Ocean & Coastal Management 118 (2015) 37–46

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Long-term trends in nutrient concentrations in Polish coastal rivers

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ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form
10 February 2015
Accepted 8 April 2015
Available online 14 April 2015

Keywords:
Coastal zone
Water quality trends
Nitrogen
Phosphorus
River

ABSTRACT

This paper analyzes the long-term changes in concentrations of nutrients in seven rivers located in the Polish part of the southern Baltic coastal zone in response to economic changes that took place between 1988 and 2013. These changes included: construction or modernization of 390 biological waste water treatment plants, reduction of untreated municipal waste waters discharged into water and soil, a decrease in fertilizer application, and a decline in animal production by about 60% LU. Statistically significant downward trends in nutrients concentrations were observed in six out of seven studied rivers. The mean annual concentration of N_{tot} changed from about 3.6 to 3.8 mg N dm^{-3} in the late 1980's and early 1990's to about 2.2 mg N dm^{-3} in the last 5 years of the study period. The average concentrations of total phosphorus showed the highest values between 1989 and 1991, with a maximum of about 0.5 mg P dm^{-3} in 1990, and were then gradually decreasing to about 0.12 mg P dm^{-3} in the late 2000's and early 2010's. Additionally, during the last 25 years the N_{tot}/P_{tot} ratio increased significantly, which is indicative of the improvement of ecological status of studied rivers. Correlation analyses indicate that significant reduction in point emission of nutrients and in consumption of organic fertilizer played an important role in the change of nutrient concentration in study rivers.

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1. Introduction

The European Water Framework Directive (WFD), recognizing close interdependencies existing in the river basin – river – coastal waters – sea systems (Buszewski et al., 2005; Grimvall et al., 2000; Howarth et al., 2000; Löfgren et al., 1999; Schernewski et al., 2008; Stålnacke et al., 1999), provides for sustainable and integrated management of surface, ground and coastal waters. Environmental considerations form the basis of the WFD, with the ultimate aim of achieving “good ecological status” in all water bodies by 2015. Adopting the European water policy included in the WFD (Directive, 2000/60/EC, 2000), has been the main objective of the long-term water management strategy in Poland.

Water quality in Poland, as well as in other Central and Eastern European countries, has been significantly impacted by political, and consequently economic changes occurring since the late 1980's. For example, in Poland mineral fertilizer use decreased from about 164 kg NPK ha^{-1} in 1989 to about 85 kg NPK ha^{-1} in 1995 (Environment, 1986–1996). Livestock stocking decreased by 21% in 1988–2008 (Pastuszak et al., 2012) and this caused a parallel decrease in the consumption of natural fertilizer. Additionally, investments in environmental protection increased significantly after 1989. This concerned especially waste water and sewage management, and caused considerable reduction in point source discharges. Thanks to the modernization of the old or the construction of new waste water treatment plants, the fraction of untreated waste water discharged into water and soil decreased from 42% in the early 1980's to 14% in 2000. The resulting changes in Poland were studied mainly in two largest rivers: the Vistula and the Oder (Korol et al., 2005; Łysiak-Pastuszak et al., 2004; Pastuszak et al., 2012; Pastuszak and Witek, 2012). Long-term changes in smaller rivers were studied to a much lesser extent.

This paper describes the changes in the concentration of nutrients in the rivers of the Polish coastal zone in response to economic and political changes that took place between 1988 and 2013. The aim was to verify the hypothesis that changes in the water quality of small rivers were associated with the changes in their catchment area. If so, the aim was to determine how significant this relationship was, and how quickly changes in land-based activities could be observed in the changes of surface water quality. Time series of nutrient concentrations measured in seven rivers in northern

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http://dx.doi.org/10.1016/j.ocecoaman.2015.04.007
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Poland were analysed in relation to the data on human activity changes.

2. Materials and methods

2.1. Study area

Long-term changes in nutrient concentrations were studied in the following rivers: Łeba, Łupawa, Słupia, Wieprza, Grabowa, Parsęta and Rega. They are located in the Polish part of the southern Baltic coastal zone (Fig. 1), between the two largest Polish rivers: the Vistula and the Oder. Hydrological conditions of the catchment area of the studied rivers are different than in the rest of the country. This region is one of the richest in water resources (Bogdanowicz, 2004), with the mean annual precipitation of about 600–700 mm, and the mean annual outflow coefficient of about 200–250 mm. It is characterized by many diverse lakes (2% of the catchment area), with the predominance of flow lakes (Bogdanowicz, 2004).

The Polish coastal rivers are relatively small (Table 1) but they drain as much as about 11% of the Polish territory. The longest of these rivers is the River Rega (188 km), while the River Parsęta has the largest catchment area (3.1 10^3 km^2). Mean annual volume of water discharged by the rivers directly or through coastal lakes into the Baltic Sea is about 0.46 km^3 (Łysiak-Pastuszak et al., 2004). Additionally, the studied rivers are characterized by relatively low ranges of flow variability. In the study region, agricultural land constitutes about 60% of the catchment area, and ranges from about 41% to 75%. Arable land dominates (about 70% of agricultural land) and forests constitute about 35% of the drainage basins.

The region is characterized by a low level of industrialization. The main sources of water pollution are associated with agricultural activity (crop and animal production) and municipal waste waters. Very light and light soils predominate. They have low field water capacity, and the river basin is highly susceptible to nutrient loss (Fotyma et al., 2012). For example, in 1989–1998 the average export of N_{tot} and P_{tot} from the catchments of the coastal rivers was about 1000 kg km^{-2} $year^{-1}$ and 70 kg km^{-2} $year^{-1}$, respectively. It was about 40% higher than the average values for Poland and for the Baltic drainage basin (Bogdanowicz, 2004).

2.2. Data sources and statistical analyses

All data analysed in this study were obtained from official sources. They were collected within the surface water monitoring programme of the Inspectorate of Environment Protection and Institute of Meteorology and Water Management. The data on water quality of coastal rivers were obtained at the sampling points situated closest to the river outlets to the Baltic Sea (Fig. 1, Table 1). The monitoring of coastal rivers was conducted by the laboratories of the Inspectorate of Environmental Protection in Gdańsk and Szczecin. Both laboratories have Accreditation Certificates of Polish Accreditation Center (PN-EN ISO/IEC 17025 standard). The frequency of sampling, and the analytical procedures are regulated by the Water Law (references methods recommended by Chief Inspectorate of Environmental Protection, Poland), which is also rooted in the EU Water Framework Directive 2000/60/EC (Directive, 2000/60/EC, 2000). The monitoring measurement program is conducted every year, with the frequency of at least 12 measurements a year. Some of the analytical methods have been changed or modified over the 25 year study period. These changes resulted from technological progress, increased consideration for human health in the laboratory and/or legislation changes. However, after each modification or change, methods were compared ("the old one with the new one") in order to establish measurement cohesion. Regular quality controls are being performed according to certified standards to ensure reliability of the results.

The following nutrient forms were analysed: total nitrogen (N_{tot}), nitrates ($N{-}NO_3$), ammonium ($N{-}NH_4$), nitrites ($N{-}NO_2$), total phosphorus (P_{tot}), and phosphates ($P{-}PO_4$). The concentration of organic nitrogen (N_{org}) and organic phosphorus (P_{org}) were estimated as the difference between total nitrogen (phosphorus) and the sum of inorganic nitrogen ($N_{inorg} = N{-}NO_3 + N{-}NH_4 + N{-}NO_2$) (phosphates), respectively. Average annual nutrient concentrations were used.

Information on social and economic changes (e.g. land use, mineral fertilizer consumption, animal production, number of municipal waste water treatment plants, amount of untreated waste water discharged to the water or ground) during the last 25 years in northern Poland were obtained from: the statistical data base of the Central Statistical Office (GUS, 1995–2013), available at: http://www.stat.gov.pl, and from the annually published Statistical Yearbooks – Environment (Environment, 1986–1996). The Central Statistical Office data are based on CSO survey, internal information systems, administrative data and monitoring reports.

The consumption of natural organic fertilizer (manure, slurry, and liquid manure) was estimated basing on the number of animals, expressed an Livestock Units (UL) (Fotyma et al., 2012). In this method one cow corresponds to 1 LU, and one pig corresponds to 0.3 LU. The amount of nitrogen and phosphorus in manure produced per single LU $year^{-1}$ was multiplied by the number of Livestock Units in a given year. The yearly amount of nitrogen and phosphorus per hectare of agricultural land was calculated according to the formulae:

$$fNorg = 63.3 \cdot LU \cdot Ar^{-1} \tag{1}$$

$$fPorg = 14.9 \cdot LU \cdot Ar^{-1} \tag{2}$$

where:

fNorg – organic nitrogen fertilizer consumption, kg N ha^{-1};
fPorg – organic phosphorus fertilizer consumption, kg P ha^{-1};
63.3 – coefficient (organic nitrogen amount in manure, slurry, and liquid manure, produced by 1 LU $year^{-1}$), kg N (Fotyma et al., 2012);
14.9 – coefficient (organic phosphorus amount in manure slurry, and liquid manure, produced by 1 LU $year^{-1}$), kg P (Ignas and Fotyma, 2012);
LU – number of animals converted into Livestock Units;
Ar – agricultural land, ha.

Statistical analyses were conducted in Statistica® v.10. The nonparametric Mann–Kendall test (M–K test) was used to analyse long term changes in nutrient concentrations in each river (Boyacioglu, 2014). To relate N_{tot} and P_{tot} concentrations (in mg dm^{-3}) to the number of municipal biological waste water treatment plants (with improved removal of biogenic substances) (MWWTP), and to the fertilizer supply, Spearman's rank-order correlation was used. The correlation of nutrient concentrations with fertilizer consumption was estimated for both mineral and organic fertilizers.

3. Results

In four studied rivers: Łeba, Słupia, Parsęta and Rega over the period of 25 years (1988–2013), a downward trend in the concentrations of all analysed nutrient forms was observed (Mann–Kendall test, $p < 0.05$) (Table 2). In the Łupawa and Wieprza rivers negative trends were observed in all but one parameter. Only

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