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Original Research

The Effect of Sewage Treatment Plants on Nitrogen and Phosphorus Loads Transported by the Warta River in the Oborniki-Skwierzyna Stretch

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Abstract

The effect of five small municipal sewage treatment plants (throughput from 100 $m^3 \cdot day^{-1}$ to 2,300 $m^3 \cdot day^{-1}$), situated on the Warta River between Oborniki and Skwierzyna, on nitrogen and phosphorus loads carried by the river was analyzed during investigations covering the period 1992/1993-2001/2002. The total share of nitrogen and phosphorus loads from sewage treatment plants in the loads in the river, calculated at the last measurement point in Skwierzyna, did not exceed one per cent. A considerably greater effect was found from non-point pollution sources and meteorological conditions, especially precipitation levels in the winter half-year.

This study analyzed nitrogen and phosphorus loads discharged to the Warta River along with treated effluents. The local effects of the concentrations of the treated effluents were not discussed.

Keywords: nitrogen, phosphorus, load, river, pollution, water

Indroduction

While analyzing biogen transport in the waters of the Warta River between Oborniki (206.3 km) and Skwierzyna (92.2 km) in the hydrological years 1992/1993-2001/2002 it was found that in the lower part of the investigated stretch [Kłosowice (137 km) – Skwierzyna (92.2 km)] the total nitrogen load decreased at the simultaneous increase in the total phosphorus load. In order to clarify this unusual phenomenon, the effect was studied in water supply and sewage disposal in towns located on the Warta River in this 114.1 km long stretch.

The aim of the study was to estimate the effect of sewage treatment plants in the Oborniki – Skwierzyna stretch on the nitrogen and phosphorus loads transported by the Warta River.

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Material and Methods

In order to calculate total nitrogen and phosphorus loads, concentrations of these elements, measured at five measurement and control points, were used along with the values of flows determined at three water-gauging stations (Fig. 1). These points and stations constitute a dense measuring network. The investigations covered the period of ten hydrological years (1992/1993-2001/2002). Measurement and control points were included in the national monitoring system of surface flowing waters. They were controlled by the Provincial Inspectorate for Environmental Protection in Poznań and Gorzów Wielkopolski. The measurements at the water-gauging stations were performed by the Institute of Meteorology and Water Management in Poznań. In the cases of measurement and control points in Obrzycko and Kłosowice, lacking water gauges, flow values were calculated through inter-

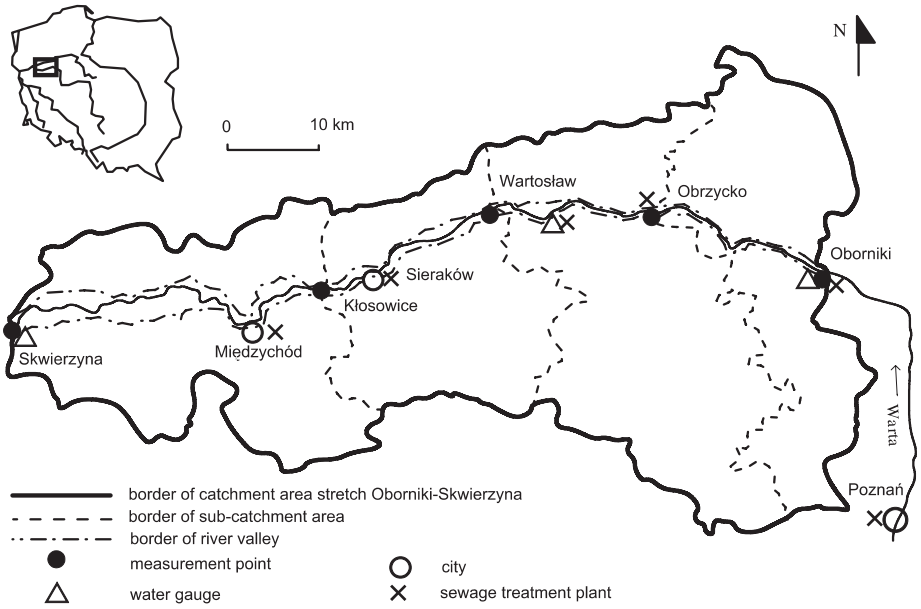

Fig. 1. Location of measurement and control points, water-gauging stations and sewage treatment plants in the Warta River stretch between Oborniki and Skwierzyna.

polation based on the area of subcatchments. This method is routinely used by the Institute of Meteorology and Water Management and consists in calculating flow levels depending on the increase in catchment areas. The areas of subcatchments for these two measurement points were determined on the basis of 1:200,000 maps using SKWER software. With the use of the JAWO program (derived from Polish "Jakość Wody" – Water Quality), diurnal, monthly and annual loads of total nitrogen and phosphorus were obtained. The load was calculated as a quotient of concentration of a given element or compound and the level of water flow on the day a given water sample was collected for analysis. This parameter presents loads of pollutants transported by the river more accurately than pollutant concentrations.

Water supply and sewage disposal were investigated for municipal sewage treatment plants with throughputs exceeding 20,000 $m^3 \cdot year^{-1}$. Sewage treatment plants in Oborniki, Obrzycko, Wronki, Sieraków and Międzychód were included in this category (Fig. 1). On the basis of data contained in inspection reports of Provicial Environmental Inspectorates in Poznań and Gorzów Wielkopolski, and information obtained directly from the sewage treatment plants, the following data were established: the precise location of effluent treatment plant discharge, the year of startup, the type of applied sewage treatment technology and the diurnal volume of sewage effluent discharge.

In order to determine the degree of nitrogen and phosphorus reduction, the following assumptions were adopted. Concentrations of nitrogen and phosphorus in untreated sewage were assumed after Kutera [1] to be at the level of 58 $gN \cdot m^3$ and 8 $gP \cdot m^3$, respectively. Removal efficiency of nitrogen and phosphorus in mechanical treatment plants is only 10%. In case of sewage treatment plants equipped with the mechanical and biological technology, the efficiency of nitrogen and phosphorus removal is assumed to be 50% and 40%, respectively. For mechanical-biological sewage treatment plants with improved tertiary sewage treatment the degree of reduction for both nitrogen and phosphorus was assumed to be 88% ([2], consultations with Prof. Ryszard Błażejewski of the Department of Hydraulic Engineering, August Cieszkowski Agricultural University of Poznań). Data on nitrogen and phosphorus concentrations in crude sewage and treated effluents given for the sewage treatment plants were incomplete and not very reliable.

In order to determine whether samples collected at measurement and control points are not located in the stream of treated effluents, the lengths of stretches in which effluents become thoroughly mixed with the river water were calculated. The dispersion of treated effluents was calculated using formulas proposed by Bleninger et al. [3]. With the formula $L_{mv} = 50h$ it is possible to calculate the distance on which vertical mixing occurs, where "h" is the depth of the river in meters. The other formula, $L_{mh} = 7(B/h)B$ defines the distance which has to be covered by water so that effluent particles could be dispersed in the transverse direction, i.e. be thoroughly mixed with the river water (B – river width in meters).

In order to establish meteorological conditions, diurnal and monthly precipitation totals were collected for the investigated ten years from three precipitation gauging stations and one meteorological station from the catchment basin of the Warta River, together with diurnal and monthly average air temperatures for four meteorological stations of the central western Poland region.

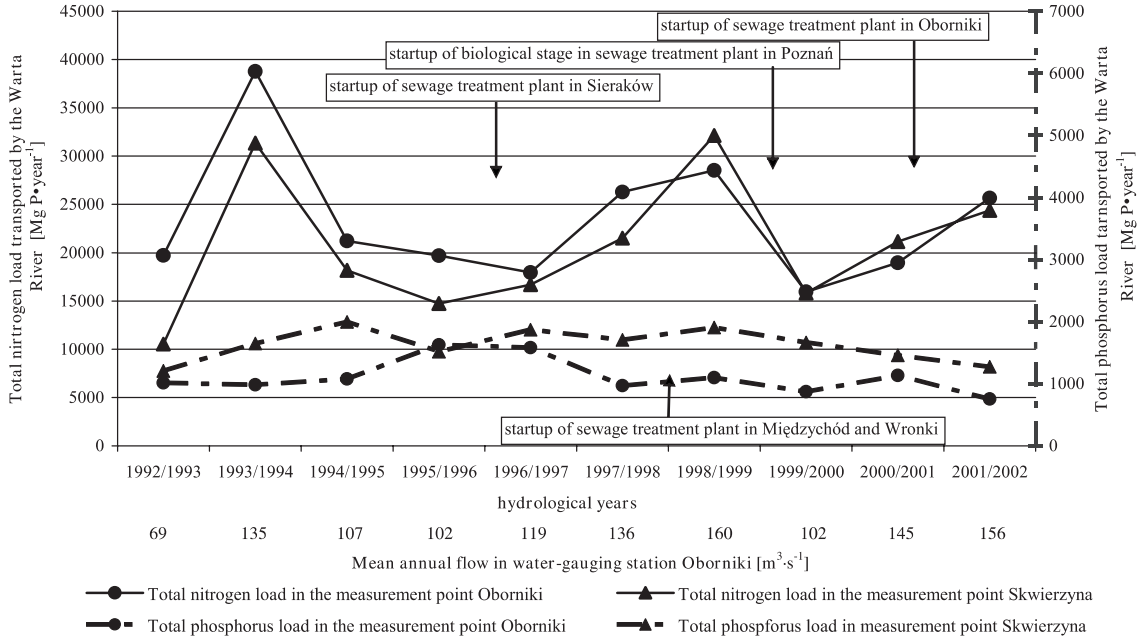

Fig. 2. Mean annual loads of total nitrogen and phosphorus transported by the Warta River in the years 1992/1993-2001/2002.

Results

Total nitrogen load discharged by the Warta in the investigated decade fell within a very wide range of 10,500--40,700 Mg·year^{-1} (Fig. 2). Usually bigger loads were observed in Oborniki. Only in the years 1998/1999 and 2000/2001 nitrogen load calculated in Skwierzyna was slightly higher than in Oborniki. Especially high nitrogen loads were recorded in 1993/1994 and 1998/1999, in which high flow values and total nitrogen concentrations were observed in the Warta waters.

Total nitrogen loads in the years 1992/1993-2001/2002 fell within the 730-2000 Mg·year^{-1} range. Only in the year 1995/1996 was the phosphorus load in Oborniki slightly higher than in Skwierzyna. This was caused primarily by climatic conditions, especially very low temperature (-0.8°C) and low precipitation (110 mm) in the winter half-year. Phosphorus from non-point sources enters surface waters first of all along with soil particles; meteorological conditions prevalent in that year reduced the process of erosion. Only in that year a decrease in total phosphorus concentration was found in the river waters between Kłosowice and Skwierzyna.

Fig. 2 presents dates of startup or modernization of municipal sewage treatment plants found between Oborniki and Skwierzyna, and of the Central Sewage Treatment Plant for the city of Poznań. Small sewage treatment plants did not have any considerable effect on nitrogen and phosphorus loads transported by the river. The startup of the biological installation of the Central Sewage Treatment Plant in Poznań resulted in a significant decrease in water nitrogen and phosphorus concentrations. Due to higher flows in the years 1999/2000-2001/2002 it did not bring about a decrease in the loads. In that period average annual total nitrogen concentration dropped from 4.56 to 4.25 mgN·dm^{-3}, whereas that of total phosphorus from 0.31 to 0.20 mgP·dm^{-3}, respectively. Very high precipitation in the winter half-year (332 mm, 319 mm), observed in 1993/1994 and 1998/1999, probably contributed to considerable amounts of nitrates being leached from soil. It seems that non-point sources have a more significant effect on nitrogen and phosphorus loads.

Międzychód is a town which discharges the highest amounts of treated effluents in the investigated river stretch (818,901 m^3·year^{-1}) (Table 1). Before 1998 municipal sewage in that town was only treated mechanically. The lowest amounts of effluents are discharged by the sewage treatment plant in Obrzycko (39,591 m^3·year^{-1}). This plant was opened in 1991 and treats sewage mechanically and biologically. The highest loads of nitrogen and phosphorus (30.3 MgN·year^{-1} and 4.2 MgP·year^{-1}) are introduced to the Warta along with the municipal sewage of Wronki. Only 22.7% of all municipal sewage produced by that town is treated there. The rest is discharged to the river in the crude form. High amounts of nitrogen and phosphorus (26.4 MgN·year^{-1} and 3.7 MgP·year^{-1}) were discharged to the Warta by Oborniki. Before the startup of a modern sewage treatment plant in 2001, large quantities of municipal sewage were discharged into the river untreated or treated only mechanically.

The share of nitrogen and phosphorus loads in the treated effluents of towns located between Oborniki and Skwierzyna in the load transported by the Warta River in the investigated stretch was studied in two periods. The first, covering the years 1993-95, pertains to the period when the analyzed plants either did not exist, or were being modernized. The other period covers the last year of the study (2002), in which most of the sewage treatment

Table 1. Nitrogen and phosphorus loads discharged to the Warta from larger towns between Oborniki and Skwierzyna in the years 1992/1993-2001/2002.

Town	Sewage volume [$m^3 \cdot year^{-1}$]	Nitrogen load [$Mg \cdot year^{-1}$]	Phosphorus load [$Mg \cdot year^{-1}$]
Międzychód	818901	16.3	2.2
Oborniki	796183	26.4	3.7
Wronki	588482	30.3	4.2
Sieraków	281072	2.0	0.3
Obrzycko	39591	1.1	0.2
Total	2,524,229	76.1	10.6

plants operated appropriately. In the years 1993-95 the share of nitrogen and phosphorus in effluents discharged to the Warta River constituted only 0.3% and 0.52% load carried by the river in Skwierzyna. In 2002 it decreased to 0.09% and 0.25%, respectively (Table 2). A considerable improvement may be observed in the degree of discharged effluent treatment. Average annual municipal sewage effluents from the towns of Oborniki, Obrzycko, Wronki, Sieraków and Międzychód amount to approx. 2.5 million m^3 (Table 1). It is only 0.06% average annual water flow in Skwierzyna (ca. 4,500·mln $m^3 \cdot year^{-1}$).

The increment in the water flow in the Warta in the section between Oborniki and Skwierzyna is ca $533 \cdot 10^6$ $m^3 \cdot year^{-1}$. Sewage discharged in this section accounts for only 0.5% of this volume. At the 200-fold effluent dilution with river water the local impact in practice is slight. This confirms the fact that nitrogen and phosphorus loads generated from municipal sewage in small towns (up to 12,000 inhabitants) have an insignificant effect on the size of nitrogen and phosphorus loads carried by a large river (Table 2).

The distance in which vertical mixing of municipal sewage effluents discharged by towns occurs in the Warta River ranged from 190 m in Oborniki to 136 m in Sieraków. Transverse mixing is more important due to the effect of sewage on pollutant concentrations at measurement points. Complete mixing of sewage effluents with river water requires the following distances: Oborniki – 13 km, Obrzycko – 14 km, Wronki – 16 km, Sieraków – 19 km and Międzychód – 10 km. Taking into consideration the river bank on which sewage effluents were discharged and water was collected for analysis, it may be stated that only the measurement and control point in Oborniki (206.3 km) was directly subjected to the effect of sewage effluents from Oborniki, discharged upriver. Sewage effluent discharge at that point was discontinued in the middle of the year 2000, which manifested itself by a decrease in the average annual concentration of total nitrogen and nitrogen according to Kjeldahl, recorded at Oborniki.

Discussion

According to Bernacka and Pawłowska [4], nitrogen and phosphorus removal efficiency in plants with the mechanical and biological tertiary sewage treatment system is 75% and 87%, respectively.

While analyzing water supply and sewage disposal in towns located on the Warta River between Oborniki and Skwierzyna it was calculated that the share of effluents from those towns is slight in comparison to the total pollution amount transported by the river. The average annual loads of nitrogen and phosphorus discharged together with effluents to the Warta above Oborniki in the years 1993-1998 was 2,371 $Mg \cdot year^{-1}$ of nitrogen, 329 $Mg \cdot year^{-1}$ of phosphorus, which constituted 10 and 30%, respectively, of the load found in the Warta at Oborniki [2]. Effluents discharged by the Central Sewage Treatment Plant for the city of Poznań account for the highest share in this respect. In 1998 they introduced 2,652.5 Mg nitrogen, while the total load in the Warta River was then 26,286.2 Mg.

In 1992 the share of nitrogen and phosphorus from municipal sewage treatment plants in the load discharged to the river was estimated at 55% [5]. In Germany the estimated share of point sources of pollution in 1995 was 40% nitrogen and 50% phosphorus [6]. The share of treated sewage effluents in the nitrogen and phosphorus loads carried by the Drawa River was 2.72 and 3.39%, respectively, whereas in the case of the Gwda River it was higher, amounting to 4.97 and 5.74%, respectively [7].

Very high loads of total nitrogen were observed in the Prosna River in the years 1993/1994 (4,667.4 $Mg \cdot year^{-1}$) and 1997/1998 (5,172.8 $Mg \cdot year^{-1}$). In the catchment of

Table 2. Contribution of towns located on the Warta between Oborniki and Skwierzyna to total nitrogen and phosphorus loads in Skwierzyna.

Load	Units	Total nitrogen load		Total phosphorus load	
		years 1993-1995	year 2002	years 1993-1995	year 2002
Transported by the Warta River	$Mg \cdot year^{-1}$	20020.4	24390.2	1617.8	1270.7
Discharged from five towns	$Mg \cdot year^{-1}$	59.39	23.14	8.36	3.18
	%	0.30	0.09	0.52	0.25

the Prosna in those two years heavy precipitation and relatively high temperature were observed in the winter half-year [8]. It corresponds to the observations taken on the Warta River in the Oborniki-Skwierzyna stretch. Also, in the catchments of the Ner and Wełna the highest loads of nitrogen were found in the years with heavy precipitation in the winter half-year [9, 10]. This confirms the assumption that the main cause of a considerable increase in the nitrogen load in a river is leaching nitrates from the soil in the winter half-year. It results from the fact that non-point sources account for a significantly higher share in the biogenic compounds introduced into the river.

Total nitrogen load discharged by the Warta during the decade ranged from 10,500-40,700 $Mg \cdot year^{-1}$, whereas that of phosphorus was significantly lower and fell within the 730-2,000 $Mg \cdot year^{-1}$ range. In the years 1992/1993 and 1998/1999 nitrogen load was highest. It was caused by meteorological conditions and considerable inflow of nitrogen from non-point sources.

The startup of a mechanical and biological sewage treatment plant in Poznań resulted in the lowering of nitrogen and phosphorus concentrations in the river water, but at higher water flows it did not cause a decrease in the loads of these elements. The share of nitrogen and phosphorus from small municipal sewage treatment plants in the loads transported by the Warta River is slight and shows a downward trend.

For the river ecosystem the concentrations of individual nitrogen and phosphorus compounds in the water are much more important than the pollutant load transported by the river. The NH_4^+/NH_3 ratio, i.e. that of the ammonium ion to undissociated ammonium, is of special importance. Although ammonium ions are not harmful, ammonia is toxic. Significant sources of total ammonia (the sum of NH_4^+ and NH_3) are municipal sewage treatment plants and pig and cattle farms. Ammonia concentration (NH_3) in water increases along with pH. In sewage-loaded waters, characterized by poor buffering capacity, sudden deaths of fish may take place as a result of exceeding the critical pH value (10.5) and the occurrence of a high NH_3 concentration [11]. Ammonia concentration toxic for freshwater fish is defined as 2.79 $mgNH_3 \cdot dm^{-3}$ [12, 13].

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