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Short Communication

Long-Term Water Quality Monitoring of a Transboundary River

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Abstract

This paper presents an assessment of the water quality of the transboundary Wisznia River (Poland). The environmental state of this transboundary river is described in terms of monthly monitoring data for the main physicochemical and biological parameters. The eight indicators of water quality taken into account included: nutrients (nitrate, phosphorus), salinity, and biological oxygen demand. Long-term water quality data (for 1990-2012), collected from two sample sites was investigated. A substantial decrease in the amount of nutrient substances in the later years can be noticed. This is the result of changes in agriculture and the construction of sewage treatment plants.

Keywords: water quality, monitoring, Wisznia, transboundary river

Introduction

The transboundary water of 263 international rivers in the world constitutes 60% of the water around the globe. 40% of the river basins around the world are transboundary waterways shared by two or more countries [1]. At the European level, due to the implementation of the Water Framework Directive (WFD), there should be integrated river basin management that will represent a unified approach toward water management. The objective of the WFD is to achieve 'good status' with regard to all of the water within the EU in 2015.To ensure its effective implementation, governments are establishing joint bodies for transboundary water cooperation. Across Europe, countries are engaging in a growing number of multilateral and bilateral agreements to regulate the use and protection of transboundary waters. These include any surface or groundwater that marks, crosses, or is located on the boundaries between two or more states. In 1992 in Helsinki Poland signed the UNECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (hereafter: the Water Convention), which entered into force in 1996. In addition, an agreement between the governments of Ukraine and Poland on Cooperation in the Field of Water Management in Frontier Waters was signed in 1996 [2].

In this work, the research area was the Wisznia River, which is a right-bank tributary of the San catchment area (Upper Vistula River basin). This is part of the Vistula River basin (the largest river in Poland), which crosses the whole country, and therefore its water pollution load may even affect water quality in the Baltic Sea. The Wisznia is 98 km in length, but only its lower section lies in Poland. The total catchment area at Nienowice gauging station is 1187.29 km^2 (201.9 km^2 in Poland). It flows out from the Roztocze region in Ukraine, and it crosses the Polish national border near the town of Starzawa (Fig. 1). The mean annual discharge amounts to:

$$Q = 6.63\ m^3 \cdot sec^{-1} = 6.50\ dm^3 \cdot s^{-1} \cdot km^{-2}\ [3]$$

Generally, rivers within the Upper Vistula basin boast substantial water resources, but these are unevenly distributed, with highly variable flows. Small flows are observed

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during dry periods in the rivers, while there are sometimes violent storms and large floods. Frequent changes in the flow are stimulating the processes of erosion of river banks and bottoms.

The Wisznia catchment area has a relatively low population (47 people per/km^2). This study is of the Polish side (consolidated surface water unit No. PLRW2000192252999) of the catchment, which is utilized mainly as agricultural land, and includes a forest-wooded area (Fig. 1). Forests occupy 10% of the total catchment area. The share of arable land in the basin under investigation is 53.4%, while grassland covers 20.2% [4]. Tributaries located in the upper section of the catchment are predominantly covered by forests, with streams such as the Bucowski Canal, Stubienko, and Kowalik streams [5, 6].

Since 2005 the Regional Inspectorate of Environmental Protection in Rzeszów and the State District Office of Environmental Protection in Lwów (Ukraine) have been conducting joint monitoring of the transboundary water. In addition, as part of the implementation of the Nitrates Directive, Regional Water Boards have been establishing nitrate-sensitive areas in areas polluted by nitrates from agricultural sources. Municipal sewage from Ukrainian towns such as Gorodka, Sudowa Wisznia, and Mościsk, as well as the checkpoint at Szeginia, also affect the Wisznia River water. Numerous studies conducted in the Upper San River basin have provided an understanding of the real threats to the surface water posed by excessive amounts of nutrients created by human activities [4, 7, 8]. The main non-point sources of pollution are nitrogen fertilizers, whereas point pollution is caused by phosphorus.

The purpose of this study was to assess the surface water quality of the Wisznia River and determine the variability of water-quality indicators of the river during 1990-2012. The following indicators were investigated: nutrients (nitrogen, nitrate nitrogen, phosphorus), sulphates, chloride, calcium, and biological oxygen demand (BOD).

Experimental Procedures

The concentrations of chemical and biological compounds were determined based on the results of analysis of water samples collected from the Wisznia River during 1990-2012 by the Regional Inspectorate of Environmental Protection in Rzeszów-WIOŚ [5]. Analyses were conducted by the VIEP laboratory in Rzeszów, which has implemented and maintains a quality management system compliant with the requirements of ISO/IEC and documents of the Polish Centre for Accreditation [7]. The methodology of water quality studies was uniform for all points, at which water was sampled twice a month. Research was conducted at the two Wisznia River sample sites: Starzawa border point (14.2 km of the river course) near the border with Ukraine and at the river mouth (the location changed to the estuary section at "Michałówka" in 2007). These two sites are representative of conditions in a typical agricultural catchment. The upper part of the Wisznia River basin consists of forest and agricultural land, which is used extensively. Part of the catchment area is located in Ukraine. In its lower course, the river flows through agricultural areas and rural communes, which are the main source of pollution. The eight indicators of water quality taken into account were: ammonium nitrogen (N-NH$_4^+$), nitrate nitrogen (N-NO$_3^-$), total nitrogen (N), total phosphorus (P), sulphates (SO$_4^{2-}$), chloride (Cl$_2^-$), calcium (Ca), and biological oxygen demand (BOD), one of the most common measurements of pollutant organic material in water, and a five-day BOD test is used in environmental monitoring. This test measures the oxygen requirements of the bacteria and other organisms as they feed upon and bring about the decomposition of organic matter.

The distribution frequency of nutrients in the Wisznia River (Fig. 2) of the above water quality indicators were established for the study period of 1990-2012. Simultaneously, water-quality indicators in the 5-degree

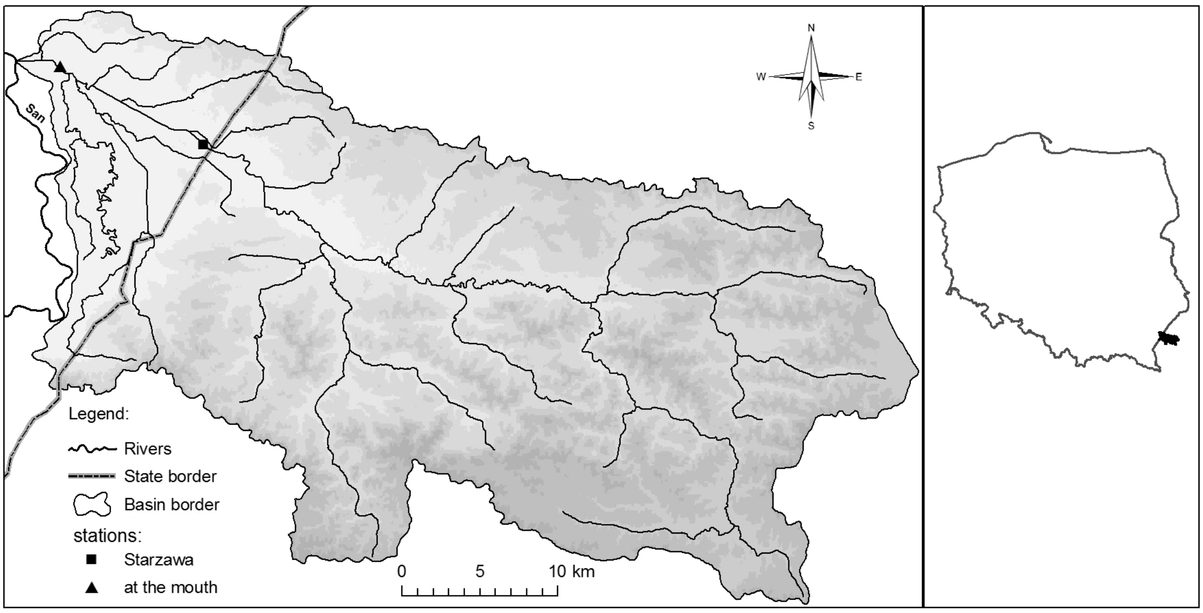
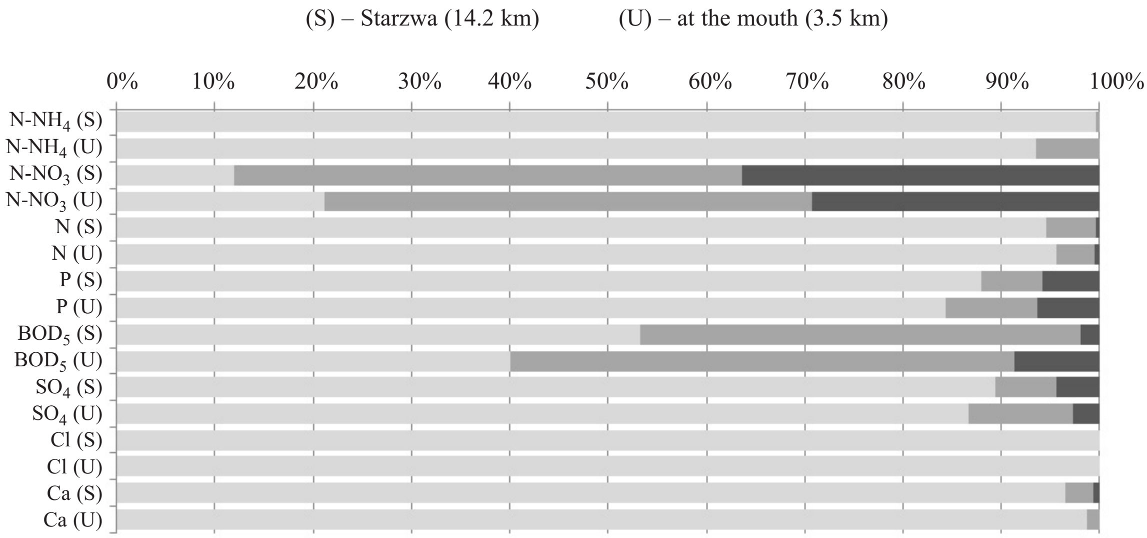


Fig. 1. Map of the Wisznia River basin with a digital relief chart (GIS) showing water quality measuring stations.



	Ca (U)	Ca (S)	Cl (U)	Cl (S)	SO4 (U)	SO4 (S)	BOD5 (U)	BOD5 (S)	P (U)	P (S)	N (U)	N (S)	N-NO3 (U)	N-NO3 (S)	N-NH4 (U)	N-NH4 (S)
class I [%]	98,7	96,6	100,0	100,0	86,6	89,3	40,1	53,3	84,4	88,0	95,6	94,5	21,1	12,0	93,6	99,6
class II [%]	1,3	2,9	0,0	0,0	10,6	6,3	51,3	44,8	9,3	6,3	3,9	5,1	49,6	51,7	6,4	0,4
beyond class [%]	0,0	0,6	0,0	0,0	2,8	4,3	8,6	1,9	6,3	5,8	0,5	0,4	29,3	36,4	0,0	0,0

Fig. 2. Distribution frequency (%) of water-quality indicators of the Wisznia River at the two sample sites: Starzawa and at the river mouth (monthly data from 1990-2012).

scale parameters were adopted according to the regulations issued by the Minister of the Environment on 20 August 2011 [9, 10]. Class 1 water quality indicates no anthropogenic impact; class 2 indicates a relatively small anthropogenic impact, and good ecological status. However, classes below 2 exhibit a negative impact and include water that is unsuitable for economic purposes, and particularly unsuitable for drinking (Fig. 2). Water quality also was characterized by statistical measurements of the parameters obtained (minimum, maximum, arithmetic mean, and standard deviation (Fig. 4) The methodology used in this study also aimed to provide information in relation to the trends of major nutrients and pollutants in the Wisznia. It focuses both on the trends considered as indicators of water quality status and on the possible differences in trends (e.g. between two sample points). According to the European Environment Agency [11, 12], the purpose of such analyses is to consider if measurable improvements of river water status and their significance can be assessed, and if these trends can be reasonably related to relevant driving forces (e.g. agriculture, rural urbanization).

Results

Nutrients

The results obtained during studies on select concentrations of nutrients showed differences. The mean values (with the range in brackets), from the investigated 1990-2012 period at the river mouth sample site (A= 1187.29 km^2) were: ammonium nitrogen (N-NH_4^+) 0.35 mg·dm^{-3} (min. 0.05, max. 1.29), nitrate nitrogen (N-NO_3^-) 4.34 mg·dm^{-3} (min. 0.03, max. 18.14), total nitrogen (N) 2.40 mg·dm^{-3} (min. 0.82, max. 11.41), and total phosphorus (P) 0.27 mg·dm^{-3} (min. 0.02, max. 3.88). The distribution frequency of nutrients in the Wisznia (Fig. 2) proved that the concentrations generally had not been high, and only N-NO_3^- was below class 2 water quality (e.g. at the river mouth site: 29.3% and at the Starzawa site 36.4%, Fig. 2). The average monthly concentrations showed a decreasing trend over time, but the correlation was not significant (Fig. 3). The highest ammonium concentration was recorded at the mouth of the San River. The concentrations of nitrogen and phosphorus indicate the first water quality class (< 5 mg N·dm^{-3} and < 0.2 mg P·dm^{-3}). Changes in nitrogen and phosphorus concentrations observed over a period of the last 20 years have shown similar trends at the two sites, and their tendencies are depicted in Figs. 3 and 4. These trends are decreasing; however, they are statistically insignificant.

Five-Day Biological Demand

Large variations of the BOD_5 concentrations were shown to have occurred in the Wisznia in 1990-2012. In this period, the mean values of BOD_5 were in the range: Starzawa (14.2 km) mean 3.19 mg O_2·dm^{-3} (min. 0.05, max. 19.5) and at the river mouth (2.3 km) mean 3.79 mg O_2·dm^{-3} (min. 0.05, max. 55.0). Often BOD_5 lowered the quality of water in the Wisznia to class 2 (Starzawa 44.8%, at the river mouth 51.3%), and sometimes even below class 3 (e.g. at the river mouth site: 8.6% and at the Starzawa site 1.9% (Fig. 2). The highest values of BOD_5 were recorded at the river mouth (Figs. 3 and 4). The distribution frequency of the BOD

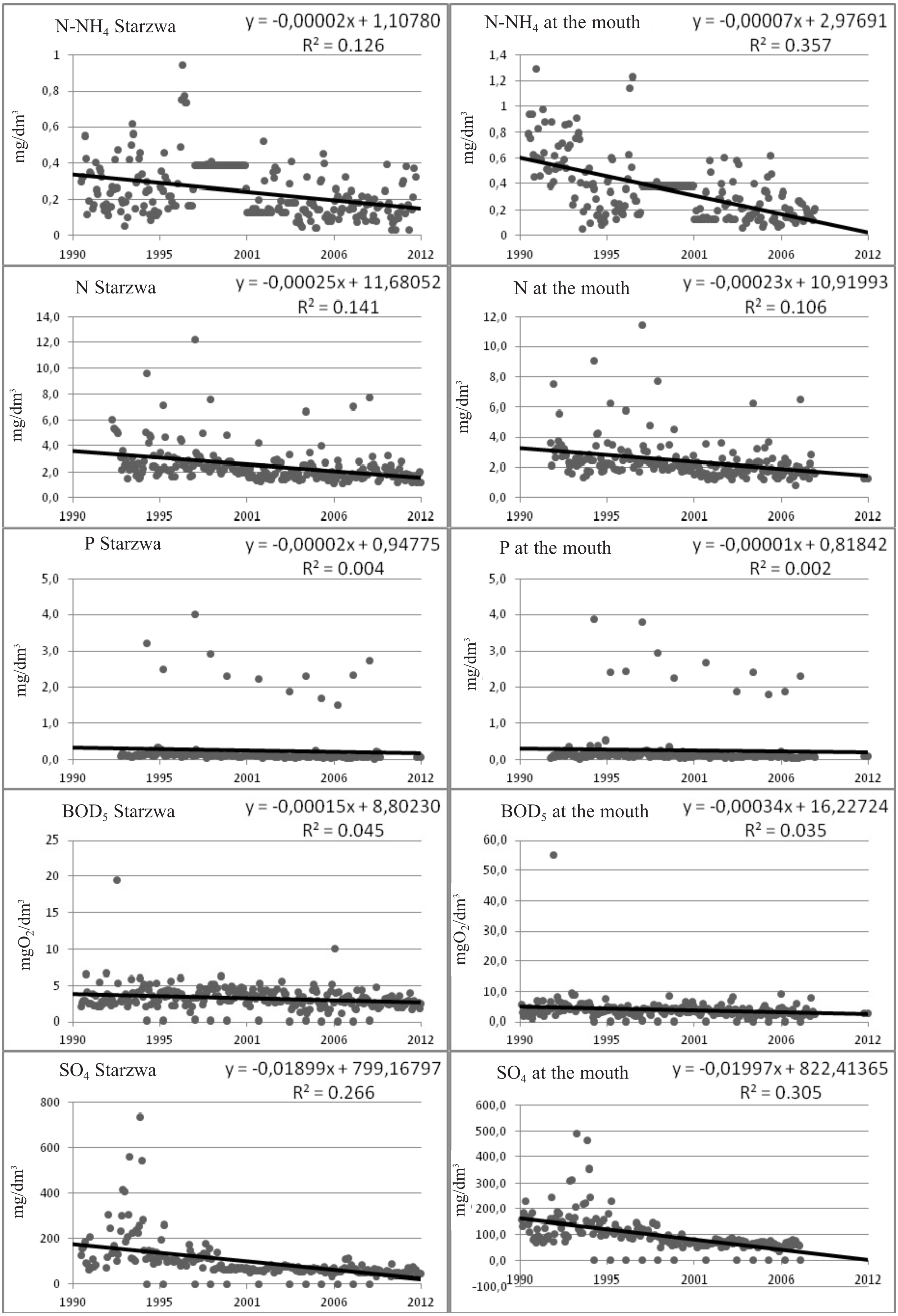


Fig. 3. Variations of monthly water-quality indicators of the Wisznia River at two sample sites: Starzawa and at the river mouth (data from 1990-2012).

index in the Wisznia (Fig. 2) proved that the concentrations generally had not been high, and were mostly in class 1 and 2 of water cleanliness.

Indicators of Salinity

Salinity indicators such as sulphates, chlorides, and calcium to some degree characterize water purity. The mean values of salinity indicators from the period under investigation (1991-2012) were in the range: Starzawa (14.2 km): sulphates (SO_4^{2-}) 90.62 mg·dm^{-3} (min. 0.05, max. 736.5), chlorides (Cl_2^-) 29.6 mg·dm^{-3} (min. 2.0, max. 104.0), calcium (Ca) 112.7 mg·dm^{-3} (min. 4.15, max. 327.6); and at the river mouth (2.3 km): sulphates (SO_4^{2-}) 100.3 mg·dm^{-3} (min. 0.07, max. 489.5), chlorides (Cl_2^-) 32.4 mg·dm^{-3} (min. 1.6, max. 96.0), calcium (Ca) 110.7 mg·dm^{-3} (min. 4.4, max. 286.0). Sulphates lowered the quality of water to class 2 (10.6% at the mouth and 6.3% at Starzawa and below class 2 (4.39%-2.8%) (Fig. 2). The sulphate concentrations were lowest at the river mouth. The excessive content of sulphates in the surface water (above 300 mg·dm^{-3}) is causing corrosion of concrete channels, culverts, and bridges. Generally, a clear fall in the salinity indicators (SO_4^{2-}, Cl^-, Ca) has been observed in the Wisznia. This coincides with a decrease in the concentration values of this component in Ukraine.

Discussion of the Results

Due to the increasing pressure of economic development and competition for scarce resources, many international water basins have suffered serious environmental, social, and political problems. Transboundary water pollution is one of the most significant problems of Latvia's internal waters, for example. Pollution coming into Latvia from neighboring states is significant for all groups of polluting substances, and in particular for biogenic elements and persistent substances [13]. Elsewhere, in the Daugava River, the load of biogenic elements is mainly formed as the result of transboundary water pollution.

The Tisza River basin (TRB) originates in the Carpathian Mountains in the territories of Romania, Slovakia and Ukraine, and is the largest catchment area among the 15 sub-basins of the Danube Basin. The surface water quality of the Tisza is mainly affected by industrial and municipal pollution, as well as agricultural runoff. Serious temporary water quality problems are still caused in tributaries (mainly Hungary, Romania, Serbia-Montenegro) as a consequence of deficiencies in municipal sewage treatment systems [14].

Ukraine still makes use of the Soviet system of water monitoring and water quality standards. The monitoring of pollutants and others in Ukraine is still insufficient (due to a lack of equipment and financing for research laboratories and environmental control authorities). International legislation on the regulation of transboundary watersheds is underdeveloped and has poor practical implementation in some cases [15]. Protecting water resources from pollution is one of the main problems for sustainable development. Therefore, the provisions of the Nitrates Directive (the 91/676/EEC) have been transposed into Polish law, inter alia, the provisions in the Water Law Act of 18 July 2001 and Regulation by the Minister of the Environment of 23 December 2002 on criteria for determining waters vulnerable to pollution from nitrogen substances from agricultural sources. One of the major sources of nitrates in the environment is farming. Use of nitrogen-containing fertilizers and livestock manure is essential for agriculture, but their excessive and inappropriate use could pose a serious threat to the environment [16]. The Nitrates Directive states that in all river monitoring, the annual average nitrate concentrations should not exceed 40 mgNO_3/l, above which there is considered to be a risk of water contamination.

In spite of the important functions that small water streams like the Wisznia River fulfil in the environment, they are exposed to many negative factors, mainly of anthropogenic origin. Increasing rural urbanization and industrialization have become the cause of significant, and not always favorable, impact of humans on the natural environment. Rural settlements have the most negative influence on water quality, followed by typical agriculture [16-18]. A similar study on water quality assessment in the Dunajec River [19] revealed the range and distribution of pollution. Research proved that during the development of rural areas in the 1970s and 1980s there was an increase in the mean annual values of contamination indices (BOD, ammonia, phosphates) [8, 16, 19, 20].

Monitoring conducted in 2009-12 by the Regional Inspectorate of Environmental Protection in Rzeszów confirmed that in 2009 the sulphate concentrations in the Wisznia River were still high, amounting to 150 mg SO_4·dm^{-3} [20]. In this work the studies conducted and the analysis of the data gathered during the period from 1990-2012 indicated that nutrient concentrations (N-NH_4^+, N-NO_3^-, N, P) were clearly low and never exceeded the boundary level of first- and second-class purity (Fig. 2). This pertained to all the analyzed components. The analysis proved that the indicators that lowered the water quality the most were: BOD_5, N-NO_3 and chlorides, while calcium had a smaller impact on the classification of water cleanness. An analysis of salinity indicators identifies that a clear improvement in water cleanness has happened in recent years. This may also be the result of decreasing anthropopressure in the area, because the main feature of the studied area is agricultural and forest land cover with a low population density. Also, in the last few years the quantity of municipal sewage reaching the Wisznia River has decreased. This resulted from the streamlining of water usage in both households and industry. Only the partially treated municipal sewage from Ukrainian border towns such as Gorlovka and Sudowej Mościsk had an impact on Wisznia River water. In addition, agricultural practices such as spreading manure as fertilizer on fields during dry periods can all contribute to nitrate contamination. The quality of the waters of the Wisznia depends to a great extent on human activities. There are three main sources of pollution:

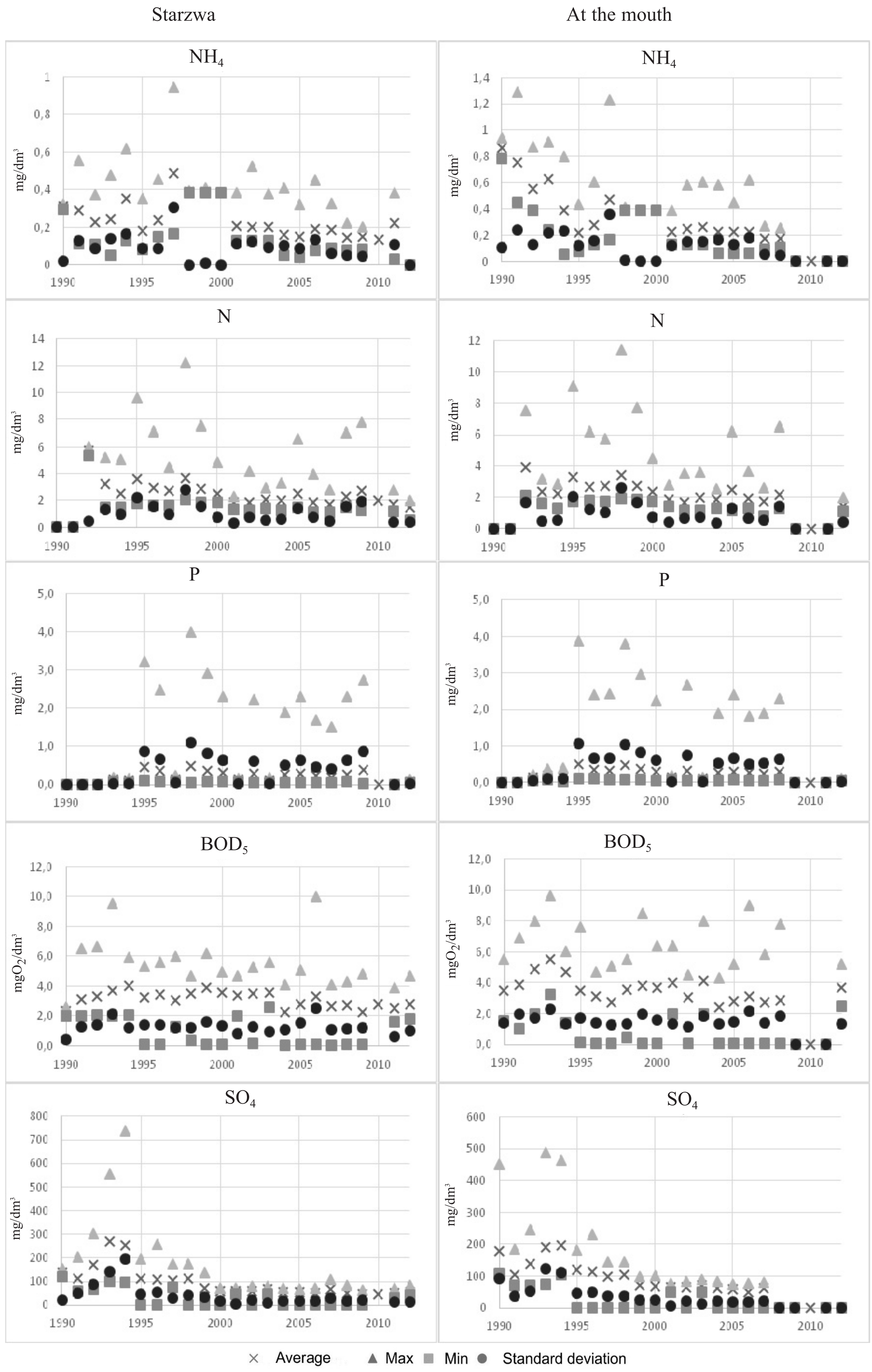


Fig. 4. Annual water-quality indicators of Wisznia River at two sample sites: Starzawa and at the river mouth (1990-2012).

– Spot sources, e.g. municipal sewage and industrial waste that reach Wisznia via sewage systems
– Spatial sources (non-point sources), e.g. run-off from areas where there are no sewage systems, from agricultural areas (manure and fertilizers) and woodland
– Linear sources, e.g. pollution from transport lines

Conclusions

The environmental state of the basin described in terms of monthly water quality data showed a substantial decrease in the amount of chemical and biological substances. This is the result of changes in agriculture and the construction of sewage treatment plants.

Special attention needs to be given to the transboundary river basins, in which some specific problems have to be overcome: there is an urgent need to properly monitor the shared water resources and cross-border pollution problems.

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