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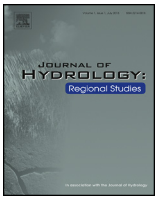

Assessment of changes in riverine nitrate in the Sesan, Srepok and Sekong tributaries of the Lower Mekong River Basin

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ABSTRACT

Changes in nitrates are of particular concern in tropical regions undergoing rapid development, as these changes may affect local and downstream riverine ecosystems. This study assessed the spatial and temporal differences in nitrate loads within the Sesan, Srepok, and Sekong (3S) Rivers, the largest tributaries of the Mekong River. Simulation results from a flow and nitrate calibrated SWAT model show large differences in year-to-year nitrate loads, a strong seasonality, and clear variability patterns in monthly nitrate loads in the 3S outlet during the wet season. The annual total nitrate loading from the 3S Rivers account for approximately 30% of the total nitrate load of the Mekong River at Pakse. Nitrate loads during the rainy season accounts for 79% of the total annual load into the Mekong River. The Sesan, Sekong, and Srepok basins have average nitrate yields of 400, 330, and 290 kg N/km^2, respectively, which is comparable with other forested catchments, but much lower than agriculture dominated catchments in the tropics. Simulations of three future climate scenarios show little variability in annual nitrate loadings under current land use/land cover (LULC), but seasonal difference in nitrate loading during rainy months was observed. Further research is needed to estimate nitrate loads in the 3S basin as influenced by LULC change and dam development, which may potentially result in complex changes to local and downstream riverine ecosystems.

1. Introduction

Global riverine nutrient inputs into the oceans have tripled during the second half of the 20th century (Jennerjahn et al., 2004). The global biogeochemical cycles of Nitrogen (N) have been significantly altered due to the increasing demand of food and energy consumption caused by increasing population and human activities (Galloway and Cowling, 2002; Seitzinger et al., 2010). The rate at which biologically available nitrogen enters the terrestrial biosphere has more than doubled in the past five decades through activities such as fertilizer production and use, fossil fuel combustion, and cultivation of leguminous crops (Galloway et al., 2004).

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Numerous studies exist on catchment-level changes that influence nutrient cycling and lead to nutrient enrichment, changes in algal and fish ecology, deterioration of water for drinking and recreational purposes, and other consequences (Smith et al., 2003; Jennerjahn et al., 2004). The main sources of high nitrate loadings in river systems are fertilizer application in agriculture, wastewater treatment effluent, and burning processes via deposition of gaseous nitrogen (Zweimüller et al., 2008). Nitrate transport to waterways from diffuse sources is a major cause of eutrophication and episodic acidification for inland aquatic systems and coastal zones (Meader and Goldstein, 2003; Wellington and Driscoll, 2004). High nitrate concentrations in streams and aquifers are also a major concern for drinkable water supplies and for the health of aquatic ecosystems (Gascuel-Odoux et al., 2010).

Climate variability is a strong driver of the hydrological cycle, and therefore it modifies the fate and transport characteristics of nutrients (Bouraoui et al., 2002). Climate is a major driver for biological, chemical and physical processes which determine nitrate cycling (Howden and Burt, 2009; Jones and Smart, 2005; Zhang and Schilling, 2005). Changes in the natural water regime alter the ability of river systems to retain, transform, and transport nutrient loads originating from upstream and upslope regions (Seitzinger et al., 2002). Climate dictates the seasonality of flows, which controls nutrient export patterns (Pionke et al., 1999). Hydrologically active periods, particularly flood events, are important because the addition of new water sources during such events mobilises distinctly new and different sources of nutrients from the catchment to the river (Buda and DeWalle, 2009). Oeurng et al. (2010) showed that strong temporal variability of nitrate transport occurred during flood events in a large agricultural catchment in south-west France. A study by Zweimüller et al. (2008) on the effects of climate change on nitrate loads in the Austrian Danube River showed that more nitrate will be transported during winter and less during summer as a direct consequence of temperature change, which is a major driver for biological, chemical and physical processes which determine N cycling and losses (Howden and Burt, 2008). Climate change will also increase the nutrient losses to surface water by accelerating soil processes such as mineralization of organic matter as has been shown in a study of the Yorkshire Ouse catchment in the UK (Bouraoui et al., 2002). In tropical regions of Australia, the effect of agriculture on nitrate yields has also been shown to be significant and nitrates were found to be transported efficiently downstream, with processes such as denitrification in channels being limited (Brodie and Mitchell, 2005). In short, the effect of climate change varies from region to region and the effect of climate on nitrate loads depends on catchment-specific parameters. It is therefore important to understand how climate change affects riverine nitrate loads on a regional and catchment specific basis.

Various models to simulate nitrogen transformation processes, fate, and transport have been developed at the catchment scale to study N dynamics and spatial interactions, including the AGricultural Non-Point Source Pollution Model (AGNPS), Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), Erosion Prediction Impact Calculator (EPIC), Soil and Water Assessment Tool (SWAT), Hydrological Simulation Program FORTRAN (HSPF), Storm Water Management Model (SWMM), and Water Quality Analysis Simulation Program (WASP) (e.g., Beasley et al., 1980; Duda et al., 2003; Edwards et al., 1994; Arnold et al., 1998; Kinerson et al., Bicknell et al., 2005; Gironás et al., 2010; Di Toro et al., 1983). Among these models, SWAT has been the most widely used to assess hydrology in catchments, as well as to help identify pollution sources (Holvoet et al., 2008), to assess impacts of climate change (Singh and Gosain, 2011), and to assess agricultural management practices (Moriasi et al., 2011). SWAT is considered to be an appropriate tool for assessing nitrate fate from daily to yearly time steps for a wide range of catchment configurations (Santhi et al., 2001; Grizzetti et al., 2003; Jha et al., 2007; Lam et al., 2010; Boithias et al., 2014; Zhai et al., 2014).

Changes in nitrate are of particular concern in tropical regions undergoing rapid development such as the Mekong basin (MRC, 2003; Galloway et al., 2004). The Mekong is the largest river basin in Southeast Asia, covering an area of 795,000 km^2 where millions of people depend on local fish and rice for their subsistence. Agricultural, ecological, and fish productivity in the lower Mekong, particularly in the Tonle Sap lake in Cambodia and the Mekong Delta in Vietnam, are attributed to the seasonal delivery of water, sediments, and nutrients (Arias et al., 2014a; Kummu et al., 2008; Lamberts, 2006). The Mekong is facing the disruption of its nutrient balance as large increases to nutrient inputs to surface water are expected in the twenty-first century due to increases in agricultural production and infrastructure development (MRC, 2003, 2011; Chea et al., 2016). In southern Vietnam, a significant disturbance to the nitrogen balance of the region has already been observed and it has been attributed to agricultural development in that region (Watanabe et al., 2002). Some large scale studies on nutrients in the Mekong have been conducted (Yoshimura et al., 2009; Liljeström et al., 2012; Li and Bush, 2015), but more detailed research on nitrate loadings is needed in key tributaries. Drastic changes in land use, climate, and water infrastructure development occurring in the key Sesan, Srepok, and Sekong (3S) tributaries of the Mekong are of great concern because these rivers' significant contribution of sediments, nutrients, water flows, and fish diversity to the downstream Tonle Sap Lake and Mekong Delta (Ziv et al., 2012; Arias et al., 2014b). Changes in water flows will be significant due to the future development of over 41 hydropower dams in the 3S basin (Piman et al., 2012) and changes in sediment as also expected to be significant (Kummu et al., 2010; Wild and Loucks, 2014; Kondolf et al., 2014). Information is currently not available as to how hydropower reservoirs operations affect nutrient levels in the Mekong, but it is well known that changes in the nitrogen cycle can occur in large hydropower reservoirs (Kunz et al., 2011). Overall, a quantification of the current nitrate levels along segments of the 3S Rivers is first needed to understand baseline levels, as well as an estimation of potential changes due to climatic change and land use conversion, as these will affect local riverine ecosystems and the provision of aquatic biodiversity, ecosystem services and fisheries to the lower Mekong.

Despite future prospects of climate change, land use conversion, and hydropower development, little is known about historical trends in spatial and temporal variability of nitrate loads from the Mekong tributaries and within the 3S basin.