.021	
	Sandstone		0.040	
	Old-diluvial regions (limestone leam)		0.077	
	Young-diluvial regions		0.036	

pollutions is based chiefly on regression models worked out for unit discharge loads of the pollutants.

The purpose of the study presented in this paper was to determine the unit loads of nutrients discharged from river watersheds characterized by different kind of their land use and differentiated geomorphological features, and to determine the nutrient losses by comparing the amounts of nutrients discharged from the watersheds with those introduced with fertilizers. Investigations, the results of which were used in the present paper, had been performed in the years 1977–79 in specialized sections of the Institute of Meteorology and Water Management in Gdańsk, Wrocław and Warsaw.

2. SCOPE AND METHODS OF INVESTIGATIONS

The study was carried out in 9-river watersheds within which 21 partial catchment areas had been separated. The selection of the watersheds was made according to the following criteria: differentiated degree of their agricultural use, distinctly defined area of each watershed, the lack of large basins along the investigated river segment and the lack of essential point pollution sources. The general location of watersheds is presented in fig. 1 and their characteristics are given in tabs. 2 and 3.

The investigations were performed in two full annual cycles. In water samples, taken every two weeks from the cross-sections closing the selected watersheds, the basic forms of nitrogen, phosphorus and potassium were determined. In cross-sections I, III-2 and IV-1 the samples were taken every day in order to determine the contents of phosphorus and nitrate nitrogen. Once a season full analyses were performed in order to characterize ionic composition and purity of water.

Fig. 1. General localization of the examined catchment areas

All the analyses were performed according to standard methods. Hydrological data were prepared by specialized units of the specific departments of the Institute. The data concerning the consumption of mineral fertilizers in communes, groups of villages or in cooperatives were obtained from the specialized regional institutions. The consumption of fertilizers within the watersheds was calculated proportionally to their areas, applying the factors determined by planimetry of maps. The amounts of nutrients contained in natural fertilizers discharged to the watershed were calculated by an indirect method, based on the data concerning the live stock population in the area investigated and on the commonly used conversion factors. Run-offs of nutrients transported by rivers from the watershed were determined from the relation between the magnitude of the carried instant loads and the accompanying flow magnitudes.

The annual load, according to which the magnitude of unit load of the given nutrient discharge was determined, was obtained from the known daily magnitudes of flows in the examined cross-sections. The above data and the equations describing the relations between the instant load of the examined pollutants and the magnitude of the flow were used for the reconstruction of the magnitudes of 24-hour loads. The sum of 24-hour loads computed for the annual cycle of investigations gave the magnitude of the annual load of the analysed substances.

Table 2

Geographical and physical features of the investigated catchment areas

River	Symbol of partial catchment area	Surface area km²	Geographical position	Altitude m	Dominant slope %	Dominant type of soil	Infiltration conditions
Wietcisa	I	236	Central Pommerania (Kaszuby and Starogard Lakeland)	155	5–7	Loamy soil, podsol, brown soil	good
Radunia	II-1	210	Central Pommerania (Kaszuby Lakeland)	200	5–7	Loamy sand, podsol, brown sand	good
	II-2	328					
	II-$R^*_{(1,2)}$	118					
Wda	III-1	940	Central Pommerania (Kaszuby Lakeland, Tuchola Forests)	120	3–4	Loamy sand, podsol	very good
	III-2	1386					
	III-$R^*_{(1,2)}$	446					
Pomorka	IV-1	4	Gniezno Lakeland	105	0.5–1	Strong loamy sand, brown sand, fera soil	moderate
	IV-2	72					
Eastern Noteć	V-1	189	Kujawy Lakeland	124	0.5–1	Strong loamy sand, pseudopodsol, black earth	moderate
	V-2	306					
Rogalin–Gopło Cannal	VI-1	28	Kujawy Lakeland	103	0.5–1	Black earth, podsol, pseudopodsol	moderately weak
	VI-2	59					
Water-course from Kuśnierz	VII-1	33	Kujawy Lakeland	103	0.2–1	Podsol, pseudopodsol, black earth	moderate
	VII-2	43					
Sucha	VIII-1	23	Central-Masovia Lowland	128	0.5	Black earth, brown soil	diversified, bad, diversified
	VIII-2	14					
	VIII-3	59					
Piaseczna	IX-1	3.3	West-Sudeten Piedmont (Kaczawa Piedmont)	255	1.4	Brown soil, podsol	bad
	IX-2	1.6		233	1.7		
	IX-3	4.5		270	2.2		
	IX-4	5.3		243	7.6		
	IX-5	11		235	3.1		

* $R_{(1,2)}$ — catchment area differential in relation to cross-sections 1 and 2.

Table 3

Land use in the investigated catchment areas

River	Symbol of catchment area	Percentage of surface area		Dominant crops	Average consumption of mineral fertilizers NPK kg/ha·year	Breeding head/km^2 of catchment area	
		Arable land	Forest			Stock	Swine
Wietcisa	I	70.6	17.2	Rye, potatoes	150	35	127
Radunia	II-1	71.0	14.0	Rye, potatoes	166	21	60
	II-2	64.7	23.4		147	12	35
	II-$R^*_{(1,2)}$	54.0	40.0		113	16	46
Wda	III-1	30.0	55.0	Rye, potatoes	40	13	29
	III-2	26.0	58.0		34	10	22
	III-$R^*_{(1,2)}$	18.6	68.6		20	6	13
Pomorka	IV-1	98.0	0	Wheat, economic plants	300	36	84
	IV-2	93.5	4.5		270	39	126
Eastern Noteć	V-1	80.4	10.5	Rye, wheat, barley, oat,	188	50	114
	V-2	81.0	11.1	economic plants, potatoes	193	50	98
Rogalin–Gopło	VI-1	95.9	0.9	Rye, wheat, barley,	230	77	65
Cannal	VI-2	95.2	1.4	oat, economic plants	250	115	105
Water-course	VII-1	83.2	13.1	Rye, wheat, barley,	240	62	162
from Kuśnierz	VII-2	84.8	11.5	oat, economic plants	220	61	154
Sucha	VIII-1	81.0	19.0	Rye, potatoes	93	60	90
	VIII-2	100.0	0		106	55	90
	VIII-3	79.0	3.0		97	63	91
Piaseczna	IX-1	64.5	33.9	Wheat, economic plants	270	0	0
	IX-2	91.1	5.0		270	0	0
	IX-3	82.3	6.4		270	154	0
	IX-4	74.5	23.0		270	0	0
	IX-5	77.7	13.9		270	150	98

* $R_{(1,2)}$ — catchment area differential in relation to cross-sections 1 and 2.

The relation between the load and flow was determined by the AREQ regression model [2] which is a modified variant of the RLQ model [1]. In this model, it has been assumed that the relation between the load and flow is described by the formula:

$$L = a + b \cdot Q^{c_{\max}} + \varepsilon$$

where ε describes the effect of casual factors, $c_{\max}$ is the value of the exponent (of the sequence of the given 15 exponents) for which the correlation coefficient takes the highest value, and simple regression coefficients a and b are determined by the least squares method.

For the loads forecasted in the above way the upper limit of confidence interval for the given level of significance $\alpha = 0.05$ can be calculated by a classical method, i.e., by adding the product of the appropriate quantile of Student's distribution and the root of variance.

Having known the values of everyday flows $x_1, \ldots, x_n$ and the relation between the load and flow determined from the formula given above, we calculate the total annual load

$$\mathrm{TAL} = g \sum_{m+1}^{M} L(x_m)$$

where $g = 0.0864$ (when TAL is expressed in tons and flow rate in m^3/s), and M is the number of days in the year. For the determined annual load the upper limit of confidence interval is determined for the confidence level $\alpha = 0.05$. The reliability of the obtained loads is proved by high values of the correlation coefficients for the separate regression lines; the values higher than 0.8 were found for 75% of the coefficients, the values of the remaining 25% being lower than 0.7. Since the flow in the River Radunia was artificially regulated and there was no correlation between the load of nutrients and the flow intensity, the annual load for this river was calculated from the mean instant loads. The correlation between the degree of land use and the run-off pollutants was analysed by determining the regression lines by means of the least squares method, according to the equation:

$$\log y = a \log x + \log b$$

where

y — value of unit discharge, kg/ha·year,
x — % of the catchment area used as arable land,
a, b — constants of the equation $y = bx^a$.

3. RESULTS AND DISCUSSION

Based on the results of psyhico-chemical analyses the investigated rivers should be classified among the clean and slightly polluted ones. The maximal values of the indices of pollution with nutrienes exceeded only sporadically the standards

Table 4

Pollution of rivers with nutrients

Catchment area		N total, mg/dm³			P total, mg/dm³			K, mg/dm³		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Wietcisa	I	0.39	4.69	0.82	0.065	0.157	0.112	1.0	3.6	1.9
Radunia	II-1	0.30	1.30	0.53	0.040	0.109	0.066	0.3	2.2	1.0
	II-2	0.30	1.57	0.58	0.052	0.286	0.076	0.3	2.5	1.2
Wda	III-1	0.24	1.45	0.56	0.060	0.164	0.111	0.2	2.5	0.9
	III-2	0.24	1.51	0.49	0.073	0.174	0.110	0.2	2.5	0.9
Pomorka	IV-1	0.50	16.29	7.09	0.022	0.336	0.083	0.6	9.8	2.9
	IV-2	0.47	18.67	5.61	0.078	0.608	0.202	3.6	33.0	11.6
Eastern Noteć	V-1	1.09	4.77	1.90	0.082	0.780	0.264	4.0	10.5	6.2
	V-2	0.98	3.13	1.90	0.053	0.887	0.180	3.5	10.2	5.5
Rogalin–Gopło Cannal	VI-1	3.71	14.91	7.57	0.320	7.000	1.679	5.3	21.5	10.7
	VI-2	1.38	20.73	9.07	0.299	5.733	1.712	7.1	33.5	15.9
Water-course from Kuśnierz	VII-1	1.42	6.52	3.38	0.129	1.907	0.458	5.5	19.5	9.6
	VII-2	1.28	8.06	3.12	0.120	1.013	0.300	3.4	14.5	8.6
Sucha	VIII-1	0.80	11.4	3.10	0.210	1.540	0.070	1.0	5.3	1.9
	VIII-2	0.65	12.57	4.93	0.050	2.600	0.130	0.5	3.6	1.9
	VIII-3	0.36	18.27	3.61	0.020	2.110	0.100	0.4	4.0	2.2
Piaseczna	IX-1	1.01	7.04	3.24	0.013	0.253	0.104	0.4	11.1	2.6
	IX-2	1.18	7.47	3.79	0.025	0.267	0.093	0.8	7.5	2.5
	IX-3	2.85	14.68	8.37	0.127	1.667	0.711	1.7	51.7	21.4
	IX-4	0.92	12.34	4.21	0.036	0.224	0.108	0.9	31.5	9.3
	IX-5	3.23	14.26	7.01	0.120	1.100	0.450	6.7	41.1	17.8

binding in Poland for I and sometimes II classes of cleaness (BOD_5 up to 10.4 mg O_2/dm^3, permanganate COD up to 29 mg O_2/dm^3, and dichromate COD up to 90.0 mg O_2/dm^3). In the majority of the investigated cross-sections, mean values of these indices were contained within the standards for the class I. The waters of the Rivers Wietcisa and Radunia were particularly clean; the highest values of the said indices still qualified these rivers to the class I. The water of all the investigated rivers was highly saturated with oxygen; the mean value of the dissolved oxygen ranged from 8.6 to 11.6 mg O_2/dm^3. The loads of nutrients differentiated substiantially both in the separate cross-sections and time. Total nitrogen concentrations in two-year cycle of investigations varied within a very broad range, i.e., from 0.24 to 20.37 mg/dm³, those of total phosphorus from 0.013 to 7.00 mg/dm³ and of potassium from 0.2 to 32.0 mg/dm³ (tab. 4).

While comparing the compositions of water in the successive one-year cycles it may be seen that in most cross-sections the mean concentrations of ammonium and

Table 5

Unit discharge of nutrients and water run-off from the investigated catchment area

River	Symboi of partial catchment area	Year 1977/78							Year 1978/79						
		Run-off m^3/ha·year	Unit discharge coefficient, kg/ha·year						Run-off m^3/ha·year	Unit discharge coefficient kg/ha·year					
			$P_{tot.}$	$P-PO_4$	$N-NO_3$	$N-NH_4$	$N_{tot.}$	K		$P_{tot.}$	$P-PO_4$	$N-NO_3$	$N-NH_4$	$N_{tot.}$	K
Wietcisa	I	1890	0.20	0.11	0.34	0.54	1.19	3.14	2234	0.21	0.16	1.02	1.36	2.63	6.44
Radunia	II-1	3877	0.26	0.13	0.37	0.59	2.07	1.85	4092	0.25	0.16	0.58	0.72	1.85	6.73
	II-2	3274	0.25	0.14	0.49	0.61	1.93	1.95	3527	0.27	0.18	0.66	0.77	1.91	6.26
	II-R	2200	0.23	0.15	0.69	0.65	1.63	2.12	2502	0.31	0.20	0.80	0.87	2.10	5.44
Wda	III-1	1777	0.17	0.14	0.20	0.41	0.94	2.16	1615	0.16	0.13	0.26	0.44	0.91	2.15
	III-2	1825	0.18	0.14	0.17	0.40	0.89	2.37	1670	0.16	0.13	0.23	0.38	0.82	2.21
	III-R	1952	0.23	0.13	0.06	0.33	0.48	2.78	1800	0.20	0.15	0.06	0.38	0.55	2.50
Pomorka	IV-1	1168	0.10	0.07	19.52	0.26	20.18	4.65	3554	0.85	0.69	49.68	1.81	52.15	13.93
	IV-2	682	0.09	0.06	4.84	0.29	5.42	081	1530	0.43	0.33	13.63	1.44	15.48	11.21
Eastern Noteć	V-1	950	0.15	0.05	0.33	0.12	1.71	5.41	1540	0.13	0.08	0.45	0.13	1.68	9.66
	V-2	1000	0.13	0.04	0.44	0.19	2.01	5.66	1460	0.09	0.06	0.62	0.23	1.71	9.19
Rogalin–Gopło Cannal	VI-1	920	0.77	0.41	4.44	0.40	6.04	8.38	1300	0.71	0.49	5.59	0.39	6.93	11.30
	VI-2	899	0.85	0.39	6.23	0.58	7.83	10.73	1382	0.85	0.51	7.61	0.70	9.32	11.61
Water-course from Kuśnierz	VII-1	903	0.24	0.14	1.71	0.16	3.05	8.40	1240	0.25	0.18	2.16	0.24	3.30	10.43
	VII-2	910	0.23	0.11	1.74	0.12	3.01	8.49	1250	0.23	0.15	1.64	0.15	2.99	10.79
Sucha	VIII-1	2937	0.09	0.05	0.46	0.22	1.01	0.62	2988	0.04	0.01	0.57	0.18	1.05	0.63
	VIII-2	3187	0.17	0.08	1.18	0.14	1.67	0.67	3000	0.07	0.04	1.30	0.11	1.66	0.77
	VIII-3	2364	0.11	0.05	0.50	0.15	0.97	0.51	2320	0.05	0.02	0.57	0.13	0.95	0.57
Piaseczna	IX-1	660	0.06	0.02	1.96	0.19	2.64	1.67	810	0.07	0.02	2.44	0.21	3.16	1.89
	IX-2	3800	0.24	0.09	13.28	0.90	16.73	10.33	4480	0.28	0.10	14.70	0.93	18.41	11.07
	IX-3	1270	0.67	0.41	6.93	2.71	11.39	24.90	1450	0.76	0.47	7.72	2.92	12.68	26.33
	IX-4	1700	0.16	0.08	5.52	0.36	7.20	16.58	2000	0.18	0.09	6.15	0.40	7.99	21.90
	IX-5	1380	0.42	0.20	6.59	0.76	9.00	18.92	1540	0.44	0.21	6.94	0.77	9.42	19.10

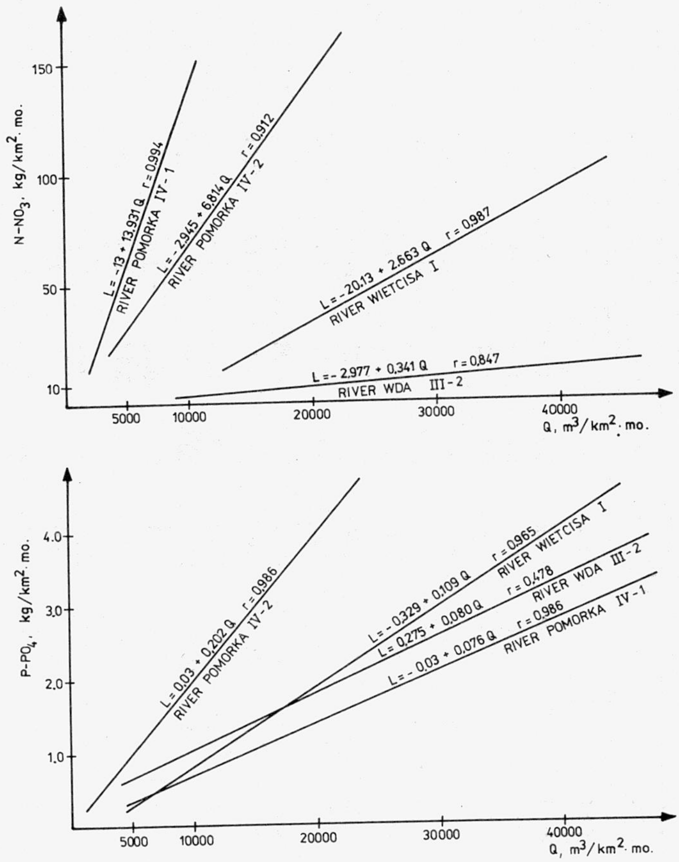

Fig. 2. Monthly discharges of N–NO_3 and P–PO_4 versus water outflow from the catchment areas

organic nitrogen, phosphorus compounds and the values of indices characterizing the contents of organic compounds were higher in the second year of investigations. This can probably be related to the more intense process of soil erosion caused by thawing of exceptionally thick snow cover in March 1979.

Intensity of washing down the pollutants from catchment area is closely related to its hydrological conditions. As it follows from the data presented in tab. 5, the amounts of nutrients discharged from the given catchment areas depended on the amount of water run-off. In most cases this dependence was directly proportional. This regularity is illustrated in fig. 2 which represents regression lines for the monthly unit discharges of nitrate nitrogen and phosphate phosphorus versus water run-off determined for the Rivers Wietcisa, Wda and Pomorka. Based on the above results it has been stated that, e.g., in March 1979 (characterized by an intense thawing) water run-off from the watershed IV-1 was 2.3 times greater than during all the remaining

Table 6

Annual losses of phosphorus and nitrogen in the run-off with respect to the amounts of organic and inorganic fertilizers introduced into catchment area

River	Symbol of catchment area	1977–78		1978–79	
		$P_{tot.}$	$N_{tot.}$	$P_{tot.}$	$N_{tot.}$
		%			
Wietcisa	I	0.70	1.30	0.70	1.83
Radunia	II-1	0.98	2.68	0.96	2.38
	II-2	1.16	3.11	1.28	3.09
Wda	III-1	2.48	4.49	2.35	4.36
	III-2	3.36	5.78	3.06	5.52
Pomorka	IV-1	0.20	14.27	2.02	38.95
	IV-2	0.19	3.85	1.04	11.67
Eastern Noteć	V-1	0.53	1.45	0.45	1.95
	V-2	0.46	1.77	0.33	2.23
Rogalin–Gopło Cannal	VI-1	1.97	4.17	1.82	5.14
	VI-2	2.26	5.43	2.25	6.69
Water-course from Kuśnierz	VII-1	0.58	1.43	0.61	2.63
	VII-2	0.56	2.01	0.56	2.17
Sucha	VIII-1	0.44	1.09	0.18	1.12
	VIII-2	0.69	1.54	0.26	1.45
	VIII-3	0.53	1.06	0.23	1.02
Piaseczna	IX-1	0.26	2.69	0.32	3.28
	IX-2	1.19	4.17	1.26	4.60
	IX-3	2.08	6.32	2.37	6.77
	IX-4	0.70	7.44	0.76	8.25
	IX-5	2.00	4.16	2.09	4.37

months of the investigated period 1978/79. The load of nitrate nitrogen and that of phosphate phosphorus were respectively 2.3 and 2.8 times higher than those discharged during the rest of the year. The unit discharge of all the components higher, as a rule, in the second year was related with a higher water run-off during spring thaw.

Nitrogen and phosphorus losses with respect to their amounts used in fertilizers ranged within 1.02–38.95% and 0.19–3.36%, respectively (tab. 6). The highest nitrogen losses have been stated in intensely fertilized watershed: Pomorka, Rogalin–Gopło Cannal and Piaseczna (tab. 3) where the concentrations of nitrate nitrogen reached periodically very high values. The average percentage of phosphorus lost with the run-off was ten times smaller. It should be noticed that high

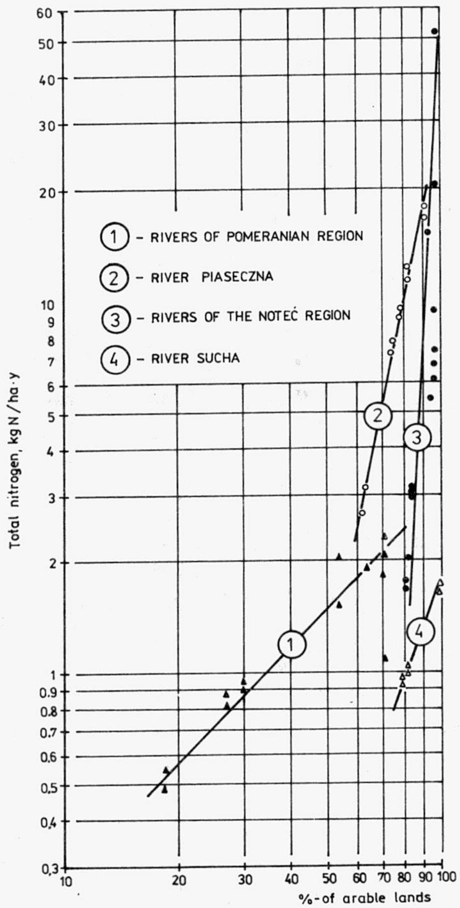

Fig. 3. Percentage of arable land versus unit loads of total nitrogen discharged from the catchment areas

losses of this component took place both in catchment areas of typical land use (Rogalin–Gopło Cannal and Piaseczna) and in that grown with forest (the River Wda). It seems that in the latter catchment area, because of inadequate amount of fertilizers, the nutrients introduced with precipitation played a more important role. The stated values of losses do not exceed the estimated ones assumed for Europe.

While analysing the influence of the degree of land use of the catchment area on the amount of pollutants washed out in hydrological cycle, we have checked the dependence of the unit load and the average annual concentration of nutrients in the examined river cross-sections on the percentage of arable lands in catchment area and the amount of nutrients introduced into the catchment area with organic and mineral fertilizers. The highest correlation has been found for the unit run-offs of nitrate and total nitrogen, but solely in catchment area having similar physiographic

Table 7

Regression equations and correlation coefficients for the relationships between the percentage of arable land and unit discharge of nutrients found for various types of catchment areas

Constituent	Catchment area	Regression equation	Correlation coefficient R
Total nitrogen	Central Pomerania	$\log y = 0.74 \log x - 1.12$	0.921
	Noteć Region	$\log y = 11.05 \log x - 20.80$	0.871
	Sucha River	$\log y = 2.22 \log x - 4.22$	0.972
	Piaseczna River	$\log y = 5.10 \log x - 8.72$	0.989
Total phosphorus	Central Pomerania	$\log y = 0.35 \log x - 1.14$	0.774
	Noteć Region	$\log y = 3.59 \log x - 7.55$	0.320
	Sucha River	$\log y = 2.08 \log x - 4.12$	0.470
	Piaseczna River	$\log y = 6.60 \log x - 13.00$	0.904
Potassium	Central Pomerania	$\log y = 0.59 \log x - 0.51$	0.522
	Noteć Region	$\log y = 0.81 \log x - 0.63$	0.185
	Sucha River	$\log y = 0.96 \log x - 1.07$	0.787
	Piaseczna River	$\log y = 4.54 \log x - 7.53$	0.540

y — unit discharge, kg/ha·year.
x — percentage of arable land in catchment area.

characteristics. The correlations for phosphorus and potassium compounds were slightly lower. Figure 3 shows regression lines for total nitrogen in the system: unit run-off of nitrogen versus percentage of arable land.

From the whole system of data-points it is possible to isolate the values corresponding to the groups of catchment areas localized in the same physiographic region of Poland. So, separate lines of regression have been obtained for the Central Pommerania, the region of the Rivers Noteć, Sucha and Piaseczna.

Equations of regression and coefficients of correlation for the above function (fig. 3) are given in tab. 7. The adequacy of these equations in the case of nitrogen components is very distinctly seen (coefficient of correlation ranged within 0.828–0.978). For total phosphorus the values of correlation coefficient varied between 0.320 and 0.904. The lowest values were stated for potassium, as they ranged from 0.185 to 0.787.

The analysis of the values of regression coefficients, performed for the separated groups of catchment areas, shows that the rivers of Central Pommerania and the River Sucha differ from the remaining ones: the slopes of their regression lines are smaller, hence the absolute value of the run-off of the nutrients and the increment of loads with the increasing percentage of arable lands are smaller.

Multidirectional effect of factors deciding upon the volume of nutrients run-off in rivers makes it, however, impossible to find a correlation between the shape of the function and physiographic characteristic of the catchment area. Thus, the obtained relationship may only be used for predicting the loads of nutrients depending on the degree of land use of a catchment area having a similar physiographic character. In other catchment areas, the parameters of the equation must be determined experimentally.

4. CONCLUSIONS

In view of the performed studies and experiments the following conclusions may be formulated:

1. A positive correlation for the examined catchment area has been stated between the percentage of arable land or the amount of nutrients introduced with fertilizers and their unit run-off. This correlation is described by the equation:

$$y = bx^a$$

where the values of its constants differ for catchment areas of different morphometric parameters, soils and subsoils, the way of land use as well as some individual features.

2. Unit indices of nutrients run-off, determined in the present paper, may be used as a basis in forecasting the quality of water in catchment areas characterized by similar parameters. In particular, they may be used while laying out a balance of nutrients flowing into lakes, the existing and newly designed water reservoirs, since technological concepts of the protection of water against the eutrophication intensified by the activity of man are based on such a balance.

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ODPŁYW SUBSTANCJI BIOGENNYCH Z ROLNICZYCH ZLEWNI RZECZNYCH

Badano wpływ zanieczyszczeń obszarowych na jakość wód powierzchniowych w dziewięciu zlewniach rzecznych, w których wyodrębniono dwadzieścia jeden zlewni cząstkowych o różnym stopniu rolniczego wykorzystania (18,6–100% użytków rolnych, w tym 11,2–91,5% gruntów ornych). Badania prowadzono w dwuletnim cyklu. Wyznaczono wskaźniki jednostkowego odpływu substancji biogennych oraz określono zależność pomiędzy procentowym udziałem użytków rolnych w zlewni a wielkością wskaźników jednostkowego odpływu tych substancji.

ОТХОД БИОГЕННЫХ ВЕЩЕСТВ ИЗ ХОЗЯЙСТВЕННЫХ РЕЧНЫХ ВОДОЗАБОРНЫХ БАССЕЙНОВ

Работа является синтезом результатов влияний территориальных загрязнений на качество поверхностных вод. Испытания охватили 9 речных водозаборных бассейнов с разной степенью хозяйственного использования (18,6–100%) сельскохозяйственных угодьев, в том числе 11,2–91,5% пахотной земли). Испытания охватили двухлетний цикл. Назначены показатели единичного отхода биогенных веществ и определена зависимость между процентным участком сельскохозяйственных угодьев в водозаборном бассейне и величиной показателей единичного отхода этих веществ.