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HYDROCHEMICAL FLOOD FLOW OF THE VISTULA – AUGUST 2001

Abstract

Intense rain in the southern part of the Vistula's watershed in July 2001 resulted in floods in many places and in flood water flows on the Vistula and its tributaries. The culmination of the flood reached the Gulf of Gdańsk in the night of 5th August 2001. In the period 4th to 6th August, 10 samples of water were taken, and the content of biogenic substances and of other components in these samples was determined. Basing on water flow measurements and on the content of the investigated components, the loads were calculated and compared with mean multi-annual loads for the period 1984-1998. It was found that the mean biogen load, related to water flow, was exceeded many times. Also the relationships between the analysed components, water flow and variability during the period of investigations were determined. Obtained results show that there may be a very significant influence of biogens on the condition of the environment and on the dynamics of biocenotic processes of the Gulf of Gdańsk in the period before and after the propagation of flood waters of the Vistula.

Introduction

Chemical investigations of the content and loads of biogenic substances, flowing with the Vistula waters, started at the beginning of the sixties [7, 10]. During the next decades, investigations of the chemistry of Vistula waters were continued, and extended to contaminating substances [1, 2, 4, 6, 16]. Also the influence of the Vistula waters and of its components on the environment of the Gulf of Gdańsk and the Gdańsk Basin was evaluated [13, 17]. However, this problem has not been finally defined, and requires comprehensive investigations.

Also flow of the organic matter and of products of its degradation [12] and the characteristics of flow into the Gulf of Gdańsk of contaminants carried by the Vistula [14, 15] were investigated. Hydrochemical monitoring of the Vistula, carried out since 1976, forms the basic and most complete material for investigations and comparisons [4]. These data allow to carry out comprehensive analyses of trends and relationships of input of chemical components and of Vistula waters in the hydro-meteorological and anthropogenic pressure aspects and from the point of view of their influence on the dynamics of environmental and biocenotic processes proceeding in the Gulf.

Table 1. Loads of biogenic substances supplied by the Vistula in the period 1984-1998 [4]

Year	Flow $[m^3s^{-1}]$	COD $[tO_2y^{-1}]$	N-NH_4	N-NO_2	N-NO_3	ΣN_{inorg}	N_{tot}	P-PO_4	P_{tot}
			$[t\ y^{-1}]$						
1984	829	672883	17314	575	45317	63206	-	3348	5447
1985	1060	917098	20125	750	59518	80393	-	4311	6834
1986	960	938511	17256	877	50558	68691	114437	3965	6599
1987	987	924131	23344	1027	69411	93782	130418	4544	6598
1988	-	1004357	24301	-	72488	96789	129339	4694	6929
1989	-	841775	21466	-	27641	49107	79570	2289	4677
1990	774	751793	16353	536	17330	34219	53943	3661	5125
1991	822	684356	15553	622	37069	53244	74397	3629	5443
1992	843	679764	16443	503	50656	67602	88847	3987	5569
1993	841	727031	13372	-	55509	68881	89203	4062	6509
1994	1024	863004	10670	481	79599	90749	130776	3486	5982
1995	1043	783151	7639	563	65618	73821	112796	4428	7321
1996	1128	831158	12486	649	60613	73748	162417	4022	5572
1997	1178	1066048	6535	751	53650	61027	119790	5461	7636
1998	1379	1186546	8597	752	90795	100147	148363	6671	8988
mean	989	858107	14999	673	55718	71693	110330	4170	6348
± SD	173	150766	5488	163	19236	18611	31331	991	1120

In the present work were used results of investigations of biogenic substances supplied by the Vistula to the Gulf of Gdańsk in the years 1984-1998 (Table 1). For each of the components, mean multi-annual values were calculated. These were compared with the supply of biogen loads during the culmination of the flood in August 2001. The listed data will not be analysed. However, one should note the relationship between the magnitude of chemical flow and water flow, as well as the maintaining high level of general phosphorus loads during the whole multi-annual period. Because of this the Vistula is the most significant source of this element in the whole Baltic Sea basin.

During a calendar year there are two maximums of Vistula flows – the melt water flow (March-April) and flood-water (July-August). At these times, the loads of most of the chemical substances supplied by the Vistula increases with water flow. The periods of maximum biogen supply coincide with or are slightly earlier than the periods of Spring and Autumn phytoplankton blooming [12]. This points to the role of the Vistula in shaping the biocenotic processes in the Gulf of Gdańsk. To date there are no detailed investigations of the composition of the chemical substance load supplied to the Gulf by the Vistula floods. The only exception are the investigations of the influence of biogens on the Gulf environment in the area of river water propagation, carried out after the passage of flood culmination in July 1997 [3].

The chemical monitoring of the Vistula, which is carried out since many years both on a systematic basis as well as during floods, allows to evaluate the environmental, infrastructural, technological and urban changes proceeding in the Vistula watershed. The analysis of contaminant input from point and non-point sources is a very important element in the progress of work on the protection of the environment of Poland's surface waters. Below a quantitative evaluation of biogen input into the Gulf of Gdańsk during the culmination of Vistula flood waters is presented. Also the possible environmental and biocenotic reaction to this input, stimulating the primary and biological production of the Gulf, is discussed.

Data and methods

Water samples for chemical analysis were taken at the outlet of the Vistula Cut from 10 a.m. August 4th until 4 p.m. August 6th 2001. Ten samples were taken, and these were analysed at the laboratory of the Department of Environment Protection of the Maritime Institute. The contents of ammonia, nitrite, nitrate and total nitrogen, phosphate and total phosphorus, COD, pH and chloride content were determined in accordance with the requirements of Polish Standards. Vistula flow data for the period August 2nd to 9th were obtained from the Wrocław branch of the Institute of Meteorology and Water Management (IMWM).

Results

Results of the analyses, including the average values of concentration (Table 2) were used for calculating the 1-second and 24-hour loads and also the total load of each analysed substance.

FLOW. Vistula flow was measured by the IMWM at the Kiezmark profile (15 km above the outlet). In the period 2-9 August, maximum flow occurred on 4th and 5th August (Fig. 1). In comparison with the long-term mean (1010 m^3s^{-1}), the average flow during that period was over 5 times larger (5335 m^3s^{-1}).

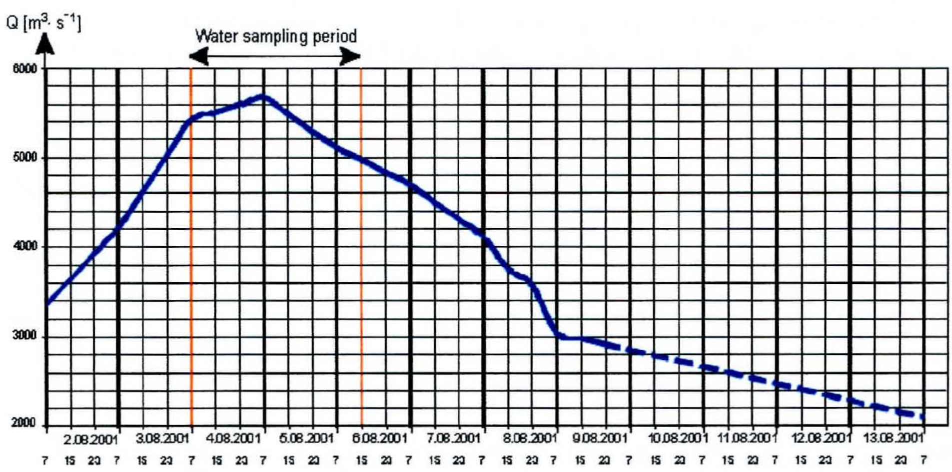

Fig. 1. Flow at the Kiezmark profile, August 2nd to 9th (14th) 2001 (IMWM data)

The values of flow at the times of sampling were taken from the flow curve. This allowed to calculate the load of substances discharged into the Gulf by the Vistula. In 1997, the propagation of flood waters into the Gulf of Gdańsk in the area of the hydrologic front [9]. However, it was not determined at what value of flow the observed phenomena occurred [3].

Discharged by the Vistula biogen loads depend directly on the size of the flow, and the variation of concentrations is rather small and connected mainly with the increase of area flow.

BIOGENIC SUBSTANCES. The average COD content – 40.3 mgO_2dm^{-3} – was high, but did not exceed the maximum values observed in the period 1984-1998. At average flow 5.4 thous. m^3s^{-1}, the COD load during 54 hours was 54.5 thous. tO_2. The period of observations represents only 1/162 part of the year, but during that time the Vistula discharged into the Gulf of Gdańsk 6.3% of the mean annual load of COD (Tables 2 to 4). This COD load could significantly increase the concentration of matter in water, decrease water transparency and change the optical spectrum of Gulf waters in the whole area of propagation of the river waters. More distinct changes of the properties of sea water were observed in the area of mixing of the waters, i.e. in the belt of the hydrologic front. The supplied hard and soft organic matter could also disrupt the oxygen balance in the whole water layer, especially in the near-bottom zone. The organic matter could result in locally intense, in spite of the relatively low temperature of the water, development of the marine nanoplankton. It could also accelerate phytoplankton blooming and increase the primary and biological production of the southern part of the Gulf of Gdańsk, close to the Vistula mouth. This set of biological processes, occurring before the autumn phytoplankton blooming, could have weakened its intensity by removing the excess of biogenic substances, mainly phosphorus, from the water.

It is also possible that the additional large biogen loads, discharged into the Gulf before the autumn blooming, could have increased its intensity and magnitude. The reach and influence of the Vistula waters in the Gulf of Gdańsk depend to a large extent on wind circulation, which shapes the frontal surfaces, and therefore the areas of direct influence on the Gulf's environment. These processes were investigated in the Gulf of Gdańsk area several days after the culmination of the flood, and it is hoped that obtained data will supplement the present paper.

COMPOUNDS OF NITROGEN. The loads of inorganic and total nitrogen depended on flow and decreased after the culmination of the flood (Tables 2-4). This concerned all the investigated compounds of nitrogen and phosphorus, and with one exception their concentrations did differ significantly from concentrations recorded in the period 1984-1998. Only concentrations of nitrites were distinctly higher, especially during the first stage of floodwater flow. The 1-second and 24-hour loads of nitrogen compounds decreased with the decrease of flow and nitrogen compound content in water. In the period of investigations, the nitrogen compound loads varied between 1.4% ($N\text{-}NH_4$) and 3.3% (N_{tot}), in relation to the mean annual loads. Only the nitrite nitrogen load was much higher, it was equal to 27.7% of the mean annual load for the period 1984-1998. This last value indicates that large amounts of sewage matter were present in the floodwater, and that the period of retention river water was rather short. Inorganic nitrogen constituted 47.2% of total nitrogen, which is a typical value for the Vistula.

PHOSPHORUS COMPOUNDS. Concentrations of inorganic and total phosphorus decreased during the investigations with decreasing flow and were similar to the values observed in the period 1984-1998 (Tables 2-4). The second and 24-hour loads were much higher than during the 15-year period because the flow was 5 times larger. During the 15-year period, the loads of phosphorus from point sources systematically decreased (development of sewage treatment plants), however supply from non-point sources was very variable and depended on the magnitude of flow.

Table 2. Results of analysis of water samples from the Vistula Cut mouth, August 4-6, 2001

Date of sampling	t	pH	N_{tot}	N-NH_4	N-NO_2	N-NO_3	ΣN_{inorg}	PO_4	P-PO_4	P_{tot}	N_{inorg}: P-PO_4	$N_{tot} : P_{tot}$	COD	S	Flow
	[hour]		[mg·dm^{-3}]								[n:1]		[mg·dm^{-3}]	psu	[m^3·s^{-1}]
04.08.01	1	7.07	2.80	0.16	0.173	0.96	1.293	0.34	0.111	0.25	26.40	25.60	32.20	0.294	5475.0
	7	7.01	5.40	0.50	0.310	1.10	1.910	0.44	0.144	0.21	30.30	59.30	39.60	0.289	5515.0
	13	7.07	1.80	0.20	0.069	1.14	1.409	0.38	0.124	0.32	26.00	12.70	37.10	0.798	5600.0
05.08.01	19	7.22	2.80	0.13	0.155	1.06	1.345	0.24	0.078	0.33	39.40	19.40	49.50	0.798	5650.0
	25	7.35	3.20	0.10	0.090	0.96	1.150	0.38	0.124	0.20	21.20	36.30	56.90	1.004	5620.0
	31	7.37	2.60	0.20	0.151	0.80	1.151	0.42	0.137	0.18	19.20	32.00	42.10	0.276	5450.0
	37	7.48	1.40	0.06	0.111	0.84	1.011	0.40	0.130	0.20	17.80	15.60	49.50	0.446	5300.0
06.08.01	43	7.49	1.80	0.07	0.118	0.84	1.028	0.22	0.072	0.16	62.60	25.20	24.70	0.439	5315.0
	49	7.40	1.40	0.10	0.077	0.80	0.977	0.22	0.072	0.15	31.00	21.30	29.70	1.734	4975.0
	55	7.48	2.20	0.02	0.082	0.64	0.742	0.20	0.065	0.16	26.10	32.10	42.10	0.533	4625.0
Mean		7.29	2.54	0.15	0.130	0.91	1.200	0.32	0.110	0.22	30.00	27.95	40.34	0.660	5335.5
±SD		0.19	1.18	0.14	0.070	0.16	0.320	0.09	0.030	0.06	13.08	13.34	9.91	0.450	332.2

Table 3. Mean content of biogenic substances in Vistula water, August 4-6 2001

Date	Q	N-NH$_4$	N-NO$_2$	N-NO$_3$	Σ N$_{inorg}$	N$_{tot}$	P-PO$_4$	P$_{tot}$	COD
	[m^{3}s^{-1}]	[mgdm^{-3}]							
04.08	5505.0	0.28	0.183	1.06	1.534	3.33	0.1260	0.260	36.30
05.08	5488.0	0.12	0.127	0.91	1.157	2.85	0.1170	0.231	49.50
06.08	4975.0	0.06	0.092	0.85	1.002	1.80	0.0697	0.157	32.16
Mean ±SD	5385.5 386.2	0.15 0.14	0.130 0.070	0.91 0.16	1.200 0.320	2.54 0.03	0.1100 0.0300	0.217 0.064	40.34 9.91

Table 4. Biogen loads discharged by the Vistula in the period August 4-6 2001

Date	N-NH$_4$		N-NO$_2$		N-NO$_3$		N$_{inorg}$		N$_{tot}$		P-PO$_4$		P$_{tot}$		COD	
	[kgs^{-1}]	[td^{-1}]	[kgs^{-1}]	[td^{-1}]	[kgs^{-1}]	[td^{-1}]	[kgs^{-1}]	[td^{-1}]	[kgs^{-1}]	[td^{-1}]	[kgs^{-1}]	[td^{-1}]	[kgs^{-1}]	[td^{-1}]	[kgs^{-1}]	[td^{-1}]
04.08	1.54	133.1	1.00	87.0	5.83	504.1	8.44	729.5	18.33	1583.8	0.69	59.8	1.43	123.6	199.83	17265.4
05.08	0.65	56.8	0.69	60.2	4.99	431.5	5.34	548.5	15.64	1351.3	0.64	55.5	1.26	109.5	271.65	23471.0
06.08.	0.29	25.7	0.45	39.5	4.22	365.3	4.97	429.8	8.95	773.7	0.34	29.9	0.78	67.5	150.99	13923.6
Total	-	215.6	-	186.7	-	1300.9	-	1707.8	-	3708.8	-	145.2	-	300.6	-	54560.0

Table 5. Comparison of biogen substance loads discharged by the Vistula in the period August 4-6 2001 with the mean annual loads for the period 1984-1998

Investigated substances	Mean annual loads for the period 1984-1998 [thous. t/year]	Floodwater load in the period August 4-6 2001		
		[t/54h]	percentage of annual load for 1984-1998	multiplication factor
N_{tot}	110.30	3708.8	3.3	5.4
$N\text{-}NH_4$	14.90	215.6	1.4	2.2
$N\text{-}NO_2$	0.67	186.7	27.7	45.1
$N\text{-}NO_3$	55.70	1300.9	2.3	3.8
N_{inorg}	71.70	1707.8	2.3	3.8
$P\text{-}PO_4$	4.17	145.2	3.4	5.6
P_{tot}	6.34	300.6	4.7	7.6
COD	858.00	54560.0	6.3	10.3
Q [m^3/s]	989.00	5335.0	-	5.4

– substances subject to increased leaching by floodwater

During the investigated period, the non-point phosphorus load was distinctly prevalent, and it was limited by the solubility of its compounds. The inorganic phosphorus load constituted 48.8% of the total phosphorus load, which is very close to the percentage of inorganic phosphorus in the total load of this element. At the same time the inorganic phosphorus load was equal to about 8.5% of the inorganic nitrogen load, and the total phosphorus load – to about 8.1% of the total nitrogen load. During the period of investigations, the phosphorus loads constituted 3.4% ($P\text{-}PO_4$) and 4.7% (P_{tot}) of the mean annual loads for the 1984-1998 period, and they were higher than the percentage of nitrogen compounds in the load.

MOLAR RATIOS. During the period of investigations, the nitrogen to phosphorus (inorganic forms) molal ratio was 30:1 and for total forms 28:1. Since the accepted so-called optimum molal ratio is 15:1, this points to an excessive supply of nitrogen during the floodwater. This is a very important balancing factor in face of the intense denitrification proceeding in the surface bottom sediments, which is strongly reducing the content of nitrogen salts in the Gulf's environment. This process determines the development of phytoplankton nondependent on nitrogen, which assimilate gas nitrogen. However, during the floodwater the molal ratios N:P were significantly lower than during average flows. This may be due to a shallow penetration of waters into the soil and their quick flow out of flooded areas.

ACIDITY (pH). During the investigations, acidity of river water decreased with decreasing flow from 7.07 at the beginning of the culmination to 7.45 (Table 2). It is supposed that since acid soil compounds are much more soluble, they are the first to be washed out from the soil and discharged into the sea.

Metabolism, mineralisation or decomposition of organic matter increase concentration in water of easily soluble acid compounds removed from the soil and its surface. After being removed from the soil surface by floodwater, other groups of organic compounds – neutral and basic – become dissolved in the water in effect reducing its acidity.

SALINITY. During the investigations the average content of chlorides was 368 $mgdm^{-3}$, and their amount increased with decreasing flow from 266 to 413 $mgdm^{-3}$ (Table 2). Because of the typical concentrations of the other investigated components, the influence of seawater on salinity should be excluded. Except one value, salinity was below 1 psu, and reflects the flow of chlorides from urban areas, roads and agricultural land, supplemented by chlorides from mine waters. In the period of investigations the chloride load was 385.1 t, which would result in 62.4 mln. t during an average year. This is over 20 times more than during mean annual flow, and indicates the level of acidity of the flooded part of the Vistula watershed. Acidification of the surface layer of the soil is a dangerous process, since it decreases the productivity of agriculture. Alternating dry and wet periods are a basic factor, which regulates soil acidity in every watershed, determining the agricultural production potential. Complete stopping of flooding can lead to gradual reduction of production, irrespective of the intensity of fertilisation and of introduced genetic modifications. Acidification of Vistula watershed soils should subjected to specialised monitoring, which is especially important in periods of lower precipitation.

Analysis of relationships between floodwater parameters

Calculations of coefficients of correlation between the flow and the content of investigated substances, discharged into the Gulf of Gdańsk during floodwater culmination, indicated several significant relationships (Table 6, Fig. 2). These relationships showed positive relationships between flow and the content of nitrate nitrogen, inorganic nitrogen, inorganic phosphorus and total phosphorus. No relationship was found between the concentration of chlorides and COD and the remaining investigated components – nitrogen and phosphorus salts. On the other hand, relationships between the concentrations of phosphorus and of ammonia and total nitrogen were quite distinct. Concentrations of biogens (nitrogen and phosphorus) depended on the acidity of water. Both in the case of inorganic and total forms, the contents of both biogens decreased with growing alkalinity. Acid soil environment increases concentrations and loads of biogens washed out from the watershed area by floodwater. Highest acidity and biogen concentrations occurred at maximum flow in the river. With decreasing flow the acidity and biogen concentrations also decreased. However the flow factor was not very significant, since at an increase of water alkalinity from 7.05 to 7.45 the concentration of inorganic nitrogen reduced by 35%, of total nitrogen by 46%, inorganic phosphorus by 45% and total phosphorus by 40%. This happened when flow became 10% smaller and ammonia concentrations decreased by 80%. Biogen loads depend on the magnitude of surface flow, on soil acidity in the watershed and on intensity of denitrification, microbiological processes, which generally are named the "area metabolism".

Analysis of coefficients of correlation (Table 6) showed a positive value for pH and negative values for concentrations of nitrogen, phosphorus salts and flow for the time of measurements. Coefficients of regression (Fig. 2) were calculated for the significant values of correlation. In the period of measurements, concentrations of investigated components decreased, and this is confirmed by the coefficients of correlation and linear regression. At simultaneously decreasing flow (and acidity) of the water, 2-3 maximums appeared on the decrease curves of the biogens. Probably these extremes reflect the supply of the Vistula with waters from flooded areas. The culmination of floodwater on the Vistula stopped and even caused reverse flow in the tributaries. After high water passed, the tributaries increased supply of the Vistula with biogens and matter, which became reflected in the decrease curves.

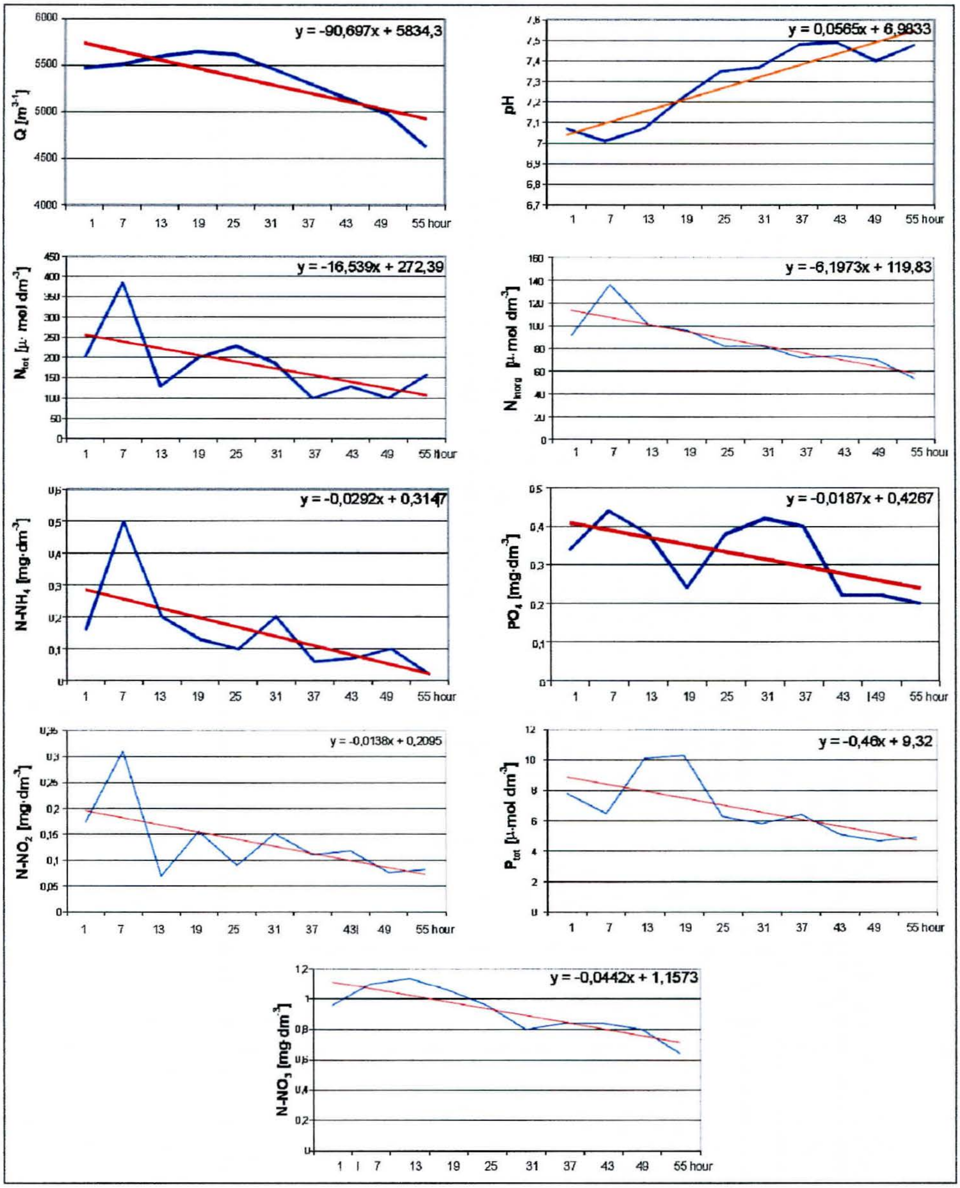

Fig. 2. Trends of hydro-chemical parameters of the Vistula during floodwater (August 4-6, 2001)

Many statistical relationships were found between the concentrations of various forms of nitrogen, there were also incidental relationships between the concentrations of nitrogen and phosphorus, and no relationships between COD, concentrations, salinity and the values of molal ratios N:P and the biogen concentrations. These results reflect the differences in the solubility of the analysed substances (chlorides > COD > N_{tot} > N_{inorg} > P_{tot} > P-PO_4) and the differences in origin and mechanisms of bio-geochemical circulation in the watershed. Problems presented here should be further analysed because they are important from the point of view of the sozological condition of the Vistula watershed and its influence on the environment of the Gulf of Gdańsk.

Table 6. Coefficients of correlation between parameters of floodwater on the Vistula (August 4-6, 2001)

t [hour]	pH	N_{tot}	N-NH_4	N-NO_2	N-NO_3	ΣN_{inorg}	PO_4	P-PO_4	P_{tot}	N_{inorg}:P-PO_4	N_{tot}:P_{tot}	COD	S	Flow
		[mg·dm^{-3}]								[n:1]		[mg·dm^{-3}]	psu	[m^3·s^{-1}]
coefficients of correlation														
1	0.915226	-0.593256	-0.654712	-0.583378	-0.850511	-0.827643	-0.603074	-0.604948	-0.694169	0.166124	-0.221041	-0.105572	0.352564	-0.826602
	1	-0.615807	-0.758253	-0.581552	-0.838027	-0.866139	-0.461677	-0.465094	-0.669695	0.141361	-0.281798	-0.058844	0.188609	-0.636549
		1	0.83147	0.866676	-0.477922	0.786294	0.468027	0.472028	0.124808	-0.080249	0.889278	0.230129	-0.372764	0.416782
			1	0.854187	-0.625859	0.929329	0.614728	0.619785	0.212455	-0.092578	0.694677	-0.05775	-0.302108	0.477309
				1	-0.419579	0.795934	0.448762	0.452399	0.094668	0.056752	0.748147	-0.0296	-0.526804	0.362377
					1	0.856797	0.468554	0.470756	0.789301	0.033985	0.089322	0.132765	-0.047365	0.844442
						1	0.595176	0.599235	0.50194	-0.008781	-0.509706	0.037526	-0.268251	0.702925
							1	0.999958	0.186768	-0.589652	0.341644	0.37583	-0.418496	0.653423
								1	0.184512	-0.585823	0.346534	0.370194	-0.417134	0.653595
									1	-0.05493	-0.329296	0.250325	-0.07539	0.691619
										1	-0.051294	-0.579467	0.000883	-0.155777
											1	0.101196	-0.316058	0.047518
												1	-0.026372	0.374125
													1	-0.172166
														1

– correlation significant at level 0.05

Summary

Water samples were taken during floodwater culmination on the Vistula (August 4-6, 2001), and in the samples the contents of nitrogen and phosphorus compounds, COD, salinity and pH levels were determined. After obtaining data on the flow of the Vistula during the period of sampling, and using the obtained values of contents of the analysed components, their loads, discharged into the Gulf of Gdańsk, were calculated. It was found that after the floodwater culmination passed, concentrations of nitrogen and phosphorus compounds decreasing with decreasing flow, and that the flow had no relationship with the concentration of chlorides and COD. On the other hand, the flow was positively correlated with pH. Biogen loads discharged into the Gulf in the period of sampling were compared with the respective annual means for the period 1984-1998. It was found that that they represented 1.4% ($N\text{-}NH_4$) to 4.7% (P_{tot}) of the annual means (Table 5). Surprisingly large were the loads of: nitrite nitrogen (27.7% of annual load), COD (6.3%) and chlorides (8.5%). The concentrations of the investigated substances in the floodwater did not differ significantly from concentrations observed in the period 1984-1998, and at five times larger flow were rather lower than at average flow. The mean molal ratios N:P of inorganic and total forms were 29:1. This indicates an insufficiency of phosphorus. Nevertheless the 48-hour load of total phosphorus could stimulate primary production of the order of 300 thousand tonnes of wet mass. The supply of very large biogen loads in the period after the summer blooming could at least partly balance their loss during that blooming, increasing the intensity of the autumn blooming. Hydrochemical investigations of Vistula floodwater, due to their role in the shaping of environmental and biocenotic conditions of the Vistula watershed and the Gulf of Gdańsk, should be the subject of special periodical monitoring (different from the type of monitoring realised at present).

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