ESTIMATION OF NITROGEN AND PHOSPHORUS FLOWS BY MATERIAL FLOW ANALYSIS IN HAIPHONG CITY, VIETNAM

Toshiya ARAMAKI[1] and Nguyen Thi Thu THUY[2]

[1]Member of JSCE, Associate Professor, Dept. of Urban Eng., The University of Tokyo
(7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan)
E-mail: aramaki@env.t.u-tokyo.ac.jp
[2]Former student, School of Environment, Resources and Development, Asian Institute of Technology
(P.O.Box 4, Klong Luang, Pathumthani 12120, Thailand)

The aim of this study is to quantify nitrogen and phosphorus flows in urban area of Haiphong city by MFA, in order to identify weakness related to solid waste and wastewater management. The system boundary is defined by the 5 urban districts in Haiphong city, and 8 components are included in the system model developed. Each flow in the model is quantified through literature and interview surveys. The visualization of N and P flows showed that, household is the process that produce highest amount of N and P loading to environment. The main potential to mitigate environmental impact by these nutrients is the appropriate management of human excreta and wastewater from households.

***Key Words** : Material Flow Analysis, Nitrogen, Phosphorus, Haiphong*

1. INTRODUCTION

Material Flow Analysis (MFA) is defined as a systematic assessment of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material[1)]. MFA is considered as an attractive tool for environmental and sanitation planning through the analysis of organic and nutrient flows in the target area, but a few studies has been done.

Brunner and Baccini[2)] assessed the potential of materials accounting techniques to forewarn of critical loadings on water, air and soil. Binder et al.[3)] applied MFA for the early recognition of environmental problems in Tunja, an urban region in Colombia. They showed that MFA is possible to apply even with poor data quality and quantity in developing countries. Then, several MFA studies[4), 5)] has been carried out in developing countries.

Because Vietnam also faces severe problems on sanitation and solid waste management as other developing countries, MFA is considered as a useful tool to discuss the key process of organic and nutrient management and to develop the appropriate management measures. Montangero et al.[6)] applied it to Viet Tri, a small city in the northern area of Vietnam. Their results indicated that 60% of the nitrogen delivered to the households in form of food was finally discharged with the excreta in surface water, fish ponds or on the soil, resulting in water pollution. Cau et al.[7)] calculated nutrients (N & P) budget of the Hanoi City, the capital of Vietnam. The model used was just a simple inflow/outflow model, consisting of only the major flows of nutrients, but they could discuss on what were the important flows that we should give more exact information.

In this study, MFA is applied to get an overview of the existing nutrient flows in Haiphong city, which is the third largest city and an important center for industrial activities in Vietnam. The indicators to be analyzed are nitrogen (N) and phosphorous (P).

2. METHODS

Haiphong City is located on the delta of Red River in the northern part of Vietnam as shown in **Fig.1.** It is the third largest city in Vietnam, just after Hanoi and Ho Chi Minh City, and is a major port and industrial center with a growing tourism center. It has a subtropical climate, dominated by the monsoons. The average temperature in winter is 19°C, in summer is 26°C, and the annual average precipitation is 1,754 mm.

They have a dense network of rivers, canals and ponds within the city, and are suffering flood events frequently due to heavy monsoon rainfall and insufficient drainage capacity. They have a sewer network in the three central districts, but no wastewater treatment has been done. According to our survey for 100 households, approximately 80% of households use septic tank, and 10% of households use other sanitary latrines. Due to the untreated grey water, seepage of septic tank and the inappropriate handling of septage, rivers, ponds and canals in the city are heavily polluted. Regarding solid waste management, it is estimated that 605 tons/day of municipal solid waste are generated in the 5 districts of Haiphong City, and 78% of them are collected[8].

There are 14 administrative units in Haiphong including 5 urban districts, 1 town and 8 suburban districts. The population of the city is 1,770,800 and its density is 1,166 people/km^2. The annual population growth during the past years has been around 1 % per year in the urban areas[9]. Total area of Haiphong city is about 1,519 km^2 in which agriculture area occupied 55.5%, forestry land occupied 10.2%, and water surface occupied 15.3%.

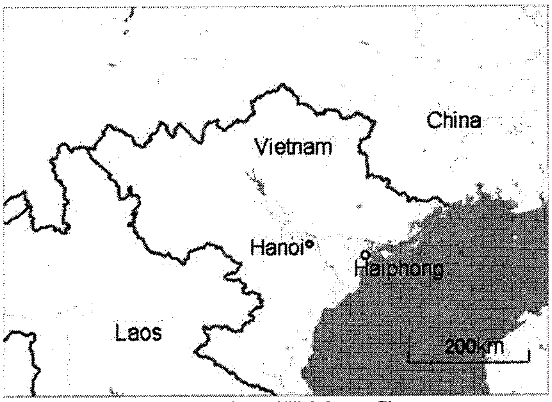

Fig.1 Location of Haiphong City

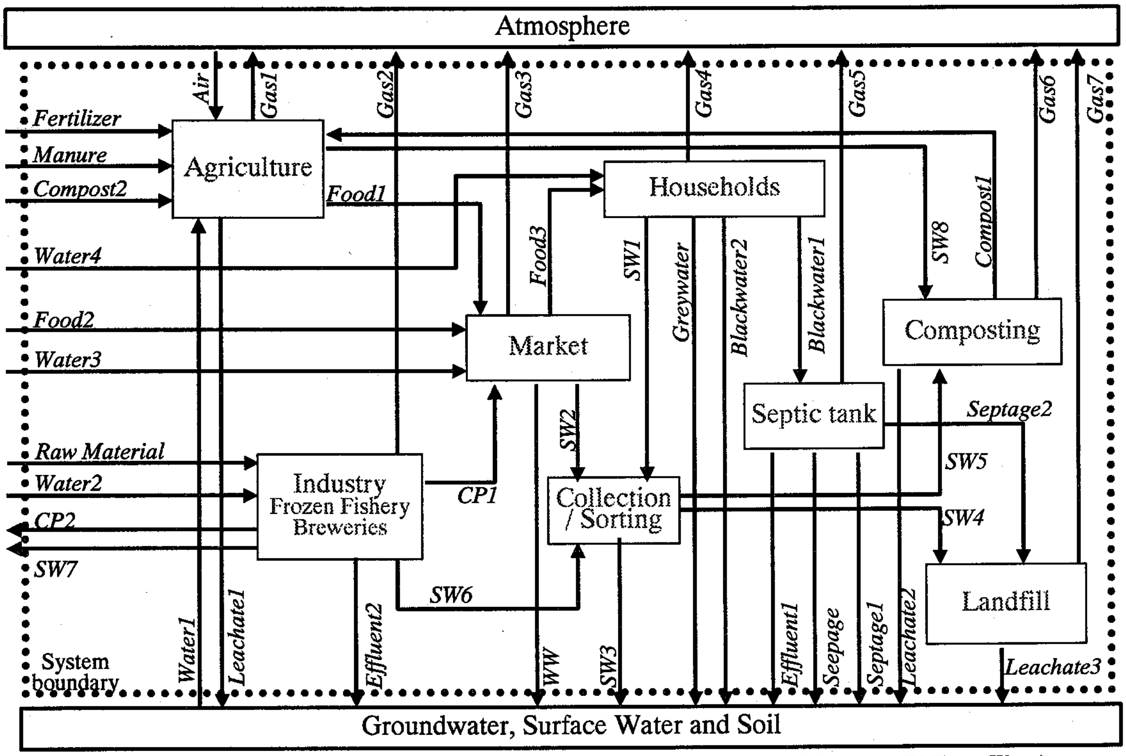

Fig.2 The model of nutrient flows in Haiphong City (*CP*: Consumer Product, *SW*: Solid Waste, *WW*: Waste Water)

In this study, 5 urban districts are selected as a target area. The population is about 0.62 million and the area is 165.4 km^2. Agricultural area is occupying only 15.8% of the total area in the 5 urban districts. Eight important components are selected to develop the model of nutrient flows. **Fig.2** shows the model of nutrient flows in Haiphong city, developed in this study.

3. ESTIMATION OF MATERIAL FLOW

To quantify each flow of the models shown in **Fig.2**, literature survey and interviews for the related authorities and 100 households are carried out. **Table 1** shows the methodology to determine each flow, and data or data source for determination.

Major agriculture activities are rice, fruit, and vegetable cultivations in this area. Because they have only data collected in the whole city area, data on agricultural activities are allocated to 5 urban districts according to the actual percentage of agricultural land use. Chemical fertilizer and manure are imported from outside of system boundary. To simplify the estimation, it is assumed that only buffalo and pig manure are used in the process. Irrigation water also contains nutrients, some of which are taken by plants whereas some were losses through drainage water and percolate into the soil. Crop residuals, mainly leaves, are normally composted onsite by informal composting and used as soil amendment in the area. All of crops produced are transferred to the markets for city consumption.

The key industrial sectors in the city are machinery manufacture, footwear, garment, construction material production, food process, breweries and rubber. Among them, frozen fishery and breweries are selected as important industries in terms of nutrient flows.

Four main markets in the city are considered in the "Market" component. The "Households" includes all households, schools, restaurants, department stores, hospitals, hotels, offices and universities. The "Composting" represents informal composting of agricultural waste and windrow composting of organic waste. There is one composting plant that serves for 5 urban districts in the city, but it is not operated now due to the problems in implementation and management of the system.

Table 1 Determination method and data source for material flows

Flow	Determination Method	Data or data source
Fertilizer	*N, P contents* x Σ [*fertilizer* (ton/ ha cultivated area) x *area* (ha) x *cycle* (cycle/y)]	*N, P contents, fertilizer*:10) *area*: 9) *cycle*: according to the interview (2-3 cycles per year)
Manure	*N, P contents* x Σ [*manure* (ton/ cultivated area) x *area* (ha) x *cycle* (cycle/y)]	*N, P contents, manure*: same as *N, P contents and fertilizer* in "*Fertilizer*" *area*: same as *area* in "*Fertilizer*" *cycle*: same as *cycle* in "*Fertilizer*"
Compost1	*transfer coefficient of N,P in composting* x (*SW8* + *SW5*) (ton/y)	*transfer coefficient of N,P in composting*: 69% for N, 99% for P
Compos 2	*N,P contents* x Σ [*compost* (ton/ha cultivated area) x *area* (ha) x *cycle* (cycle/y)] – *Compost 1* (ton/y)	*N,P contents, compost*: same as *N, P contents and fertilizer* in "*Fertilizer*" *area*: same as *area* in "*Fertilizer*" cycle: same as *cycle* in "*Fertilizer*"
Food1	Σ [*N,P contents* x *production* (ton/y)]	*N,P contents*: same in "*Food 3*" *Production*: 10)
Food2	Mass balance of "Market"	
Food3	(For crop commodities) *N/P ratio* x *P contents* x Σ [*food consumption* (ton/y)] (For livestock commodities) *N/P ratio* x *N contents* x Σ [*food consumption* (ton/y)]	*N/P ratio*: 10.0 except for Soybean in crop commodities, 5.0 for livestock commodities *P contents*: 0.4 mg/g (vegetable),0.2 mg/g (fruits), 0.1 mg/g (sugar), 3.3 mg/g (cereals), 0.185 % (rice) *N contents*: 3.2 (fish), 0.5 (milk), 19.87 (meat) and 11.95 (egg) from several literatures

Table 1 Determination method and data source for material flows (continued)

Flow	Determination Method	Data or data source
Raw material	Σ [*N,P contents* x *raw material* (ton/product) x *production* (product/y)]	*N,P contents* : 3.2% for N, 0.64% for P in fishery factory, 33mg/g for N and 3.3 mg/g for P in Beer factory *raw material*: 1.1 ton/1 ton fishery product, 1 kg/ 1L beer product *production*: 9)
CP1	Σ [*N,P contents* x *production* (ton product/y) x *%consumption within area*]	*N,P contents*: same in "*Raw material*" (for fishery product), 0.65g/l for N and 0.41g/l for P (for Beer product) *production*: same in "*Raw material*" *%consumption*: 10% of beer and fishery product
CP2	Σ [*N,P contents* x *production* (ton product/y) x *%export*	*N,P contents*: same in "*CP1*" *production*: same in "*Raw material*" *%export*: 90% of beer and fishery product
Water1	*N,P contents* x Σ [*water consumption* (m^3/ha/cycle) x *area* (ha) x *cycle* (cycle/y)]	*N, P contents*: 0.25mg/l for N (average quality in water source), P is negligible *water consumption*: same as fertilizer in "Fertilizer" *area*: same as area in "*Fertilizer*" *cycle*: same as cycle in "*Fertilizer*"
Water2	*N,P contents* x Σ [*water consumption* (m^3/product) x *production* (product/y)]	*N,P contents*: 0.15mg/l for N, P is negligible *water consumption*: 8m^3 / 1 ton fishery product, 10L water / 1L beer product *production*: same as production in "*Raw material*"
Water3	*N,P contents* x *Total water consumption for market*	*N,P contents*: 0.15mg/l for N, P is negligible *Total water consumption for market*: 5,211 m^3/day
Water4	*N,P contents* x *Total domestic water consumption*	*N,P contents*: 0.15mg/l for N, P is negligible *Total domestic water consumption*: 85,600 m^3/day
Greywater	*N,P concentrations* x {*TC of domestic WW* * *Water 4* – [*flush wate* x *population* x *percentage of HH access to sanitation*]}	*N,P concentrations*: 49.5 mg/L for N, 2.85 mg/L for P *TC of domestic WW*: 85% water consumption in households *flush water*: 30L/c/d *population*: 620,400 *percentage of HH access to sanitation*: 90%
WW	*Transfer coefficient of WW* x *Water3*	*Transfer coefficient of WW*: 90%
Effluent1	*N, P contentrations* x [*flush water* x *population* x *percentage of HH access to septic tank*] x *% discharge to drainage*	*N, P contentrations*: 2.97mg/L for P, 57mg/L for N *flush water and population*: same as grey water *percentage of HH access to septic tank*: 80% *% discharge to drainage*: 90%
Effluent2	*N, P concentration* x *wastewater* (m^3/product) x *production* (product/y) and *N,P emissions* (kg/product) x *production* (product/y)	*N, P concentration*: 45mg/L for N and 18mg/L for P in beer factory *N, P emission*: 8.4 kg/ton for N and 2.73kg/ton for P *wastewater*: 9L/1L beer product *production*: same as production in Raw material
Seepage	mass balance in "Septic tank"	
Leachate1	*Transfer coefficient of seeping water in soil* x *Water 1*	*Transfer coefficient of seeping water in soil*: 45% by Kruitkul[11)]
Leachate2	*Transfer coefficient of leachate in compost* x (*SW5* + *SW8*)	*Transfer coefficient of leachate in compost*: 1% for N and P
Leachate3	*Transfer coefficient of leachate in landfill* x (*SW4* + *Septage 2*)	*Transfer coefficient of leachate in landfill*: same in "*Leachate2*"
Air	*Planted area of soybean* x *N fixation per area*	*Planted area of soybean* : same as *area* in "*Fertilizer*" *N fixation per area*: 56,250 g N/hectare

Table 1 Determination method and data source for material flows (continued)

Flow	Determination Method	Data or data source
SW1	*N,P contents* x *Total domestic SW collected by municipality* per day x 365 days/y	*N,P contents*: 3.18 g/kg for N[12], 0.205% for P[13] *Total domestic SW collected by municipality*: 218 ton/day(57% for food waste)[8]
SW2	*N,P contents* x *Total market SW collected by municipality* per day x 365 days/y	*N,P contents*: same in "*SW1*" *Total market SW collected*: 193 tons/day
SW3	*N,P contents* x (*SW1*+*SW2*+*SW6*) x *% of illegally dumped SW*	*N,P contents*: same in "*SW1*" *% of illegally dumped SW*: 22%
SW4	*N,P contents* x (*SW1*+*SW2*+*SW6*) x *% of SW transported to landfill*	*N,P contents*: same in "*SW1*" *% of SW transported to landfill*: 78%
SW5	*% Organic SW to composting* x *SW4*	The process has stopped, so considered as 0.
SW6	*N,P contents* x *SW per product* (ton/product) x *production* (ton/y)	Only for fishery industry *N,P contents*: same in "*Raw material*" *SW per product* : 0.1ton / ton fishery product *production*: same as *production* in "*Raw material*"
SW7	*N,P contents* x *SW per product* (ton/product) x *production* (ton/y)	Only for beer industry *N,P contents*: same in "*Raw material*" *SW per product* : 0.34 kg/L beer product *production*: same as *production* in "*Raw material*"
SW8	*N,P contents* x Σ *Agriculture SW use for composting per cycle* (ton/cycle) * *cycle*/y	*N,P contents*: 4mg/g for N, 0.4 mg/g for P *Agriculture SW use for composting*: 50% of rice straw, produced 5.5-8 ton/ha (interview)
Gas1	*Rice straw burnt* (tons) x *NOx and N_2O emissions per straw burnt + respiration*	*Rice straw burnt*: 50% of rice straw, produced 5.5-8 ton/ha (interview) *NOx and N_2O emissions per straw burnt*: 2.5 and 0.07 g/kg *Respiration*: 20% of N loading
Gas2	Mass balance in "Industry"	
Gas3	ignored	
Gas4	*%water loss to atmosphere* x *household water consumption + respiration*	ignored
Gas5	ignored	
Gas6	*Transfer coefficient of gas in compost* x (*SW5* + *SW8*)	*Transfer coefficient of gas in compost*: 30% for N, 0% for P
Gas7	*Transfer coefficient of gas in landfill* x (*SW4* + *Septage 2*)	*Transfer coefficient of gas in landfill*: same in "*Gas6*"
Blackwater1	*N substance per person per day in human waste* * *population* * days/y * *% household access to sanitation*	*N,P emissions per person*: 12.5 for N and 1.5 for P *population*: same in "*Greywater*" *% household access to sanitation*: 90%
Blackwater2	*N,P emissions per person per day in human waste* * *population* * days/y * *% household do not access to sanitation*	*N,P emissions per person*: same in "*Blackwater1*" *population* : same in "*Greywater*" *% household do not access to sanitation*: 10%
Septage1	*N,P contents* x *septage generation* (kg/c/d) x *population* (persons) x 365 days/y * *% HH access to sanitation* x *% illegally septage discharged*	*N,P contents*: 0.97% for N, 0.17% for P *septage generation* : 1 kg/capita/day
Septage2	*N,P contents* x *septage generation* (kg/c/d) x *population* (persons) x 365 days/y x *% HH access to sanitation* * *% septage transported to landfill*	*N,P contents*: same in "*Septage1*"

4. RESULTS AND DISCUSSION

(1) Estimated nitrogen and phosphorus flows

Through balancing input and output in each component, the estimated nitrogen and phosphorus flows per person of Haiphong city are presented in **Fig.3** and **Fig.4**.

Fig.3 indicates that food import account for 2/3 of total nitrogen input to the system. Raw materials to the industries and the import of chemical fertilizer account for more than 10% of total nitrogen input. Regarding the nitrogen output from the system, direct disposal of septage to the environment has the highest contribution, which accounts for 20% of total output. Discharges of seepage from septic tank and grey water also have significant portions around 15 % of total output.

Fig.4 shows that food import is also the important flow for phosphorus input to the system. It accounts for 55% of total phosphorus input. Chemical fertilizer and manure are also important flows, which account for 23% and 15%, respectively. Regarding the phosphorus output from the system, discharge from agricultural activity is the most significant flow, and it accounts for 40% of total phosphorus output. Direct disposal of septage to the environment is also significantly contributed to the phosphorus output.

Food import is hard to control in terms of nutrient management, thus the appropriate management of septage from septic tank is the most important issue, identified through this analysis. Reduction of nitrogen in seepage and grey water discharge is also important, especially for nitrogen. The appropriate usage of fertilizer seems to be more important for controlling phosphorus emissions.

However there are several points that are difficult to explain in these results. As the result of mass balance in "Industry" component, there is a significant value for *"Gas2"* in **Fig.4**, which is usually considered as negligible. Both for nitrogen and phosphorus, around 50% of input are discharged in the "Households" component. It means that the remaining 50% of input are stored in our body, but it seems to be higher than we have imagined. These points imply that further investigations and discussions are necessary to improve these results.

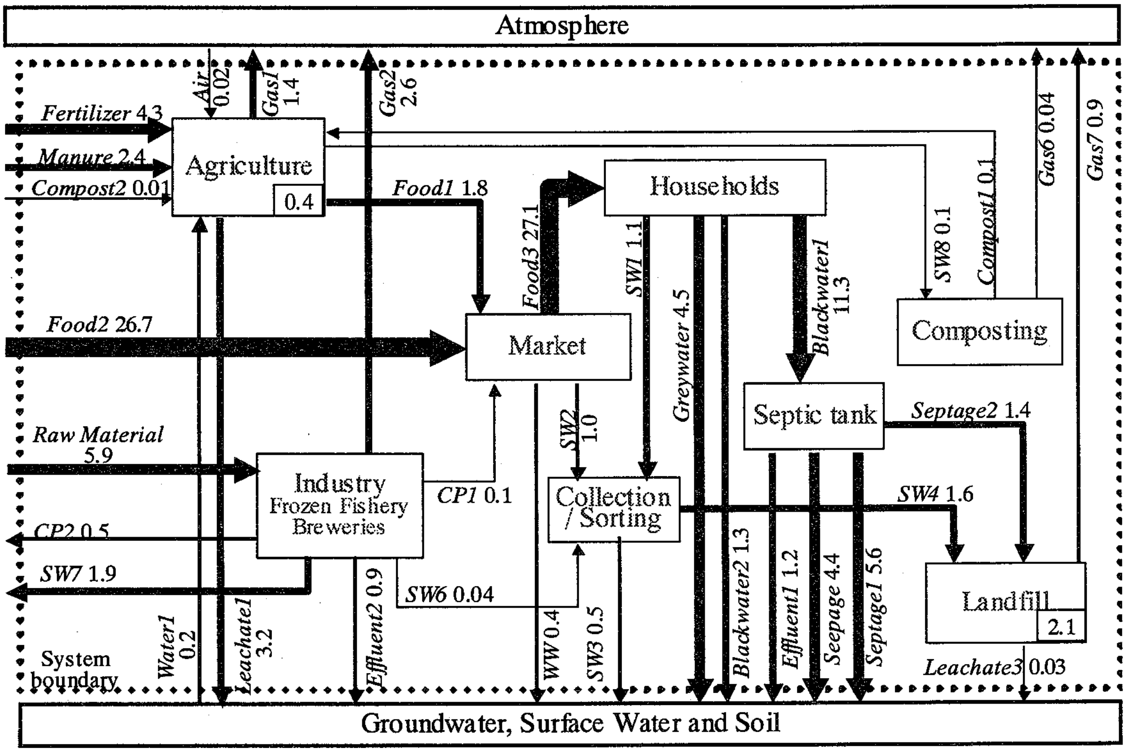

Fig.3 The Estimation of N Flows in the System of "Haiphong Urban Districts" in g/person/year

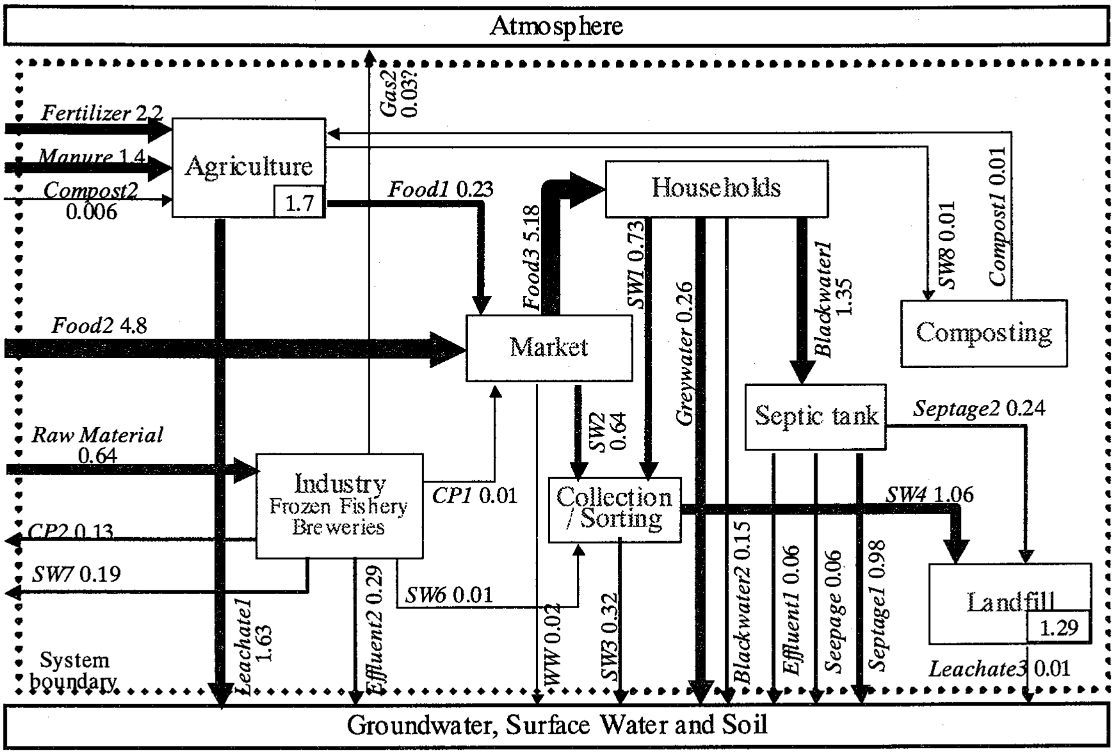

Fig.4 The estimation of P Flows in the System of "Haiphong Urban Districts" in g/person/year

Table 2 Comparison the Estimated N Fluxes per capita with Haiphong and other researches

	Kumasi[4)]	Pak Kret[5)]	Viet Tri[6)]	Hanoi[7)]	Haiphong
Fertilizer, Manure and Compost input to Agriculture	0.4	7.4	8.2	0.5	6.7
Food input to Household	13.2	9.7	8.5	26.0	27.1
Solid waste from Household	6.4	2.3	0.7	3.6	1.1
Black water from Household	9.5	7.9	7.8	No data	12.6

(2) Comparison with other researches

In order to obtain the unique characteristic of this region, nitrogen flows obtained from this study are compared with past researches for other regions. **Table 2** shows the estimated nitrogen flows in Haiphong and other researches. Because target flows in each research are not same, only 4 inputs and outputs shown in this table are compared.

From the tables, it can easily be seen that there were some differences in estimated results. The differences in "fertilizer, manure and compost input to agriculture" can be caused by different level of agricultural activities among the target areas. Pak Kret and Viet Tri are the suburb area of Bangkok and Hanoi, the capital cities in each country, and higher agricultural activity with other areas.

For "food input to household", this study and Hanoi are much larger than other 3 researches. The estimated values in these studies including this study can be considered to include a significant error due to many assumptions for estimation. Therefore several parameters assumed in the estimation, such as N content in various type of food, have a significant influence on the result.

"Solid waste from household" is also different in each study. This difference may be caused by the way of collection from household. Organic waste may be recycled in household at source before collection by municipality in some area. The nitrogen flux of "Black water" is relatively similar among the target areas.

5. CONCLUSIONS

This study is conducted to quantify nutrient flows using MFA, to identify weakness related to solid waste and wastewater management in Haiphong City, Vietnam. The system model of nutrient flows is developed first, then each flow in the model is quantified through literature and interview surveys.

The visualization of N and P flows through the system shows that "Households" is the important process that produce significant amount of N and P loading to the environment. The main potential to improve nutrients emission is to optimize excreta and wastewater management from households. Fertilizer practice is also important especially for phosphorus control.

Through the comparisons with other studies for other regions, the differences among areas may be caused by not only the regional characteristics, but also assumptions in the estimation of nitrogen flows. Therefore the further research is necessary to improve the accuracy of MFA result.

Finally, we would like to appreciate the financial support by CREST program in Japan Science and Technology Agency to conduct this study.

REFERENCES

1) Brunner P. H. and Rechberger H. : Practical handbook of material flow analysis, Lewis Publishers, New York, 2004.
2) Brunner P. H. and Baccini P. : Regional Material Management and Environmental Protection. *Waste Management and Research*, 10, 203–212, 1992.
3) Binder C., Schertenleib R., Diaz J. H., Bader H. P. and Baccini P. : Regional water balance as a tool for water management in developing countries. *Water Resources Development*, 13, 1, 5–20, 1997
4) Belevi H. et al. : Material Flow Analysis: A Planning Tool for Organic Waste Management in Kumasi, Ghana. EAWAG/SANDEC, ETH Zurich, Switzerland, 2002.
5) Sinsupan T. : MFA for Planning of Domestic Wastes and Wastewater Management: Case study in Pak Kret Municipality, Nonthaburi, Thailand. Master's thesis, Asian Institute of Technology, 2004.
6) Montangero A., Thai N. T. K. and Belevi H. : Material Flow Analysis as a Tool for Environmental Sanitation Planning in Viet Tri, Vietnam, 30th WEDC International Conference, Vientiane, Lao PDR, 2004.
7) Cau L. N., Thanh N. C., Satoh H. : Nutrient budget analysis as an Indicator of Urban Sustainability: a case study in Hanoi, Vietnam. *Proceedings of the first international symposium on Southeast Asian Water Development*, October 2003, AIT Bangkok, Thailand, 2003.
8) VIWASE : Feasibility Study on Haiphong City Drainage, Sewerage and Solid Waste Management Project stage I (2004-2010), Main Report, 2004.
9) Haiphong Statistical Office : Haiphong 50 year Construction and Development. Statistical Publishing House, 2005.
10) Haiphong Department of Agriculture and Rural Development : Production of Agricultural Products, Data in five Urban Districts in 2004.
11) Kruitkul T. : Sustainable Agriculture: Soil and Fertilizer. Department of Soil Science, Kasetsart University, 1997.
12) Lemna International, Inc. : Feasibility Studies Report in Designing a Total Solid Waste Treatment Plant for Treating Urban Solid Wastes in Hanoi City. Lemna International, Inc., Minneapolis, Minnesota, The United States of America, 2002
13) Cau L. N. : Nutrient Budget Analysis and Its Applications as an Indicator of Urban Sustainability: Case Study in Hanoi, Vietnam, AIT thesis, 2003.