Journal of Hydrology: Regional Studies 15 (2018) 203–216

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

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

# Spatio-temporal analysis of phosphorus concentrations in a North-Eastern German lowland watershed

Stefan Koch*, Petra Kahle, Bernd Lennartz

*Agricultural and Environmental Sciences, University of Rostock, Chair for Soil Physics, Justus-von-Liebig-Weg 6, 18059 Rostock, Germany*

ARTICLE INFO

*Keywords:*
Catchment hydrology
Dissolved reactive phosphorus
Total phosphorus
Artificial drainage
Monitoring
Sub-basin scale

ABSTRACT

*Study region:* The Warnow River Basin, an agriculturally dominated lowland watershed in North-Eastern Germany with a considerable extent of artificial drainage.

*Study focus:* We analyzed a 21-year data set (1990–2010) of dissolved reactive (DRP) and total phosphorus (TP) concentrations in surface waters to evaluate trends and seasonality of phosphorus (P) concentrations and pathways of P losses from soils.

*New hydrological insights for the region:* Phosphorus concentrations were moderately spatially variable over the investigation period and mean DRP and TP concentrations ranged from 57 to 132 $mg\,l^{-1}$ and 114 to 184 $\mu g\,l^{-1}$ respectively. The mean annual DRP and TP loads ranged from 0.04 ± 0.01 to 0.15 ± 0.05 and 0.12 ± 0.05 to 0.27 ± 0.06 $kg\,ha^{-1}\,a^{-1}$, respectively. We detected significant negative temporal trends of P concentrations and loads in the decade 1990–2000. In the 21st century, the TP concentrations and loads tend to increase moderately. The results underline the importance of baseflow for DRP export and storm flow events for TP export, and emphasize the importance of artificial drainage systems modifying the hydrological regime of soils and surface waters alike. The P export rates during storm events and the proportion of particulate phosphorus in artificial drainage systems should be monitored at a higher temporal resolution to obtain a comprehensive database necessary for developing management strategies to reduce P loads in agricultural used landscapes.

## 1. Introduction

Eutrophication of surface waters is still a major environmental concern worldwide, and losses of phosphorus (P) from arable land being a major contributor (Sharpley et al., 2015). The enrichment of P in surface waters generally leads to an increased growth rate of algae and inferential consumption of oxygen (Carpenter, 2005). The reduction of point and non-point sources of P is therefore a priority for future land use (Daniel et al., 1998). The European Water Framework Directive (Directive 2000/60/EC) commits European Union member states to achieve a good qualitative status of all surface water bodies. Current recommendations for a good qualitative status are concentrations of dissolved reactive phosphorus (DRP) and total phosphorus (TP) below 100 and 150 $\mu g\,l^{-1}$, respectively (Länderarbeitsgemeinschaft Wasser, 1998). By the year 2000, the year the Water Framework Directive became law, numerous German rivers and streams did not fulfill these requirements.

Although eutrophication is a general concern in Europe, the Baltic Sea is, in particular, threatened by eutrophication through its geographical situation. The watershed of the Baltic Sea is about 1,745,000 $km^2$, which is approximately four times larger than the Baltic Sea itself (Stålnacke et al., 2015).

* Corresponding author at: University of Rostock, Faculty of Agricultural and Environmental Sciences, Justus-von-Liebeig-Weg 6, 18059 Rostock, Germany.
*E-mail address:* stefan.koch4@uni-rostock.de (S. Koch).

https://doi.org/10.1016/j.ejrh.2018.02.001
Received 1 November 2017; Received in revised form 25 January 2018; Accepted 1 February 2018

In Germany the P input to water bodies was 23,000 t $a^{-1}$ in 2012–2014 and decreased by more than 72% compared to 1983–1987 mainly due to improved waste water treatment (UBA, 2017). With the reduction of point source loads in recent decades, nonpoint pathways have become dominant sources of phosphorus. Today the proportion of diffuse to point sources of phosphorus loading is 65% to 35% (Kunkel et al., 2017).

Generally, agriculture is the major source of P input into water bodies (Gentry et al., 2007). A successful cultivation of crops as well as the preservation of soil fertility is, however, depending on a sustainable nutrient management, including the use of mineral and organic fertilizers (Cordell et al., 2009). It is usually assumed that the agronomic soil status affects the phosphorus losses from land to water, primarily in form of dissolved reactive phosphorus (DRP; McDowell et al., 2001) or by fast transport processes, such as surface runoff, shallow interflow and macropore flow (Schärer et al., 2007). Kronvang et al. (2007) found increasing agricultural shares of the P losses to surface waters in 35 catchments (< 30 $km^2$) in the Nordic-Baltic-region of Europe, but no relationship with the short term P surplus on agricultural land. The annual P loss was greatest in the catchments characterized by soil erosion and high proportion of surface run-off. Today, there is increasing evidence that particle facilitated P transport through the soil profile and the release of P from the sediment to surface water bodies may be an important contributor to the eutrophication of rivers and streams (Outram et al., 2014; King et al., 2015).

Tile drainage is a common practice in agriculture to decrease soil moisture and improve aeration especially in lowland catchments. It shortens the residence time of water in the soil and therefore forms an important pathway for solutes to surface water bodies (Kladivko et al., 1999). The impact of surface runoff to riverine P concentrations may be negligible in lowland catchments; however, single storm events can advance the P transport from the soil to surface water via artificial drainage (King et al., 2017). Tiemeyer et al. (2009) determined low P concentrations in tile drainage water in German lowland catchments, but highlighted the relevance of preferential flow pathways along earthworm burrows and root channels. Zimmer et al. (2016) observed excessive yellow-brown ochre flocs in the drain water after storm events, containing high P amounts as formed by fungal mycelia with precipitated Fe- and Mn-(hydr) oxides at the surface. Nausch et al. (2017), who examined concentrations, fractions and association of P with other elements in a lowland watershed in North-Eastern Germany, found increasing total phosphorus concentrations in the succession tile-drain outlet, adjacent ditch and brook and further downstream stations as a result of elevated dissolved reactive phosphorus, particulate reactive and organic phosphorus. Variable concentrations and losses of TP and DRP over different winter seasons with elevated concentrations during intensive snowmelt events were observed in the same watershed (Tiemeyer et al., 2009). Danz et al. (2013) likewise highlighted that a small number of rainfall and snowmelt runoff events accounted for the majority of the total event loading.

Our understanding of the tile drainage pathway in the context of P export needs to be further explored (Sharpley et al., 2015). For a better understanding of the interactions between agriculture and water quality on the basin and sub-basin scale, land use (data soil, drainage, tillage, crop choice), fertilizer management data (input, timing) and hydrological data should be recorded regularly (Daloğlu et al., 2012). Most important, long-term observations of P concentrations and possibly other nutrients (e.g. nitrogen) and contaminants (e.g. heavy metals) are needed to better understand the spatial and temporal variability of the P concentrations and loads in rivers. Because of the general lack of long term data for North-Eastern Germany, the main drivers of P transport from land to surface waters are not well understood.

The aim of this study was to analyze the temporal and spatial variability of P concentrations and P loads in the surface water bodies of an agricultural lowland watershed in North-Eastern Germany with a considerable extent of artificial drainage over the period 1990–2010. We wanted to test the capability of water quality data with bi- to four-weekly temporal resolution, a resolution that is common in governmental monitoring programs, to uncover intra- and inter-annual variability and long-term trends. The 20-year data set allowed to assess the impact of the political regime shift that took place in the former Soviet Union hemisphere in the early 1990ies on environmental quality parameters. The dataset was, therefore, subdivided in the period 1990–1999 and 2000–2010. Furthermore, we intended to detect the regional distribution of P pathways to surface waters using multiple linear regression and non-linear regression models.

## 2. Material and methods

### 2.1. Study site

The Warnow River basin (3028 $km^2$) is located in the federal state of Mecklenburg-West Pomerania in North-Eastern Germany (Fig. 1) and consists of nine sub-basins (Table 1). The climate is influenced by the Atlantic Ocean with a mean annual precipitation of 643 mm and a mean annual temperature of 10.4 °C (1990–2010). The basin is characterized by gentle slopes with a maximum elevation of 146 m. The land use (DLR, 2003) is dominated by agriculture (71%); further uses are forests (22%), wetlands (< 1%), open water areas (4%), and artificial surfaces (4%). The land use distribution changed within the past 20 years by a reduction in arable land and urban sprawl. About 42% of the Warnow River basin is artificially drained by subsurface drainage systems or drainage ditches. Approximately 100 waste water treatment plants of varying sizes are located in the watershed (Fig. 1).

Dominant soil types according to the World Reference Base (WRB) classifications (FAO, 1998) are Luvisols (43%), Cambisols (19%), Stagnosols and Gleysols (21%) under arable use, while grassland and forests are typically situated on degraded Histosols (16%) (Fig. 1). A comprehensive characterization of land use and soil composition of the Warnow River basin is given by Koch et al. (2013).

The Warnow River (143 km length) discharges into the Baltic Sea. The mean streamflow was 16.7 $m^3 s^{-1}$ in the period from 1990 to 2010. The elevation difference from spring to the mouth is 68 m. A weir and a dam at the Warnow River gauge station "Rostock" strongly influence the streamflow measurements at this point (sub-basin Upper Warnow).