In-Channel Nitrogen Retention in a Small Tropical Stream in Thachin River Basin, Central Thailand

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Abstract

This study estimated ammonium retention in a drainage canal in tropical region. We first surveyed seasonal patterns of inorganic nitrogen loading from three land use types, pig farm, aquaculture and paddy field in Thachin River basin. The maximum ammonium concentration observed was then use in a tracer experiment to estimate ammonium retention in a drainage canal. Our results showed that pig farm is the largest point source of nitrogen among three land use types, and ammonium concentrations in the canal in pig farm area were significantly higher, about 10 to 20 times higher than in rice farm and aquaculture areas during the dry season. Ammonium concentration decreased as water flows into a larger canals and the main stream of the Thachin River, suggesting dilution and in-channel nitrogen retention. Co-injection of NaCl and NH_4Cl revealed the presence of ammonium retention in the study canal. The ammonium retention increased as the injected ammonia arrived but quickly stabilized around 1 mgL^{-1}. This result suggests that maximum ammonia concentration of 40 mgL^{-1} observed in the canal would likely be beyond the capacity of the in-channel ammonium retention. Therefore, the smaller effect of in-channel retention in the concentrated canal in pig farm is expected.

Keywords: ammonium retention; in-channel retention; tracer study; tropical stream

1. Introduction

In Southeast Asia, sewage without treatment is still directly discharged to rivers and canals in many areas, causing severe water quality problems (Smith et al., 1999). The Thachin River in central Thailand is not an exception. The Thachin River basin experiences intensive agricultural, livestock farming, and aquaculture activities which have rapidly increased between 1980 and 1995 due to economic growth (Schaffner et al., 2009b). As a result, the water quality has been rapidly degraded, and especially the middle and lower segments of the river experience elevated ammonia and phosphorus level and low dissolved oxygen concentration. In some critical areas, where there are intensive pig farm, aquaculture, and paddy field, the dissolved oxygen concentration reaches close to zero, and the ammonia and total phosphorus concentrations exceed by two to ten times of the Thai water quality standards (Schaffner, 2007). From 2000 to 2002, the Thachin River was named as the most polluted river in Thailand, and the river has been a focus of government and public concern (Simachaya, 2003; Schaffner et al., 2009b).

There have been several studies on water quality conducted in the main stem of the Thachin River (Mahujchariyawong and Ikeda, 2001; Simachaya, 2003). However, few studies were carried out in the tributaries and the irrigation canal system in the basin where people rely heavily on water for their livelihood and their survival, and where many aquatic organisms inhabit (Schaffner et al., 2009a). Observation of tributaries and canals will improve the management strategy of the Thachin River.

Aquatic ecosystems regulate transport of organic matter and nutrients through processes such as biotic uptake, microbial immobilization, transient storage, and sorption. Transient storage processes exert considerable effects on nutrient retention by increasing residence time, especially nitrogen due to its soluble form in water (Jones and Holmes, 1996; Gooseff, 2005). Many studies on in-channel nitrogen retention and transient storage have been carried out in streams of temperate region (Triska et al., 1989; Salehin et al., 2003; Ensign and Doyle, 2005; Gooseff et al., 2005; Schulz et al., 2003), and there are little studies in tropical region (Gücker and Boëchat 2004), especially in lowland streams. In addition, nitrate is commonly reported to be the dominant form of inorganic nitrogen, and many studies on nitrogen retention focused on nitrate and fewer studies on ammonium retention. In the Thachin River, ammonium is reported to be the dominant form of inorganic nitrogen (Schaffner et al., 2009b). This study focused on ammonium retention in drainage canals in tropical region. The unique setting of our study canals, tropical and ammonium-dominated, will improve the understanding of nitrogen retention in lotic system.

In this study, we examined retention capacity of drainage canals in the Thachin River basin. Firstly, we periodically sampled water from drainage canals in three land use types, pig farm, aquaculture and paddy field, to observe the distribution and seasonal patterns of inorganic nitrogen. The observed concentration was then used to set the condition of tracer study, co-injection of NaCl and NH_4Cl, to estimate in-channel retention of nitrogen. Many streams and rivers in tropical region face severe eutrophication problems, and understanding the natural abilities of rivers and canals to retain and remove nitrogen will provide useful information to improve river management.

2. Materials and methods

2.1 Study site description

The Thachin River basin, located in the Central Plains of Thailand, covers a total area of 12,000 km^2 with a population of around 2,5 million (DOPA, 2010). The Thachin River flows 325 km southward to the gulf of Thailand and is a branch of the Chao Phraya River, which is one of the fourth largest deltas in Southeast Asia (Figure 1). In the Central Plains of Thailand, the climate is dominated by monsoon regime which has two seasons, a dry season from November to April and a rainy season from May to October. In the period between 2005 to 2010, the Kamphaeng Saen weather station, located in Nakhon Pathom province, recorded an average annual rainfall of 1075mm with over 80% in a rainy season. The average monthly temperature ranged from 24°C to 30°C.

Nakhon Pathom province which is located in the middle to lower part of the Thachin River basin has numerous natural and artificial channels flowing through intensive pig farms, paddy field, and fish farm areas. Agricultural land use dominates the province of Nakhon Pathom, accounting for 63%. In 2009, there was 63,826.24 ha in rainy season and 6,4313.44 ha in the dry season (data obtained from the Department of Agricultural Extension of Thailand). Intensive use of fertilizer and pesticide is common, and paddy field is considered as the main nonpoint source of nutrient and toxic substance to the Thachin River (Simachaya, 2003; Schaffner et al., 2009b).

Aquaculture is another production sector that has contributed significant nutrient load to the Thachin River. Wastewater from fish and shrimp farm, which is considered as the point sources, discharges into the canal system and subsequently flows into the Thachin River (Schaffner et al., 2009b). In 2009, there was shrimp farm of 13,202.4 ha in the province of Nakhon Pathom (data obtained from the Department of Fisheries of Thailand). Nakhon Pathom province is also the third most important areas for pork production in Thailand with the approximately 80% of all pig farm in Thailand are located along the canal system in the Thachin River basin. Schaffner et al. (2009a) estimated that the total nitrogen loading from pig farm in Nakhon Pathom province is 2,380 tons per year, accounting for 71% of the total basin. As the results of intensive land use, the canal and its tributaries of the Thachin River in Nakhon Pathom provice have been experienced exceeded ammonia and phosphorus level and low dissolved oxygen concentration.

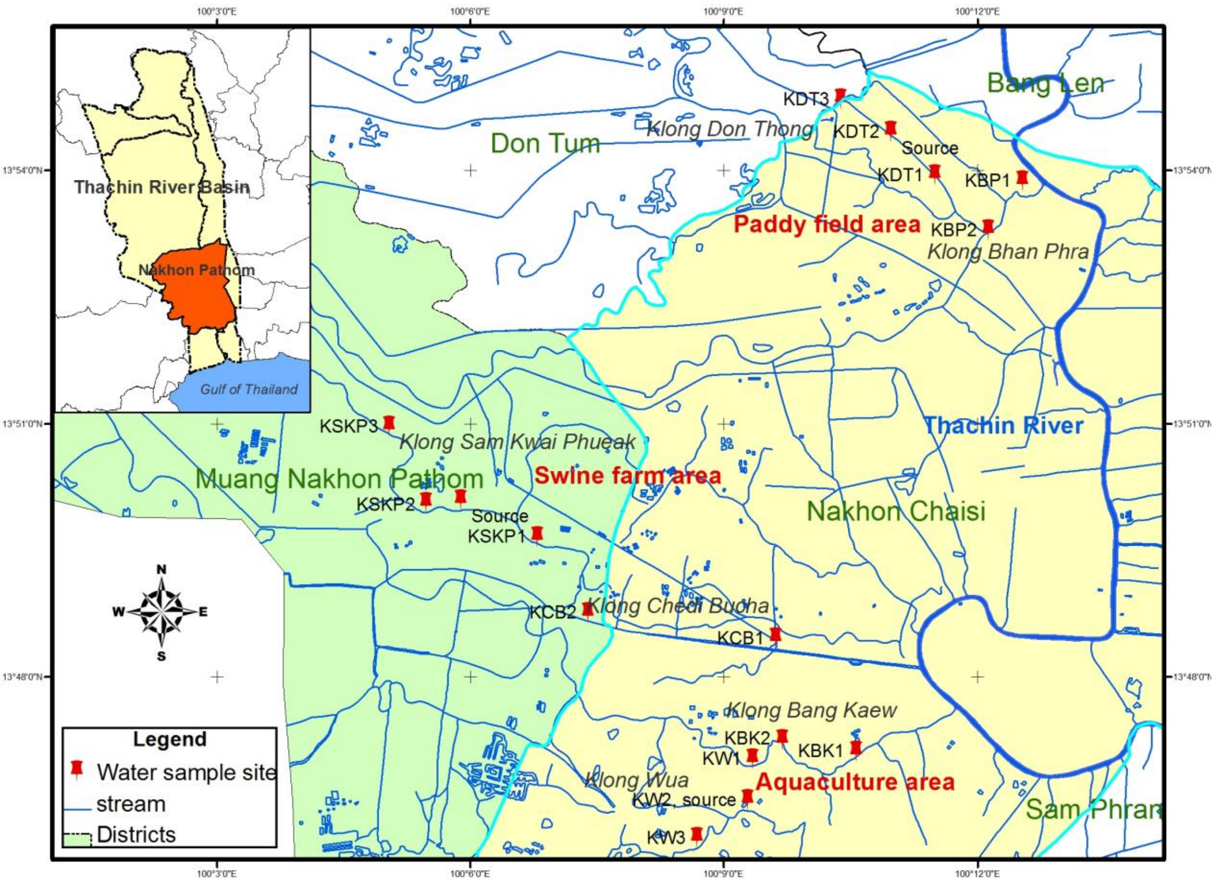

Figure 1. Map of the water sampling locations in the Thachin River basin.
Data were obtained from the Remote Sensing and GIS department, Environment and Resource Studies Faculty, Mahidol University.

2.2 Methods

1) Water sampling

Three sampling areas were selected from Nakhon Chaisi and Muang Nakhon Phathom districts to study the water quality condition, in particular nitrogen, of canals. Each sampling areas represents a land use type, either paddy field, pig farm or aquaculture ponds. At each sampling area, 6 water samples were collected periodically: a sample of direct discharge from the farm, 3 samples (upstream, middle, and downstream) at a selected small canal receiving directly discharges, 2 samples from a larger canal that drain into the Thachin River (Fig. 1). In pig farm area, there are 31 pig farms and three food production factories with the areas of roughly 32 ha and 61 thousands pigs, along the small canal. Based on our survey, only 11 pig farms, 35% of the total pig farms, have waste water pond. The remaining pig farms discharge untreated water directly to the canal that causes strong smell and results in high concentration of ammonia in the canal. The small study canal in aquacultural farming areas were surrounded by 52 fish and shrimp ponds with approximately 144 ha. There is also a small orchard farm growing, such as mango, guava, and rose apple. In the rice paddy area, the small canal was surrounded by rice paddy expect for a small orchard farm growing Calotropis gigantean, Orchid, Jasmine, Mango and Sansevieria cylindrica Bojer.

Based on the hyetograph, water sampling was conducted 6 times to capture seasonal pattern. We sampled in January, which are dry season, and in April, June, August and September, which are rainy season.

We carried out in-situ measurement of temperature, dissolved oxygen (DO), and salinity, using handheld sensors YSI 85, and collected water sample for nitrate and ammonia analysis. The handheld sensors were calibrated before each sampling. Water samples were transported back to the lab on ice, and they were filtered within 24 hours of sampling. The samples were preserved by adding 0.5 ml H_2SO_4 per 500ml to lower pH< 2 and kept in refrigerator at 4 degrees Celsius before analysis. Concentration of NO_3-N and NH_3-N were analyzed based on the Standard Methods for the Examination of Water and Wastewater by using Nesslerization method and Brucine method, respectively in the lab.

2) Stream tracer experiment

A stream tracer experiment was carried out in 200 meters reach of a small drainage canal inside Kasetsart University Kamphaengsean Campus, located in Nakhon Pathom province. Irrigated hay fields surround the experiment canal, and emergent and floating plants were present in the canal. To study nitrogen retention, a pulse co-injection of conservative (NaCl) and non-conservative (NH_4Cl) tracer was conducted on 2 November 2010. A concentrated solution of tracer was added to the canal at upstream point of the experiment reach. To ensure quick mixing of tracer with canal water, a weir to concentrate flow to the center of the canal was constructed just downstream of the injection point. At 200m downstream of the injection point, we measured specific conductance, using handheld meters, and sampled water for ammonium and nitrate analysis. Water samples were handled in the same way as described above. We injected enough tracers to reach the highest ammonium concentration observed during the water sampling of canal in three land use types at the upstream boundary of the experiment reach.

Specific conductance was used for surrogate of chloride concentration (Gooseff and McGlynn, 2005) by constructing calibration curve between specific conductance and chloride concentration before the experiment. It was made sure that calibration point covered the range of specific conductance we observed at the sampling location. Specific conductances measured during the experiment were converted to chloride concentration using the calibration curve.

3. Results and Discussion

3.1 Inorganic Nitrogen Concentration and Land Use Types

The spatial distribution of nitrogen concentration revealed strong effects of land use type on water quality. The dominant form of inorganic nitrogen was ammonium at all locations, and its concentrations were significantly higher in the canal in pig farm area, about 10 to 20 times higher than in the rice farm and aquaculture canals during the dry season (Fig. 2). The drainage from pig farm was very high in ammonia concentration, 75.75 mgL^{-1} to 179.75 mgL^{-1}, and it was reflected on the much higher concentration compared to other two sampling areas. A study on nutrient loading in the Thachin River showed that in Nakhon Phathom province pig farm is one of the largest point source of nitrogen (Schaffer et al., 2009).

Concentration of ammonia in small canals, receiving water from sources, was significantly higher than larger canals, receiving water from small canals, (Fig. 3). At the pig farm areas, ammonia concentration in the larger canal was 8.51 mgL^{-1}, which is 4 times lower than in the smaller canal in January water sampling. It suggests that the canal system itself have ability to reduce nitrogen concentration through dilution or in-channel processes, before discharging to the main river. Compared to the ammonia concentration in the Thachin River, monitored 4 times/year from 2000 to 2009 (data obtained from the Pollution Control Department of Thailand), the ammonia concentration we measured in the canal system was much higher than in the main stem of the Thachin River. The highest ammonia concentration in the main stem at the Nakhon Chaisi district was 2.1 mgL^{-1} in Feb 2009, which is 15 times lower than the highest concentration in similar season in the small canal we measured(Fig. 3). This finding reveals severe problems, much more than the main stem, that canal system faces in the Thachin River basin. Seasonal variation of ammonia concentration was also observed. It was high in dry season and low in wet season, which the canal in pig farm area showing the trend most significantly (Fig. 2).

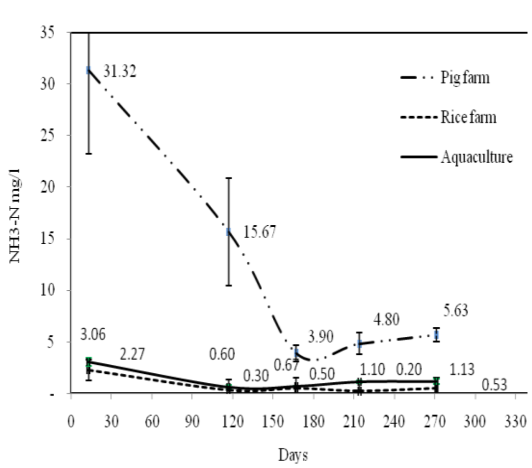

Figure 2. Concentration of ammonia at three sampling locations, pig farm, rice farm and aquaculture, from January to September 2010. Data show the concentrations in the small canal receiving drainage directly, and the error bars indicate 1 standard deviation.

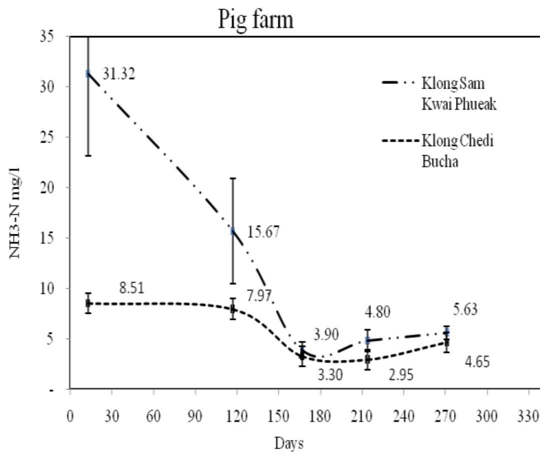

Figure 3. Concentration of ammonia in the study small canal, receiving a large quantity of drainage from pig farm, and in a larger canal, receiving water from small canals. Data were collected from January to September 2010.

The high ammonium concentrations corresponded with the pattern of dissolved oxygen (DO) concentration. DO was lowest in the pig farm canal and much higher in rice farm and aquaculture areas (Fig. 4). The low concentration of DO, which hinders nitrification, also explains ammonium as the dominant form of inorganic nitrogen. Nitrate concentration was consistently low with 0.1 mgL^{-1} and < 0.1 mgL^{-1}at all sampling locations. A common seasonal pattern was apparent among the three land use types. DO concentration in aquaculture and rice paddy area is likely affected strongly by farming practice, as drainage from aquacultural pond and rice paddy tend to be aerated water.

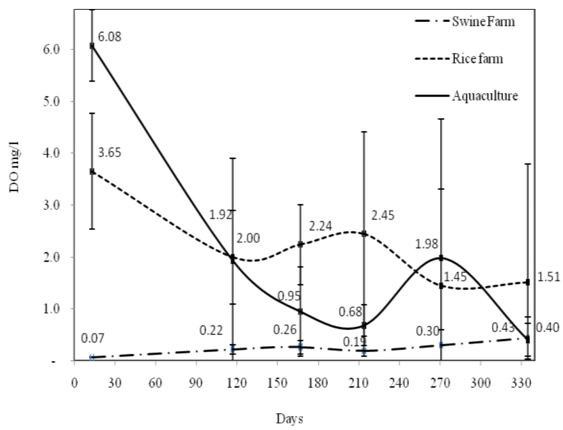

Figure 4. Concentration of dissolved oxygen at three sampling locations, pig farm, rice farm and aquaculture, from January to December 2010. Data show the concentrations in the small canal receiving drainage from particular landuse directly, and the error bars indicate 1 standard deviation.

3.2 Ammonium Retention in a Drainage Canal

Co-injection of NaCl and NH_4Cl was carried out to estimate ammonium retention. Concentrations of chloride and ammonia were measured at 210m downstream of the injection point (Fig.5). Chloride arrived at the sampling location, 40 minutes after injection, and returned to the background after 2 hours. Peak concentration of 67.4 mgL^{-1} was observed 55 minutes after the injection. Observed ammonia concentration showed similar pattern, but returning to the stable concentration early, 90 minutes after the injection. Peak ammonia concentration reached 7.3 mgL^{-1}, 5.4 mgL^{-1} above the background concentration.

Ammonium retention was estimated using the difference between observed and predicted ammonia concentrations. The predicted concentration, the expected concentration if there was no retention of ammonium, was derived from the chloride concentration. Observed concentration was consistently lower than predicted concentration, indicating presence of ammonium retention (Fig. 5). Ammonium retention results from biotic processes such as nitrification, plant uptake, and microbial immobilization (Gücker and Boëchat 2004), and abiotic processes, such as volatilization and sorption (Triska et al. 1994). Nitrate-N concentration was measured periodically throughout the experiment, and it stayed at ≤ 0.1 mgL^{-1}, suggesting that nitrification was negligible in the canal water where dissolved oxygen concentration was at or below 3.2 mgL^{-1}. Canal water had pH of 7.2, which does not support volatilization. Emergent and floating vegetation were observed throughout the canal. Presence of vegetation in water increases transient storage, which in turn increase ammonium retention through uptake and microbial immobilization (Gücker and Boëchat 2004). With the elevated ammonium concentration during the experiment, sorption to the sediment may account for considerable portion of ammonium retention (Triska et al. 1994).

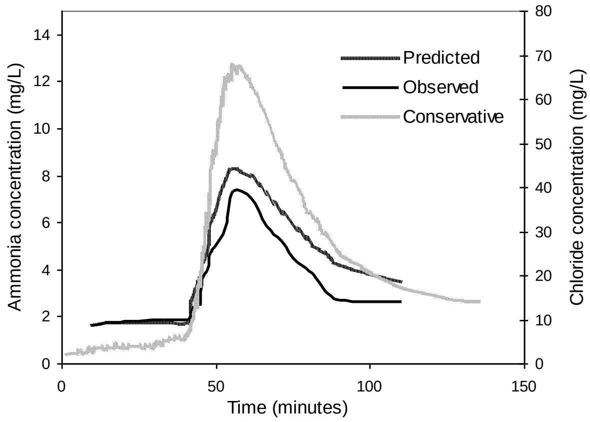

Figure 5. Concentration of ammonia and chloride at 210m sampling point was plotted against the time after injection. Data were collected on November 2, 2010. Using the chloride concentration, we calculated the expected concentration of ammonium if there were no retention, and it was also plotted as "predicted" ammonia concentration.

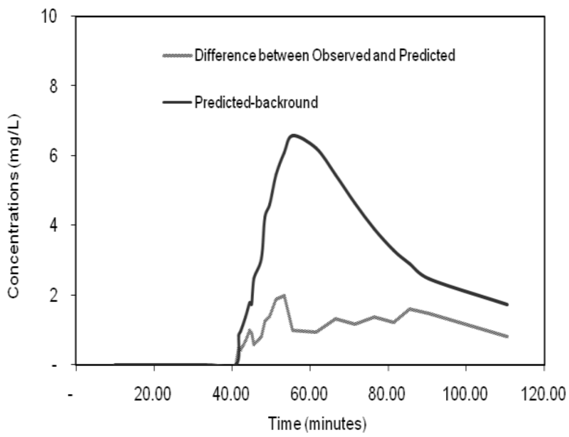

Figure 6. Predicted concentration of injected ammonia (predicted-background) and ammonium retention (Difference between predicted and observed) at 210m sampling point was plotted against the time after injection. Data were collected on November 2, 2010.

When the ammonium retention was compared to the predicted ammonia concentration, it showed that the retention increased as the injected ammonia arrived but quickly stabilized around 1 mgL^{-1} (Fig. 6). In the canal through concentrated pig farms where we carried out water sampling, the highest ammonia concentration observed was 40 mgL^{-1} in January, in the middle of dry season. Discharge from pig farms reached > 125 mgL^{-1}, and input from those sources with high ammonia concentration result in high canal ammonium concentration, especially in dry season. Although we cannot directly apply findings from a small drainage canal to a much larger canal, our results suggest that 40 $mgL^{-1}$of NH_4-N would likely be beyond the capacity of the in-channel processes to result in significant decline of ammonium concentration in canal water. Besides, in a larger canal, amount of vegetation relative to the volume of water is much smaller than the smaller canal, and smaller transient storage and thus smaller relative ammonium retention from uptake and immobilization is expected.

4. Conclusions

This study shows that ammonium concentration observed was much higher in small canals, receiving drainage from various source activities, compare to larger canals or the main stream of the Thachin River where previous studies have focused, and highlighted a severe excess nitrogen loading problem that canal network faces. The canal throughpig farm showed highest ammonium concentration, compared to aquaculture and rice paddy area. Ammonium retention estimated from the stream tracer experiment in a small drainage canal was around 1 mgL^{-1}, which is much lower than the ammonium concentration observed in the canals. Our results suggest that the effect of in-channel retention of ammonium is smaller in periods with high ammonium concentration.

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