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Modeling the contribution of point sources and non-point sources to Thachin River water pollution

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ABSTRACT

Major rivers in developing and emerging countries suffer increasingly of severe degradation of water quality. The current study uses a mathematical Material Flow Analysis (MMFA) as a complementary approach to address the degradation of river water quality due to nutrient pollution in the Thachin River Basin in Central Thailand. This paper gives an overview of the origins and flow paths of the various point- and non-point pollution sources in the Thachin River Basin (in terms of nitrogen and phosphorus) and quantifies their relative importance within the system. The key parameters influencing the main nutrient flows are determined and possible mitigation measures discussed.

The results show that aquaculture (as a point source) and rice farming (as a non-point source) are the key nutrient sources in the Thachin River Basin. Other point sources such as pig farms, households and industries, which were previously cited as the most relevant pollution sources in terms of organic pollution, play less significant roles in comparison. This order of importance shifts when considering the model results for the provincial level. Crosschecks with secondary data and field studies confirm the plausibility of our simulations. Specific nutrient loads for the pollution sources are derived; these can be used for a first broad quantification of nutrient pollution in comparable river basins. Based on an identification of the sensitive model parameters, possible mitigation scenarios are determined and their potential to reduce the nutrient load evaluated.

A comparison of simulated nutrient loads with measured nutrient concentrations shows that nutrient retention in the river system may be significant. Sedimentation in the slow flowing surface water network as well as nitrogen emission to the air from the warm oxygen deficient waters are certainly partly responsible, but also wetlands along the river banks could play an important role as nutrient sinks.

1. Introduction

Major rivers in developing and emerging countries suffer increasingly severe degradation of water quality. Due to population growth and economic development, plus the associated intensification of human activities in river catchments, the pressure on the water bodies rises, especially in peri-urban and urban areas. Intensive crop agriculture, aquaculture, pig and poultry production (Steinfeld et al., 2006) as well as industries and domestic areas discharge increasing amounts of untreated wastewater to surface waters, in excess of their capacity to cope with such loads. The resulting water quality degradation is a threat to the ecosystem and to human health.

The conventional approach to address degradation of river water quality is based on mathematical river water quality models which allow simulations of hydrodynamic and water quality transformation processes within the river water (Rauch et al., 1998; Shanahan et al., 1998; Somlyódy et al., 1998). In Asian countries today, the most frequently used water quality simulation programs are QUAL2E (e.g. in Azzellino et al. (2006)), WASP (Ambrose et al., 1988) and MIKE11 (DHI, 2007) (e.g. in Zhua et al. (2008)). Such models require hydrological river data and time series of input data describing the discharge into the main river. All pollution sources are considered as point discharges to the river body; non-point pollution sources are not specifically addressed (Shanahan et al., 1998). The models do not investigate the origins and pathways driving the discharge, so that the processes generating the pollution are not understood. The simulated water quality projections and mitigation scenarios are broad and generalized and lead to strategy plans that do not clearly identify and prioritize effective mitigation measures. Thus for instance, different waste management options cannot be compared with regard to their power to reduce nutrient loads in surface water (Shanahan et al., 1998).

The current study uses a mathematical Material Flow Analysis (MMFA) as a complementary approach to address the degradation of river water quality in developing and emerging countries. The MMFA

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focuses on the processes and pathways involved in generating the discharge to the river. In the first step, an overview is gained of the orders of magnitude and relative importance of the various pollution flows from their origin into the river system. In a second step, the key parameters influencing these flows are determined, on the basis of which then, mitigation measures at the sources of the pollution can be derived and evaluated.

To investigate the potentials of the MMFA approach as a basis for the remediation of river water quality in developing and emerging countries, the Thachin River Basin (TRB) in Central Thailand was selected as a case-study area. This area is characteristic of intensively used rural and peri-urban tropical delta river systems such as the Central Plains to the north-west of Thailand's capital Bangkok. Due to accelerated economic development in Thailand between 1980 and 1995, with an average economic growth rate of 7.8%/year, human activities in the basin strongly increased. This led to a degradation of the environment and to increasing pollution problems (PCD et al., 1997). By 2002, the degradation of the surface water quality in the basin had become of great concern to the government and public, to the extent that the Thachin was considered the country's most polluted river (Office of Natural Resources and Environmental Policy and Planning, 2002; Simachaya, 2003). This triggered the initiation of public awareness and political efforts towards rehabilitating the water quality of the Thachin River Basin. Strategy and action plans were elaborated together with concerned stakeholders (TCS and PCD, 2001, 2004) based on river water quality rehabilitation studies which used the water quality models mentioned above (Simachaya, 1999; PCD and Pro-En Technologies, 2002; PCD and Environmental Consultant, 2004). These studies did not explicitly compare the nutrient loads produced at the origins of the various pollution sources and in particular the pollution loads from non-point sources were not adequately quantified (Simachaya, 1999). Questions regarding the key sources, namely how the pollution is generated and how it may be most effectively mitigated at its source, remained unanswered.

The aim of the current case study is therefore to quantify and model the nutrient flows from the various point and non-point pollution sources into the Thachin River, and to determine effective mitigation measures. To achieve this aim, the following specific research questions are addressed:

- Which are the key nutrient flows from the various pollution sources to the river system? What is the spatial relevance of these nutrient flows within the basin (provincial level)?
- Which are the key parameters driving these nutrient flows?
- What possible measures could be taken to most effectively reduce nutrient pollution in the Thachin River Basin? And what would be their respective mitigation effects?

2. Study area: the Thachin River Basin (central Thailand)

The Thachin River Basin is part of the Central Plains of Thailand, with an area of approximately 12,000 km^2 (PCD et al., 1997) and a population of 2.5 million (REO5, 2004). The Thachin River is an effluent arm of the great Chao Phraya River. It originates in Chainat Province, approximately 180 km to the northwest of Bangkok, and meanders along a 320 km north–south stretch to the Gulf of Thailand, through the provinces of Chainat, Suphanburi, Nakhon Pathom and Samut Sakhon (Fig. 1).

The Thachin River Basin is subject to a monsoon climate, with average annual rainfall of 960 mm at Suphanburi station (1971–2000; see Fig. 1). Of this, 88% occurs between May and October (TMD, 2000).

Agriculture occupies roughly 52% of the basin's area (REO5, 2003). Crop production is intensive, with high fertilizer and pesticide inputs. Irrigated, high-yielding rice is the main crop. Rain-fed or partially irrigated field crops such as sugar cane, maize, cassava and sweet corn are grown towards the edge of the basin. A particular cultivation form

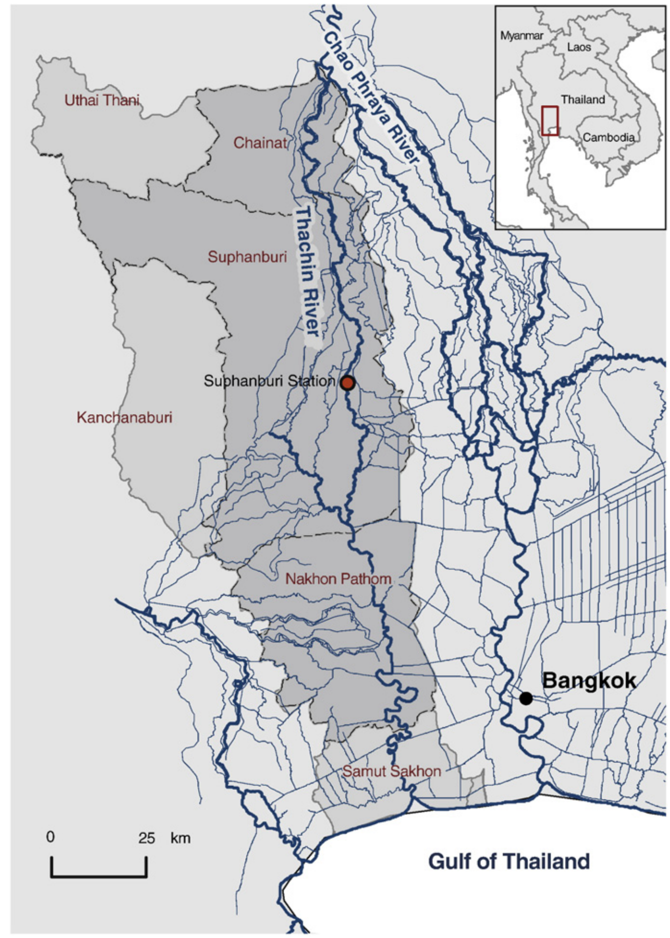

Fig. 1. Thachin River Basin and its main provinces (GIS sources: PCD (1995), Kasetsart University and IRD (1996)).

of “raised beds” (i.e. plots extracted from the marshy coastland by digging trenches and using the extracted soil to raise surrounding “beds” (Kasetsart University and IRD, 1996)) allows intensive and increasingly diversified fruit and vegetable production. Various types of aquatic plants are cultivated along the banks of the river and major canals.

The Thachin Basin is a major region for animal husbandry: pig farming in the basin covers 15% of national pork production (DLD, 2004). Poultry production (large-scale commercial farms, integrated poultry–fish farming and free-range husbandry at household level) contributes roughly 6% to national production (DLD, 2002). Aquaculture has been gradually moving from the traditional coastal shrimp production towards inland freshwater fish and shrimp production (Flaherty and Vandergeest, 1998; Funge-Smith and Briggs, 1998; Flaherty et al., 1999). Currently, the main fish crops in the Thachin River Basin are tilapia, freshwater shrimp, snakehead and catfish (Wittmer, 2005).

While the northern basin is largely rural in character, urbanization pressure has led to urban centers and ribbon settlements arising along canals and main roads in the southern basin. The southern basin provinces of Nakhon Pathom and Samut Sakhon belong to the Bangkok Metropolitan Region and have consequently undergone significant industrialization. Today they contain large industrial estates and numerous single factories with various types of production.

As a result of intensive land use and civilization pressure, high nutrient levels and associated oxygen depletion are apparent, especially in the southern basin reaches. An analysis of the official data for the Thachin River and its canals, monitored four times/year since 1991 (Simachaya, 2002; PCD, 2004, 2005), reveals that 80% of the measured