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Impact of forecasted changes in Polish economy (2015 and 2020) on nutrient emission into the river basins

Marianna Pastuszak [a], Tomasz Kowalkowski [b,*], Jerzy Kopiński [c], Jarosław Stalenga [c], Damian Panasiuk [d]

[a] National Marine Fisheries Research Institute, ul. Kołłątaja 1, 81-332 Gdynia, Poland
[b] Department of Environmental Chemistry and Bioanalytics, Faculty of Chemistry, Nicolaus Copernicus University, ul. Gagarina 7, Toruń, Poland
[c] Institute of Soil Science and Plant Cultivation—State Research Institute, ul. Czartoryskich 8, 24-100 Puławy, Poland
[d] Cardinal Stefan Wyszyński University in Warsaw, Faculty of Biology and Environmental Sciences, ul. Wójcickiego 1/3, 01-938 Warszawa, Poland

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ABSTRACT

Poland, with its large drainage area, with 50% contribution of agricultural land and 45% contribution of population to overall agricultural land area and population number in the Baltic catchment, is the largest exporter of riverine nitrogen (N) and phosphorus (P) to the sea. The economic transition has resulted in substantial, statistically significant decline in N, P export from Polish territory to the Baltic Sea. Following the obligations arising from the Helsinki Commission (HELCOM) declarations, in the coming years, Poland is expected to reduce riverine N loads by ca. 25% and P loads by ca. 60% as referred to the average flow normalized loads recorded in 1997–2003. The aim of this paper is to estimate annual source apportioned N and P emissions into these river basins in 2015 and 2020 with application of modeling studies (MONERIS). Twelve scenarios, encompassing changes in anthropogenic (diffuse, point source) and natural pressure (precipitation, water outflow due to climate change), have been applied. Modeling outcome for the period 2003–2008 served as our reference material. In applied scenarios, N emission into the Oder basin in 2015 and 2020 shows an increase from 4.2% up to 9.1% as compared with the reference period. N emission into the Vistula basin is more variable and shows an increase by max. 17.8% or a decrease by max. 4.7%, depending on the scenario. The difference between N emission into the Oder and Vistula basins is related to the catchment peculiarities and handling of point sources emission. P emission into both basins shows identical scenario patters and a maximum decrease reaches 17.8% in the Oder and 16.7% in the Vistula basin. Despite a declining tendency in P loads in both rivers in all the scenarios, HELCOM targeted P load reduction is not feasible.

1. Introduction

The intensity and spatial diversity of nitrogen (N) and phosphorus (P) emission into river basins and then into recipient water reservoirs depends on numerous natural as well as anthropogenic factors (Hatfield and Follett, 2008; Kowalkowski et al., 2012; Kronvang et al., 2005; Oenema et al., 2005). The natural factors encompass: type of bedrock, type of soil, slope, and area covered by lakes in a given catchment (Behrendt et al., 2005; Lepistö et al., 2006). The main anthropogenic factors are within the agricultural sector (diffuse nutrient outflow), and the Waste Water Treatment Plants (WWTPs), a predominant point source. The diffuse nutrient emission depends very much on land use/cover, physiographic features, management, meteorology, and hydrology, whereas point sources emission is mainly related to size of population inhabiting the catchment, and to handling of sewage produced (Pastuszak et al., 2012b; Rekolainen et al., 1995; Stålnacke et al., 2003, 2004; Vagstad et al., 2004). High human population density may also contribute to higher diffuse N outflow, as it is connected with accelerated nitrogen cycling through fertilizer use, food movement, atmospheric pollution, and land disturbance (Howarth et al., 1996).

Riverine geochemistry and material fluxes have been altered on the global scale by agriculture, deforestation, mining, urbanization, industrialization, irrigation, and damming (Humborg et al., 2006; Meybeck, 2001). The river borne fluxes of N and P to the oceans have increased worldwide by 4-fold (Martin et al., 1981). In some regions, the Western European rivers included, N fluxes through the atmosphere and through the rivers have increased by 10–15 fold or more (Howarth, 2008; Meybeck, 2001). Intensification of agricultural activity is reflected in an increase in application of natural and mineral fertilizers. Nausch et al. (1999) report 17-fold and 8-fold increases in the consumption of mineral nitrogen and phosphorus fertilizers in the Baltic Sea drainage basin in 1950–1988, with some decreasing tendency in the years that followed.

Poland, with its large drainage area, the largest Baltic population (45%) and the largest Baltic agricultural area (50%), is one of the main exporters of N and P to the Baltic Sea (Pastuszak, 2012). Since the

* Corresponding author. Tel.: +48 56 665 60 64; fax: +48 56 611 4837.
E-mail address: pinez@chem.umk.pl (T. Kowalkowski).

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early 1990s, Poland has made remarkable environmental progress, meeting most of its environmental targets and decoupling a number of environmental pressures from economic growth. Polish agriculture, which considerably contributes to diffuse N, P fluxes, underwent dramatic changes, with a substantial increase in both the animal number and the application of mineral and natural fertilizers over the years 1960–1980. That increase was followed by a substantial decrease in these parameters during the transition period (Fotyma et al., 2012; Igras and Fotyma, 2012; Pastuszak and Witek, 2012; Pastuszak et al., 2012a,b). The economic structural changes during the transition period have also contributed to progress on a number of some other fronts e.g. reductions in air pollutants emissions (Błaś et al., 2008; GUS, 1991–2010), declines in water withdrawal, construction of 1864 modern and efficient WWTPs in the years 1995–2008 resulting in ten-fold decrease of volume of untreated sewage (Pastuszak et al., 2012a,b), enormous progress in developing of technical infrastructure for livestock production, which undoubtedly contributes to decline in nutrient emission from dispersed point sources in agricultural sector (Lipiński, 2012; Pietrzak, 2012). Temporal fluctuations in pressure were mirrored in an 2–3 fold increase in N and P emission into the Oder basin in the 1960–1990 (Behrendt et al., 2005), followed by a decreasing tendency in the Vistula and Oder basin in 1995–2008 (Kowalkowski et al., 2012; Pastuszak et al., 2012a,b). The reduced N, P emission into river basins resulted in noticeable and statistically significant declines in N and P discharges into the Baltic Sea (Pastuszak and Witek, 2012; Pastuszak et al., 2012a,b).

Introduction of market economy in Poland has launched adjustment processes in agricultural production. Changes in the structure of this production were also related to changes in livestock population and production, livestock output, and milk yield. The processes of concentration and specialization of production have also been progressing (Kopiński, 2013). Changes in the prices of raw materials and products of animal origin, resulting from the supply and demand relationship had decisive influence on these developments. Supply and demand are derived from the income of the population and the needs and tastes of consumers. Trade liberalization and increasing globalization often enhance the dynamics of these changes. Apart from domestic agricultural policy, Polish agricultural sector is strongly related to policy of the European Union (EU), e.g. still discussed arrangements concerning the final shape of the future Common Agricultural Policy (CAP) (Krasowicz et al., 2012). Possible alterations in this sector may affect N and P surplus. The higher is the surplus the higher is the risk of nutrient leaching, particularly N, from the soil (e.g. Oenema et al., 2005). N and P surplus in agriculture depends in turn on (i) arable land area, (ii) the amounts of applied mineral fertilizers, (iii) livestock population which is connected with production and thus amounts of applied natural fertilizers, and (iv) sown areas and yields of main crops (Fotyma et al., 2012; Igras and Fotyma, 2012).

GIS-oriented model MONERIS, served as a tool to forecast the source apportioned N and P emission (from diffuse and point sources) into the Vistula and Oder basins in 2015 and 2020 for 12 scenarios (for details see to next section). The selected two years of our studies are consistent with years which often appear in legal acts and strategies (EFMA, 2011; Strategy…, 2012). Poland, as a member of the European Union (EU), is obliged to implement the EU directives, including the Marine Strategy Framework Directive assuming improvement of parameters responsible for the Baltic eutrophication. The latter problem is expected to be solved by a significant reduction of riverine N, P loads. Poland, the largest exporter of N, P to the Baltic Sea, is expected to considerably reduce N, P loads in the years to come (HELCOM, 2011, 2013a,b). Polish economy is dynamically developing, therefore it is interesting to estimate (i) how various pressures imposed by anthropogenic factors (agricultural sector, regional changes in population, handling of sewage, developing infrastructure etc.) and change in precipitation will in turn affect N and P emission into the rivers and then into the Baltic Sea in the years to come, and (ii) whether, under the circumstances, Poland is likely to fulfill the HELCOM obligations.

2. Material and methods

Our knowledge in the area of expected changes in agricultural and other sectors of Polish economy was based on Polish legal acts and strategies (EFMA, 2011; Strategy…, 2012) as well as EU regulations which are, or will be implemented in near future (Jadczyszyn and Rutkowska, 2012); we have also used the data from the Central Statistical Office (GUS) reports (GUS, 1991–2010, 2008, 2009a,b,c, 2010a,b, 2011a,b,c).

2.1. Study area

Almost all of Poland (99.7%) lies within the Baltic Sea drainage basin. Most of the land belongs to the large drainage basins of the Vistula River (194,424 km^2, with 168,699 km^2 within Polish borders, constituting ca. 54% of Polish territory) and the Oder River (118,861 km^2, with 106,056 km^2 within Polish borders, constituting ca. 34% of Polish territory). Small rivers drain the remaining area (>11%) and discharge directly to the Baltic Sea, (HELCOM, 2004; Fig. 1).

With surface area of 31.3 million ha (312×10^3 km^2), Poland ranks among Europe's larger countries. Rural areas cover approximately 29.7 million ha, which represents more than 95% of the total area of Poland. Poland is largely a lowland country, with 91.3% of its area located in the lowland zone. Nearly 87% of the entire Polish area has a land slope below 3°. Thus, slow-flow systems predominate in Poland, with majority of water and nutrients infiltrating through the soil layers before they reach subsurface waters or groundwater (Wrzesiński, 1998).

Poland is one of the countries with the largest share of agricultural land in the total area of the country. The average global share of agricultural area is less than 36%. Agriculture and forestry are the two main forms of land use in Poland. In 2006, the agricultural land and the utilized agricultural area (UAA) accounted for 61% and 51%, respectively, of the entire Polish territory.

Polish agriculture is dominated by small farms, of 1–5 ha. They constitute over 55% of the total number of farms, but hold only about 20% of agricultural land. The largest fragmentation of individual farms is observed in southern and south-eastern part of the country i.e. mainly in the Vistula river basin (Krasowicz et al., 2012). Poland has poor natural conditions for agricultural production as sandy formations occupy about 50% of the total area, while very acid and acid soils cover almost 50% of the agricultural land. Significant threat to the quality of soils in Poland and to their resistance to the loss of mineral nitrogen and phosphorus compounds is associated with water erosion. The largest share of soils at risk of surface water erosion occurs in the southern mountainous part of the country. The hydro-physical properties of soils, i.e. water retention and water permeability in both saturated and unsaturated zones are of great importance as they not only shape soil water balance but also determine water availability for crop growth. The soil physical properties also impact the fate and transport of plant nutrients, particularly the transfer of nutrients into deeper soil layers (Walczak et al., 2002).

The population of Poland has grown from around 25 million in 1950 to over 38 million in 2009, leading to a population density of 124 persons/km^2. The Vistula and Oder basins within the Polish territory are inhabited by 21.3 million and 13.2 million people, respectively (GUS, 2010b). Rural (14.8 million) and urban (23.3 million) population account for 38.8% and 61.2% of the total Polish population, respectively.

Between 1990 and 2010 the percentage of population that was served by WWTPs in urban and rural areas increased from 54% to 89% and from 3% to 28.8%, respectively. However, it has to be remembered that there is an expansion of individual sewage treatment plants serving single or multiple adjacent households in rural areas, and these facilities are not covered by the official statistics. Such plants are practically not found in cities, especially in large ones (GUS, 2010b; Krasowicz et al., 2012).

Poland's climate is moderate i.e., intermediate between maritime and continental climates. Poland finds itself in the zone of atmospheric fronts, and as a result, the fairly wet and mild winters, with average