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Nitrogen and Phosphorus Flow Analysis from Pig Farming in Bang Pakong Basin, Eastern Thailand

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Abstract

Material/Substance Flow Analysis, a systematic environmental management method, is applied to assess the current situation of nutrient (nitrogen-N and phosphorus-P) pollution arising from pig farming (including slaughterhouse activities) in Bang Pakong Basin (BPB), Eastern Thailand. This study was conducted by using the present information, based on several reliable sources, for calculations. The results of this study indicate that water supply and animal feed are the main mass inflows to the pig farms totaling 9.86 and 0.61 million tons per year respectively. The key nutrient inflows from animal feed are calculated as approximately 15,000 tons of nitrogen and 3,300 tons of phosphorus per year. All wastewater from pig farming to degrade water quality of the basin is about five million tons per year, which contains 3,250 tons of nitrogen and 1,030 tons of phosphorus per annum. According to this study, three scenarios are set and proposed to reduce the nutrient loads into the receiving water of the basin: 1) if all farms gathered and recycled dung to use as fertilizer and fish feed, this act alone would reduce nitrogen and phosphorus by 11% and 12% respectively; or 2) collecting all wastewater to a treatment system could decrease nitrogen and phosphorus amounts by 14% and 8% respectively; or 3) by combining both scenarios (1+2) the overall reduction for nitrogen would stand at 23% and 18% for phosphorus.

Keywords: Material/Substance Flow Analysis; Nitrogen; Phosphorus; Bang Pakong Basin; Eastern Thailand

1. Introduction

Diffuse water pollution, arising from livestock activities, has been concerned principally as a result of the intensification of the food production system and the increasing use of high nutrient feed. In Thailand, the total number of livestock (e.g. pig and poultry) increased 35% from 1998 to 2005 (DLD, 2009). This has led to intensified farming practices where a large number of animals are raised in a relatively small area, with the waste production (e.g. manure, slurry, and wastewater) from these farms has increased proportionately, thus its disposal has become problematic precisely because of the limited land area available. The livestock waste products contain valuable quantities of nutrients, such as nitrogen (N), phosphorus (P) and organic substances. The nitrogen and phosphorus become part of a complex transport and transformation process through different environmental media, like air, soil, and water. Key environmental problems from this nutrient pollution can be recognized as eutrophication of surface water, the leaching of nitrate to groundwater, the accumulation of macro nutrients in the soil, the volatilization of ammonia, and the emission of nitrous oxide to the air. In Thailand, several studies have focused on the environmental impact related to lack of manure management (FAO, 2004; Rattanarajcharkul *et al*., 2000). Pig farming is one of the main intensive livestock activities along the rivers (e.g. Thachin River and Bang Pakong River) and can be the point of origin for the nutrient pollutions (N and P) which subsequently degrade the water quality of the waterways. Therefore, a better understanding of the pig farming system and how it contributes to these nutrient pollutions should be measured and assessed to maintain an environmental balance (or a nutrient balance) and to discover the ways and means to keep these pollutions to a minimum.

Material/Substance Flow Analysis (MFA/SFA) is one method to achieve environmental management and sustainability analysis. It has been utilized in different system levels (global, national, regional, etc.), taking into consideration the types of flows (substances, materials, energy), and frames of reference (socioeconomic system, ecosystem) to give comprehensive information concerning related pollutant sources and pathways (Fischer-Kowalski and Hüttler, 1998; Baccini and Brunner, 1991). Schaffner, Bader, and Scheidegger first developed the Mathematical Material Flow Analysis (MMFA) for the nitrogen and phosphorus flow analysis model of the Thachin River Basin in Central Thailand. It has been recently applied to assess river water pollution and mitigation potentials for nitrogen and phosphorus (Schaffner *et al*., 2009; Schaffner, 2007).

This paper, as a part of the entire research, concentrates on pig farming (including slaughterhouse activities) by applying the Schaffner and colleagues model. The MFA/SFA was carried out to understand a holistic overview of the total nitrogen and total phosphorus flow from pig farming to surface waters in the Bang Pakong Basin (BPB) of Eastern Thailand. The results will also be able to depict key nitrogen and phosphorus inflows and outflows from pig farming operations and to propose effective measures in order to reduce nitrogen and phosphorus loading into the receiving waters of the basin.

2. Study Area: Bang Pakong Basin

The boundaries of the Bang Pakong Basin (BPB) in this study comprise six provinces including Nakhonnayok, Chachoengsao, Prachinburi, Sakaeo and a portion of Saraburi (3 districts), and Chonburi (6 districts), with a total area of 2.3 million ha (see Fig. 1). It is located in the eastern part of Thailand. The topography of the basin is highland in the upper part, but flat to slightly sloping in the middle and the lower part. The average annual rainfall is 1,400 mm/year. The main river of the basin is the Bang Pakong River that originates from the merging of the Nakhonnayok River and the Prachinburi River, running roughly 122 kilometers into the Gulf of Thailand. This river plays an important source for nutrient drainage into the estuary and the Gulf of Thailand. According to Boonphakdee and Fujiwara (2008), concentrations of nutrients (N and P) were low in the upstream area of the river, whereas concentrations in the middle and downstream range were high.

Pig farming is one of the main anthropogenic activities in the BPB, and most farms are located close to the main water bodies – the middle of the Bang Pakong River and its tributaries in Chachoengsao and Prachinburi Provinces (see Fig.1). In 2005, the amount of pig production in the BPB was approximately 1.7 million pigs per year, raised on 2,827 farms, which represented about 20% of the total pig production of the entire country (DLD, 2005). In Table 1, the proportion of pig production facilities in the basin are classified into three sizes: 10% are raised in small farms (less than 500 pigs), 15% in medium farms (500-1,000 pigs), and 75% in large farms (more than 1,000 pigs) (DLD, 2009; DLD, 2005). Pigs are normally kept in open housing systems, on slatted or solid floors. Slaughterhouses are separate enterprises located nearby the production units. The collection and efficiency of waste treatment at pig farms and slaughterhouses is relatively low, depending on farm management and treatment technology (or different farm size as stated above). Two waste-cleansing techniques are conducted currently at the farms: 1) the manual collection of dung before cleansing by water, and 2) the flushing of manure and excreta with water like slurry. The wastewater is then collected and treated in a natural pond or an anaerobic digester (AD) treatment system, or else discharged directly to the local river and canals. Dung has fertile nutrients which can be reused for adjacent crop farms as organic fertilizer and for aquaculture as fish feed.

3. Methods

The method used in this study is a traditional Material Flow Analysis (MFA) and a Mathematical Material Flow Analysis (MMFA) based on the mass balance concept in a specific area and time. This concept is undertaken to determine and quantify materials (e.g.

Table 1. Number of pig farm and production in Bang Pakong Basin in 2005 (DLD, 2009; DLD, 2005)

Province	Number of farms	Number of pig production (pigs per year)			
		Small farms (<500 pigs/farm)	Medium farms (500-1000 pigs/farm)	Large farms (>1000 pigs/farm)	Total
Nakhonnayok	179	44,000	40,000	120,000	204,000
Chachoengsao	747	72,000	60,000	252,000	384,000
Prachinburi	461	14,000	38,000	232,000	284,000
Sakaeo	726	4,000	2,000	22,000	28,000
Saraburi (3 districts)	160	10,000	12,000	164,000	186,000
Chonburi (6 districts)	554	30,000	92,000	474,000	596,000
Bang Pakong Basin	2,827	174,000 (10%)	244,000 (15%)	1,264,000 (75%)	1,682,000 (100%)

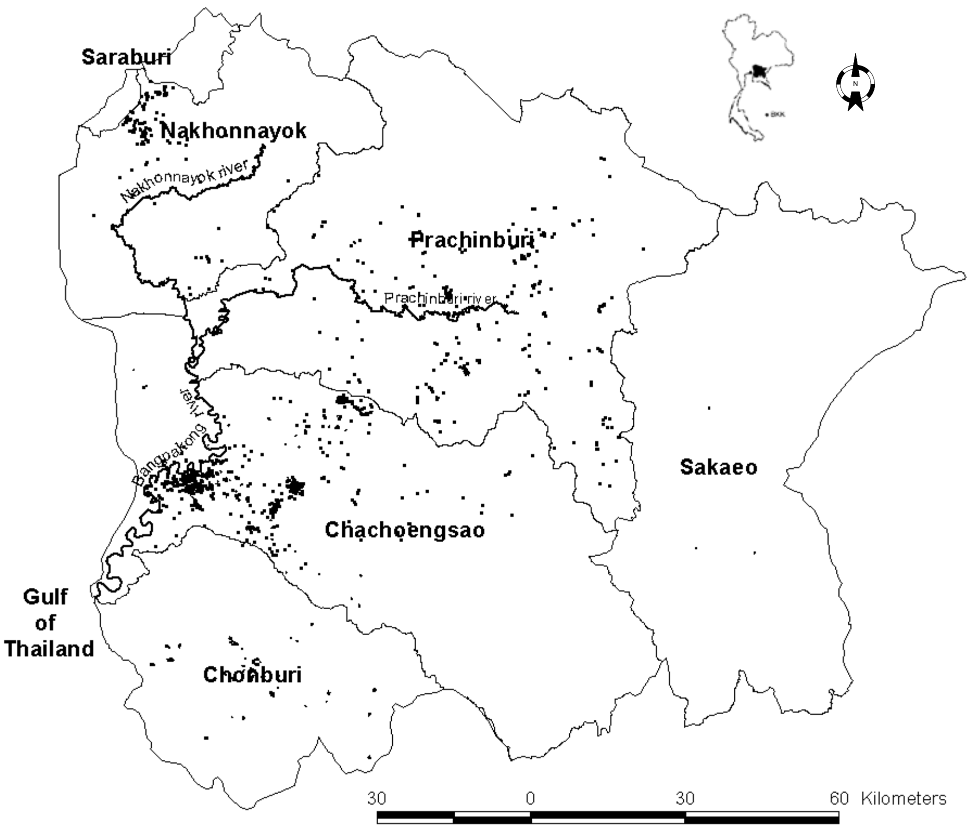


Figure 1. Boundaries of Bang Pakong Basin and pig farming locations (in black dots) (ONEP, 2009)

water, feed) and substances (nitrogen and phosphorus) that flew through pig farming facilities (including slaughterhouse) in the year of 2005. The calculation basically multiplied the flow rates of materials by the concentrations of nitrogen or phosphorus. Finally, the results of the nitrogen and phosphorus inflow and outflow are shown simply in a diagram representing each flow in terms of tons per year. In this study, the general MFA procedure and the MMFA method were carried out in four steps as follows (see more details in Schaffner *et al*., 2009; Kwonpongsagoon *et al*., 2007a; Kwonpongsagoon *et al*., 2007b):

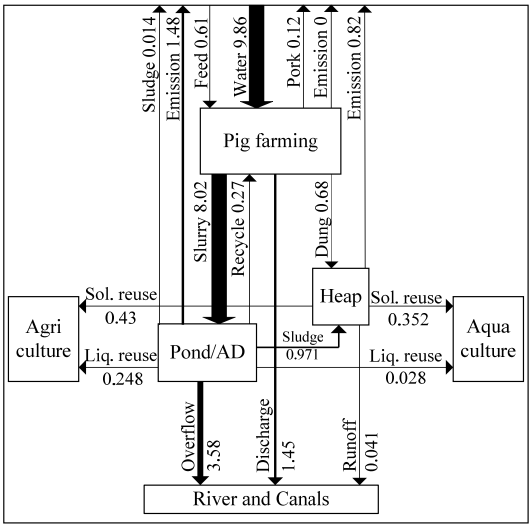
(1) System analysis: current situation is analyzed to identify goods and processes associated with nitrogen and phosphorus;
(2) Data acquisition and calculation: gathering reliable and complete data for the year of 2005 from several sources such as statistical databases at the Department of Livestock Development (DLD), theses and journal articles, government and consultant reports, and interviews with experts and farmers;
(3) Model and simulation approach (applied from Schaffner (2007)); and
(4) Scenario calculation: simulate measures to reduce as much of the nitrogen and phosphorus loads as possible into the river and canals of the BPB.

4. Results and Discussion

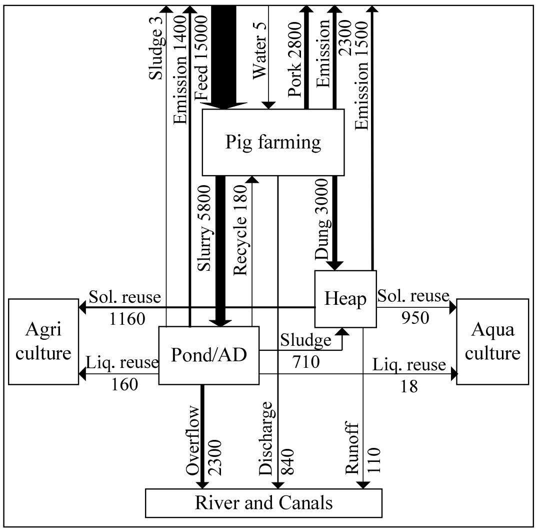
Figs. 2a, 2b, and 2c demonstrate the results of mass (materials or goods), nitrogen, and phosphorus flow analysis respectively through pig farming in the Bang Pakong Basin. In this study, pig farming consists of pig housing, slaughterhouse operations and the treatment unit (e.g. heap and pond/anaerobic digester (AD)). It has two input flows like feed and water; seven output flows like pork, solid and liquid waste reuse, sludge, emission from pig housing and treatment units, overflow, discharge, and runoff; and four internal flows like slurry, recycle, dung, and sludge from pond/AD to heap (see all in Fig. 2).

4.1. Existing situation of nitrogen and phosphorus flow

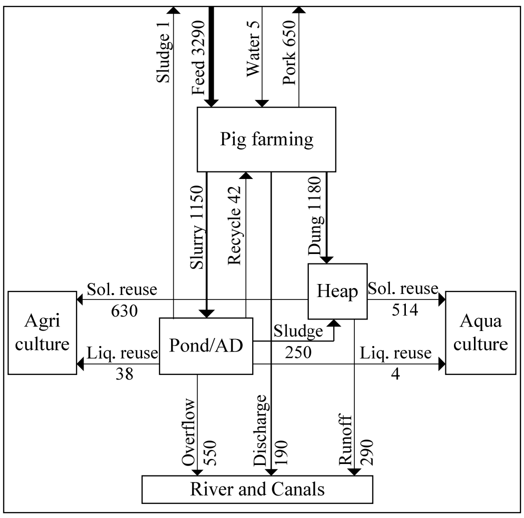
Based on the data collection and the simulation results as shown in Fig. 2, the main nitrogen and phosphorus input to pig farming is largely present in feed for raising of the livestock. It is estimated that the feed for pigs contained approximately 15,000 tons of nitrogen (Fig. 2b) and 3,300 tons of phosphorus per annum (Fig. 2c). Pig production systems can generate large quantities of waste, including solid waste called “dung” and



(a) Mass flow [million ton per year]



(b) Nitrogen flow [ton per year]



(c) Phosphorus flow [ton per year]

Figure 2. Simulation results of (a) mass, (b) nitrogen, and (c) phosphorus flows for pig farming (including slaughterhouses) in Bang Pakong Basin. Abbreviation: AD = anaerobic digester, Sol. reuse = solid waste reuse, Liq. reuse = liquid waste reuse

wastewater called "slurry". The dung is collected into heaps for drying out and then sold as fertilizer and fish feed. This study shows that only 50% of small pig farms collected the dung into heaps, but 80% of medium pig farms, and up to 85% of large pig farms did the collection (see Table 2). On an average the efficiency for dung collection and separation is about 55%. A portion of wastewater (slurry) produced from the cleansing process from both the pig house and the slaughterhouse is treated by a wastewater treatment system, such as a natural pond system or an anaerobic digester (AD). But some wastewater is still directly discharged into the local bodies of water without any treatment. Small farms treated 25% of the wastewater by using ponds, and another 7% of the wastewater was treated by utilizing an anaerobic digester. For medium and large farms, the numbers were 75% and 4%, and 70% and 30% respectively. Moreover, slaughterhouses treated 20% of the wastewater using ponds, and only 2.5% by using anaerobic digesters. The remaining wastewater was directly discharged into local systems at the following rates: small farms-68%, medium farms-21%, and slaughterhouses-77.5%. The result shows that only large farms collected and treated all their wastewater.

According to calculations (see Figs. 2b and 2c), the amount of nitrogen and phosphorus in dung is approximately 3,000 and 1,180 tons respectively, while N and P are about 5,800 and 1,150 tons respectively in slurry. Since the collected dung is considered a rich nutrient resource, most of it is recycled as organic fertilizer for agriculture (crop farms) or as fish feed for aquaculture in the nearby areas. All liquid and solid waste to be reused in agriculture and aquaculture contain 2,288 tons of nitrogen and 1,186 tons of phosphorus. Even though some waste is collected and treated in ponds or in AD systems, the waste collection as mentioned previously and the efficiency of waste treatment systems (pond and AD) in slaughterhouses and pig farming is quite low. In Fig. 2, it also shows that all polluted water from pig farming to degrade water quality of the basin can result from the overflow of wastewater treatment systems, direct discharge from pig houses, and runoff from dung heaps. This accounts for 5.07 million tons per year of total wastewater which contains 3,250 tons nitrogen (76% of total nutrient pollutants in wastewater) and 1,030 tons phosphorus (24% of total nutrient pollutants in wastewater) per year.

4.2. Scenarios analysis to reduce the nitrogen and phosphorus loads

In the present study, the overflow of wastewater treatment systems, the direct discharge of facilities liquid waste, and runoff are found to be the key processes responsible for the transfer nutrients into the surface water (Fig. 2). In many other countries like Australia, Ireland and the U.S., the farmers control the generation and delivery of pollutants (i.e. nutrients) through Nutrient or Best Management Practices (NMPs/BMPs) guidelines. The concept of these guidelines is to prevent or reduce the discharged pollutants from non-point sources (often associated with animal waste management) to water resources by effective and practical means while optimizing farm profits and production (Tucker *et al*., 2010; EPA, 2003; EPD, 2002; Beegle *et al*., 2000; US EPA, 1993).

With regard to the guidelines, two waste-cleansing practices are currently in use at the farms in this basin, namely dung collection/separation and the flushing of pig slurry. However, the percentage of performance is relatively low, especially in small farms and slaughterhouses. The question arises: what will happen if the current performance practices can be improved? As a result, three scenarios have been established and analyzed change the loading of nutrients (N and P). Table 2 summarizes the three scenarios, showing alternative practices and the potential change of nitrogen and phosphorus loading, compared with the current situation. In scenario 1, all pig farms collect/separate dung into heaps and sell it as crop fertilizer and fish feed, we investigated the potential of nutrients load reduction by increasing the percentage of pig farms to collect/separate the dung up to 100%. The simulation result indicated a potential nitrogen and phosphorus load reduction of 11% and 12% respectively. The second scenario was to collect all cleansing liquid waste from pig's houses and slaughterhouses for treatment. It shows that 14% of total nitrogen and 8% of total phosphorus could be reduced. Finally, combining the two previously proposed scenarios would reduce 23% of nitrogen and 18% of phosphorus.

5. Conclusion

To conclude, this study shows that pig farming, one of the main livestock activities of the basin, can significantly contribute to the high nitrogen and phosphorus loads from overflow of wastewater, direct discharge of liquid waste, and runoff from dung heaps to the receiving water, and subsequently cause water pollution in the bodies of water in the BPB. This accounts for the 3,250 tons of nitrogen and the 1,030 tons of phosphorus discharged per year. Pig feed is the key input material to add high nitrogen and phosphorus into the system. As evaluated in the scenario analysis, it shows that a single scenario can reduce only about 10% of nitrogen and phosphorus; whereas the combination of the two measures (scenarios) could potentially decrease about 20% of nitrogen and phosphorus into the surface water of the basin. Finally, the results of the study are expected

Table 2. Three proposed scenarios for the reduction of mass, nitrogen and phosphorus loads in Bang Pakong Basin (BPB)

Parameter description	Value		Mass from PIG to BPB		N from PIG to BPB		P from PIG to BPB	
	Current	Potential	Reduced NET load [Mt/yr]	Potential reduction [%]	Reduced NET load [tN/yr]	Potential reduction [%]	Reduced NET load [tP/yr]	Potential reduction [%]
Current NET load			5.07		3,270		1,020	
Scenario 1: All pig farms collect/separate dung into heaps								
Percentage of small farms separate dung to heaps	50	100	4.98	2	2,900	11	900	12
Percentage of medium farms separate dung to heaps	80	100						
Percentage of large farms separate dung to heaps	85	100						
Scenario 2: 100% collection of wastewater from pig house								
Percentage of wastewater from small farms to pond	25	93						
Percentage of wastewater from medium farms to pond	75	96	4.26	16	2,800	14	940	8
Percentage of wastewater from slaughterhouse to pond	20	97.5						
Scenario 1+2			**4.19**	**17**	**2,510**	**23**	**840**	**18**

to be worthwhile in providing better information for discussion of measures and options from a management point of view.

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7. References

Baccini P, Brunner PH. Metabolism of the anthroposphere. Springer-Verlag, Berlin. 1991.

Beegle DB, Carton OT, Bailey JS. Nutrient management planning: justification, theory, practice. Journal of Environmental Quality 2000; 29(1): 72-9.

Boonphakdee T, Fujiwara T. Temporal Variability of nutrient budgets in a tropical river estuary: the Bangpakong river estuary, Thailand. EnvironmentAsia 2008; 1(1): 7-21.

DLD. Statistics of Livestock in Thailand 1999-2008. Department of Livestock Development, Ministry of Agriculture and Cooperatives, Thailand. 2009 (in Thai).

DLD. Annual Statistics of Livestock in Thailand 2005. Department of Livestock Development, Ministry of Agriculture and Cooperatives, Thailand. 2005 (in Thai).

EPA. Reference document on best available techniques for intensive rearing of poultry and pigs. Environmental Protection Agency, Wexford, Ireland. 2003.

EPD. Code of practice – Livestock waste management. Environmental Protection Department, Hong Kong. 2002.

FAO. Livestock waste management in East Asia, Project preparation report. Food and Agricultural Organization of the United Nations, Rome. 2004.

Fischer-Kowalski M, Hüttler W. Society's Metabolism the Intellectual history of Material Flow Analysis, Part II, 1970-1998. Journal of Industrial Ecology 1998; 2(4): 107-36.

Kwonpongsagoon S, Waite D, Moore S, Brunner P. A substance flow analysis in the southern hemisphere: cadmium in the Australian economy. Clean Technologies and Environmental Policy 2007a; 9(3): 175-87.

Kwonpongsagoon S, Bader HP, and Scheidegger R. Modelling the cadmium flows in Australia on the basis of a Substance Flow Analysis. Clean Technologies and Environmental Policy 2007b; 9(4): 313-23.

ONEP. Database of geographic information system: agricultural ecosystem. Office of Natural Resources and Environmental Policy and Planning, Ministry of Natural Resources and Environment, 2009 (in Thai); [Cited 2007 May 8]. Available from: http://bangpakong.onep.go.th/MapResource.aspx

Rattanarajcharkul R, Rucha W, Sommer S, Menzi H. Area-wide integration of specialized livestock and crop production in Eastern Thailand. Proceedings of the 9th International Conference on the FAO ESCORENA Network on recycling of agricultural, municipal and industrial residues in agriculture, Gargano, Italy. September 6-9, 2000.

Schaffner M. Applying a Material Flow Analysis Model to assess river water pollution and mitigation potentials: a case-study in the Thachin River Basin, Central Thailand. Ph.D. Dissertation. Swiss Federal Institute of Aquatic Science and Technology, Zürich. 2007.

Schaffner M, Bader HP, Scheidegger R. Modeling the contribution of point sources and non-point sources to Thachin River water pollution. Science of The Total Environment 2009; 407(17): 4902-15.

Tucker RW, McGahan EJ, Galloway JL, O'Keefe MF. National environmental guidelines for piggeries - second edition. APL project 2231, Australian Pork Limited, Deakin, ACT, Australia. 2010.

US EPA. Guidance Manual for Developing Best Management Practices (BMPs). United States Environmental Protection Agency. 1993.

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