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# A Mixed Approach For Nutrient Management Planning In Southeast Asian Countries

Pham Ngoc Bao[1], Toshiya Aramaki[2], Do Thu Nga[3], Testuo Kuyama[4], Bijon Kumer Mitra[5]

[1, 4, 5] Institute for Global Environmental Strategies (IGES), 2108-11 Kamiyamaguchi, Hayama, Kanagawa 240-0115, Japan.

[2]Faculty of Regional Development Studies, Toyo University, 2-36-5 Hakusan, Bunkyo-ku, Tokyo 112-0001, Japan.

[3]Hanoi University of Science, Vietnam National University, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam.

**Abstract**

Southeast Asia (SeA) region has experienced impressive economic, population and urban growth in the last decades. The region faces big challenges and difficult choices, between economic growth and environmental protection, especially from water pollution, in pursuing sustainable development. Deterioration of water quality in lakes, rivers and reservoirs in urban areas due to nutrient pollution from anthropogenic sources, either point or non-point sources, has recently been recognized as one of the most serious environmental problems throughout the region. The nutrient pollution problem in water environment has been well-recognized and addressed in many developed countries, but not in developing countries, especially in the SeA region. This paper provides a comprehensive assessment on the current status of nutrient management across the region, and investigates possible reasons why current efforts fail to address the issue. In addition, the paper examines the possibility of introducing a mixed approach, from planning stage using a Material Flow Analysis (MFA) tool to implementing stage utilizing regulatory and economic incentive measures to effectively address the nutrient pollution from both point and non-point sources.

**Keywords**: agriculture; economic incentives; nutrient pollution; southeast asia; urban wastewater.

## I. Introduction

Southeast Asia (SeA) region is one of the fastest growing regions in term of both economic, population and urban growth (OECD, 2014). As a result, the challenge of attaining a sustainable pattern of development globally will be determined by what happen in this region. However, the region still faces big challenges and difficult choices, between economic growth and environmental protection, particularlly water resources protection, in pursuing sustainable development. Countries' basic infrastructure in SeA region, for instance, sewerage systems, are unable to accommodate the rapid urbanization, population growth and economic development, especially in urban areas. As a result, a number of water resources in the SeA countries are now under threat, both in terms of quality and quantity. Deterioration of water quality in lakes, rivers and reservoirs in urban areas, due to nutrient overenrichment from human waste, urban runoff, domestic wastewater and agricultural activities, is rapidly growing and recognized as one of the most serious environmental problems throughout the region. However, nutrients like nitrogen and phosphorus, are also an fundamental to ensure global and regional food security through the 21st century (Sutton et al., 2013). In addition, nutrients also represent a nexus that unites many of our concerns e.g., water, food, energy security and climate change, human health and the environment. Unfortunately, improperly use or inadequate management of water resources, as well as insufficient understanding and lack of effective mechanisms to address the issue of nutrient pollution, especially in water environment, have led to a growing number of problems, including shortage of nutrients in some areas causing poor growth and development, overuse of nutrients in other areas, leading to severe water contamination due to eutrophication and harmful algae blooms, which decrease soil quality (Corrales and Maclean, 1995; Carpenter et al., 1998; Postel and Carpenter, 1997; Correll, 1998; Selman et al., 2008; Glibert, 2013). The United Nations Under-Secretary General and Executive Director of the United Nations Environment Programme has recently emphasized that without swift and collective action, the next generation will inherit a world where millions of people suffer from food insecurity caused by too few nutrients, where the nutrient pollution threats from excess will become more extreme in other areas, and where unsustainable use of nutrients will contribute to biodiversity loss and accelerating climate change (Sutto et al., 2013).

This paper provides a comprehensive assessment on the current status of nutrient management across the region based on an intensive literature review and on-going research outcomes of the authors, and investigates possible reasons why the current efforts still fail to address the issue. Based on this assessment, the paper examines the possibility of introducing a mixed approach, from the planning stage using a material flow analysis (MFA) tool to implementing stage utilizing regulatory and economic incentive measures, to effectively address nutrient pollution from both point and non-point sources. Constraints and factors affecting effective implementation of these solutions under the context of the Southeast Asian region are also discussed.

## II. Sources and driving factors of nutrient pollution in the region

### 2.1. Understanding the major pollutant sources

SeA is a sub-region of Asia, which is located south of China, east of India, west of New Guinea and north of Australia. For the purpose of this paper, we define SeA as 10 members of the regional economic organization, the Association of Southeast Asian Nations (ASEAN), which includes Brunei, Cambodia, Indonesia, Lao, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam. SeA has a land area of 4.3 million square kilometers, which is about 3.3 % of the world's land area (ADB, 2009).

Southeast Asia is home to more than 600 million people in 2014 (Wikipedia, 2015), with population rising by almost 2% annually compared to 1.4% globally (ADB, 2009). The highest population in SeA is in Indonesia (249.9 million in 2013). By the year 2025, it is estimated that the population in Indonesia will reach 282 million, while two more countries, the Philipppines will have its population exceeding 100 million, and Vietnam would have grown to 97.4 million (World Bank, 2015a).

Many countries in the region are leading producers of goods such as rice, coffee, sugar, palm oil and cocoa. For example, according to the Southeast Asia Commodity Digest, Vietnam is the world's No. 2 coffee producer. Meanwhile, Malaysia and Indonesia are the world's biggest producers of palm oil (SACD, 2015). In addition, Asian countries are the dominant producers of rice (Fuu et al., 2011). The aggregate demand for rice in Asia is expected to increase by 50 percent during 1990-2025 (FAO, 2000). Vietnam and Thailand are two of the world's biggest rice growers/exporters. Correspondingly, rice production in Vietnam, which was 9.0 million tons in 1961, gradually increased by a factor of four by 2007, to 35.6 million tons. Vietnam uses 7.7 million tons of inorganic fertilizers each year, and the average annual increase in fertilizer consumption was 7.2 % for urea (most popular in Vietnam), 13.9% for phosphate-based fertilizers and 23.9 % for potassium-based fertilizers (World Bank, 2015b). Fertilizer consumption has increased even faster in recent years in Vietnam; it was approximately 8.9 million tons in 2010, almost double the volume used in 2005 (VFA, 2010). According to FAO (2015), fertilizer consumption in both South and East Asia have been increasing at a fast pace. It is one of the largest fertilizer producing and consuming regions in the world. Therefore, any development in South Asia and East Asia in regard to fertilizer application affects the global supply-demand situation significantly.

Major sources of nutrient pollution in water bodies of the SeA countries are diverse: agriculture, aquaculture, urban domestic and industrial wastewater, urban and farm runoff, fossil fuel combustion. In the United States and the European Union, agricultural sources such as commercial fertilizers and animal manure are typically the primary sources of nutrient pollution in aquatic ecosystems. Meanwhile, in many countries in SeA, especially in urban areas, poor sanitation and inappropriate or untreated urban wastewater are believed to be the primary sources of nutrient pollution, beside agricultural sources, leading to the creation of low oxygen conditions, and a number of species and benthic ecosystems disappeared, alongside huge economic losses (World Bank, 2008).

#### *a. Urban, peri-urban and industrial sources*

Municipal and industrial wastewater are considered "point sources" of nutrient pollution because they discharge nutrients, primary nitrogen and phosphorus, into water bodies via a pipe or other discrete conveynance. These sources are believed to be the most controllable sources of nutrients as they are often regulated in both developed and developing countries. In many developed countries, percentage of both municipal and industrial wastewater treated is quite high. In North America, or in Japan, for example, more than 90% of sewage has been treated. Moreover, advanced wastewater treatment technologies or additional chemical and biological treatment processes are applied for N and P removal. In the SeA region, only about 60% of the population has access to an improved sanitary facility and more than 300 million are still defecating in the open (WHO, 2010); less than 35 % of sewage has been treated (Selman and Greenhalgh, 2009). For instance, according to Bao and Kuyama (2013) and ADB (2013), percentage of urban sewage connection treated in Lao PDR, Cambodia, Myanmar, Vietnam is only 6%, 9%, 10% and 19%, respectively. Montangero et.al. (2007) roughly estimated that 4,400±790 tones of phosphorus per year are discharged in Hanoi wastewater; 44% coming from agricultural waste products, 36% from liquid effluent of households.

In addition, low attention to nutrient recycling and lack of appropriate wastewater treatment policies have been indicated as one of the key drivers of nutrient threats in the region (Sutton et al., 2013).

Major cities in SeA countries reply heavily on onsite septic tanks with very poor performance for wastewater disposal. Even when sewage is treated in these countries, the wastewater treatment plants have often been designed to remove solids, BOD and COD, not nutrients. Consequently, nutrient level in the effluent from these plants is very high and fails to meet national water quality standards.

In many SeA countries, combined sewer system has been utilized to collect stormwater, domestic wastewater and industrial wastewater, thus during heavy rain events, urban stormwater runoff is another significant source of nutrient pollution in urban areas.

There is a high incidence of untreated industrial wastewater being discharged into sewers and natural bodies of water, although most of the countries require that industrial wastewater should be treated before discharge (UNEP, 2004). For instance, in Vietnam, fewer than 30% of the industrial zones have centralized wastewater treatment systems. A large portion of industrial wastewater is not treated to meet the national environmental standards. More than 30,000 small and medium-sized establishments outside industrial zones have little or no wastewater treatment system. Among those industries, pulp and paper mills, food and meat processing, agro-industries are major sources of industrial nutrient pollution (Hoang-Anh, 2010).

***b. Agricultural sources***

Agriculture has significantly contributed to remarkable regional growth, registering one of the most impressive sectoral performances in the past decade. Millions of farmers are applying chemical fertilizers, pesticides and other chemicals, in pursuit of higher yields and larger net revenues. Most farmers cultivate small plots and receive little guidance regarding optimal application rates and methods for minimizing surface nutrient runoff (Balasubramanya and Wichelns, 2012). Findings from intensive literature review indicate that agriculture is a predominant "non-point" source of nutrient pollution in many countries in SeA, including Vietnam and Thailand (FAO, 2004; Gerber and Menzi, 2006; Khai et al., 2007; Schaffner, 2007; Do-Thu et al., 2011). Non-point pollution from agriculture and urban areas often constitutes an even greater total pollutant load than industrial pollution (WWAP 2014). Do-Thu et al. (2011), and Do et al. (2013, 2014) have revealed that that the agricultural system in a rural area of Vietnam was a significant source of nutrients, which affect the surrounding environment mainly due to the overuse of chemical fertilizers. Another finding from a case study conducted in a suburban community of Hanoi, Vietnam, indicated that the component receiving the largest amount of nutrients was a rice paddy field, 435.1 kg-N/ha/year and 89.8 kg-P/ha/year, in which 40% of N and 65% of P were derived from chemical fertilizer. In addition, the study also revealed that the total nutrient loads to the water bodies in 2010 was 187.3 kg-N/ha/year and 13.4 kg-P/ha/year, of which the paddy field accounted for 70% of nitrogen and the fish pond for 60% of phosphorus (Giang et al., 2012).

Based on the extensive literature review, the agricultural sector in SeA was for many years not subject to the strict regulations established under general environmental protection law. There is more and more evidence that the ultimate causes of non-point pollution from agricultural lands is excessive fertilizer use, due to the fact that fertilizers are often subsidized in these countries (Evans et al., 2012) and misperception of farmers that higher amounst of fertilizer inevitably result in higher yields and larger net revenues (Balasubramanya and Wichelns, 2012), and high density livestock operations (Carpenter et al., 1998). The critical agricultural non-point sources of water pollution in SeA region are outlined below:

<u>Nutrient runoff from agricultural fields</u>

As many SeA countries are trying to expand the agricultural sector, through diversification of agriculture and extensive multiple cropping programs, thus demand for agricultural chemicals and fertilizers in particular continues to grow. Between 1980 and 2000, increase in the use of mineral fertilizer has been particularly strong in Asia, especially in SeA, with +117 % for N and +154 % for P. For instance, the percentage change in mineral fertilizer use from 1992 to 2002 in Vietnam, Malaysia, Thailand, Philippines, Myanmar, Lao PDR is +100%, more than 20%, +60%, about +30%, about +90%, and +80%, respectively (Evans et al., 2012).

Compared to other regions in the world, Asia, mainly South and East Asia, is the leading user of mineral fertilizer with more than 57.7 % and more than 57.6 % of the global consumption for N and P, respectively (Figure 1) (FAO, 2015).

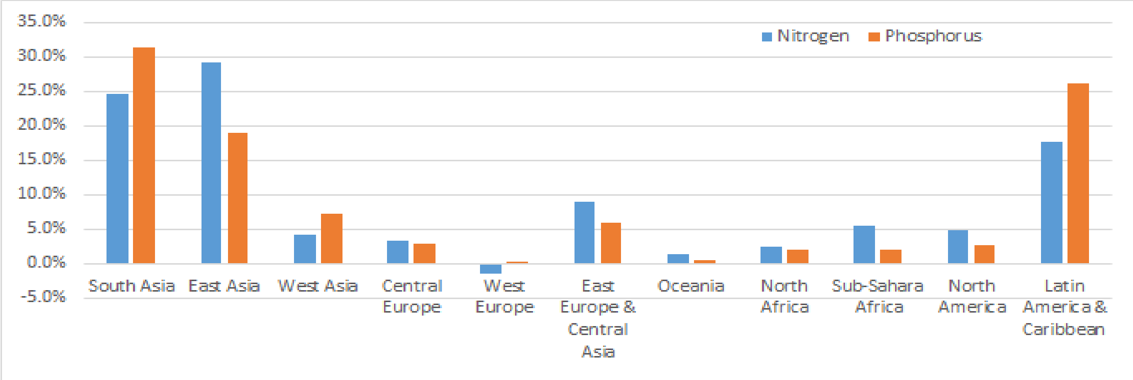


**Figure 1.** Regional and subregional share of world increase/decrease in nitrogen & phosphorus fertilizer consumption, 2014-2018
(Source: The figure is prepared by IGES based on data from FAO, 2015)

In 2012, 179 million metric tonnes (Mt) of fertilizer (109 Mt of N, 41 Mt of $P_2O_5$, and 29 Mt of $K_2O$) were applied to 1.6 million hectares (Mha) of arable land and permanent crops; i.e., an average application rate of 115 kg nutrients/ha (FAO, 2014; Drechsel et al., 2015). Meanwhile, the Asian fertilizer industry in the coming years is expected to grow at a compound annual growth rate (CAGR) of 6.1%, greater than the period of 2012-2017. In terms of nutrient usage, nitrogen fertilizers would continue to dominate the market with 57.2% share in 2017 followed with increased shares of phosphate and potash fertilizers of 29.7% and 13.1% respectively (ReportLinker, 2014).

Millions of farmers are now applying as much fertilizers, pesticides and other chemicals as possible in pursuit of higher yields and larger net revenues. Most of the farmers receive little guidance regarding optimal application rates or methods for minimizing the surface run-off and deep percolation that carry undesirable constituents into streams and shallow aquifers (Balasubramanya and Wichelns, 2012). Consequently, misuse and excessive use of mineral fertilizers, which has been becoming a common practice in many SeA countries, is one of the major factors responsible for land degradation, soil nutrient imbalances, eutrophication and algal blooms in freshwater systems and coastal waters in this region. The excess nutrients are lost through volatilization, surface water runoff and leaching to groundwater. Based on MA (2005) findings, on average, about 20% of nitrogen fertilizer is lost through surface runoff or leaching into groundwater. Also, under some conditions, up to 60% of the nitrogen applied to crops can be lost to the atmosphere by volatilization. Phosphorus, which binds to the soil, is generally lost through sheet and erosion from agricultural lands (Table 1 and table 2).

Table 1. N and P application on crops and pasture from mineral fertilizer and animal manure in SeA region and in the world

| **Region** | **Crops** | | | | **Pasture** | | | | **Contribution of manure to N fertilization** |
|---|---|---|---|---|---|---|---|---|---|
| | Area | Mineral fertilizer | Manure | | Area | Mineral fertilizer | Manure | | |
| | million ha | N | N | P | million ha | N | N | P | percentage |
| | | *(thousand tonnes)* | | | | *(thousand tonnes)* | | | |
| Southeast Asia | 87.0 | 4216.0 | 941.0 | 512.0 | 15.0 | 0.0 | 477.0 | 259.5 | 10 |
| World | 1436.0 | 73467.0 | 20664.0 | 11734.7 | 625.0 | 4331.0 | 12384.0 | 6816.6 | 30 |

(Source: FAO and IFA, 2001; FAO, 2006).

Table 2. Estimated N and P losses to freshwater ecosystems from manured agricultural lands in SeA region and in the world

| **Region** | **N from animal manure** | | **N losses to freshwater courses** | **P from animal manure** | | **P losses to freshwater courses** |
|---|---|---|---|---|---|---|
| | Crops | Pasture | | Crops | Pasture | |
| | *(thousand tonnes)* | | | | | |
| Southeast Asia | 941.0 | 477.0 | 355.0 | 512.0 | 15.0 | 63.2 |
| World | 20664.0 | 12384.0 | 8362.0 | 11734.7 | 625.0 | 1483.2 |

(Source: FAO and IFA, 2001; FAO, 2006).

The average N fertilizer use is about 8 (0-20) kg/ha.year in Sub-Saharan Africa, 60 (0-120) kg/ha.year in Latin America, 80 (50-300) kg/ha.year in Europe and North America and 40 (10-200) kg/ha.year in South and Central Asia . Meanwhile, as mentioned earlier, the average global application rate is about 115 kg nutrients/ha. If nutrient use efficiency (NUE) is less than 60%, a large proportion of the fertilizer applied ends up in surface and ground waters, or as a gaseous emission ($N_2O$ and $NO_2$) to the atmosphere. In the meantime, the average rate of N fertilizer application in Southeast Asia is up to more than 250 (50-1000) kg/ha.year and the average crop NUE in this region is only 30% (Sutton et al., 2013). For instance, the average rate of fertilizer application per hectare of arable land in Vietnam, Indonesia, Thailand between 2010-2014 is 297.1, 194.8, 153.2, respectively (World Bank, 2015c).

Manure from animal feeding operations

Nowhere in the world have the rapid growth of livestock production, and its impact on the environment, been more evident than in SeA region. During the 1990s alone, production of pigs and poultry doubled in China, Thailand and Vietnam. By 2001, these three countries alone accounted for more than half the pigs and one-third of the chickens in the entire world (FAO, 2004; FAO, 2006). Most of the water used by livestock in SeA region returns to the environment, threatening surface and groundwater water quality as well as the coastal waters of South China Sea, especially livestock pollutants from three countries including China, Thailand and Vietnam (FAO, 2006). It was estimated that pig production accounts for about 42 percent of nitrogen and 90 percent of phosphorus flows into the South China Sea. Its major sources come from the Pearl River basin in Guangdong Province, the Chao Phrya River basin in Thailand and the Red River and Dong-Nai River basins in Vietnam (FAO, 2007).

Meanwhile, the Thachin River, central to Thailand's pig farming industry, has become a focal point of governmental and public concerns (DLD and FAO, 2004). The coverage and efficiency of wastewater treatment systems in pig farms and slaughterhouses are low. Dung is considered a valuable resource (Rattanarajcharkul et al., 2001) and is collected separately to fertilize adjacent cropland or fish ponds for sale. Liquid waste is collected and treated in natural pond systems (earth lagoons) or discharged directly into the nearby canals (Kwanmeung, 2002). Few farms use more advanced anaerobic digester treatment systems. Reuse of liquid manure is rare due to its low fertilizing value and high handling and transportation costs (DLD and FAO, 2004).

Gerber and Menzi (2006) identified structural changes in the sector leading to changes in manure management practices which have caused negative environmental impacts. The growth in scale and geographical concentration in the vicinity of urban areas are causing severe land/livestock imbalances that hamper manure recycling options such as use as fertilizer on cropland. In such conditions, the costs of transporting manure to the field are prohibitive. In addition, peri-urban land is too expensive for affordable treatment systems such as biological lagoons. As a result, most of the liquid manure from such operations is directly discharged into waterways (Table 3). Treatment is only practiced on a minority of farms and is largely insufficient to reach acceptable discharge standards.

Table 3. Estimated relative contribution of pig waste, domestic wastewater and non-point sources to nitrogen and phosphorus emissions in water systems of the selected SeA countries

| Country/ Province | Nutrient | Potential Load (tones) | Percentage contribution to nutrient emissions in water systems | | |
|---|---|---|---|---|---|
| | | | Pig waste | Domestic wastewater | **Non-point source** |
| Thailand | N | 491 262 | 14 | 9 | 77 |
| | P | 52 795 | 61 | 16 | 23 |
| Vietnam | N | 442 022 | 38 | 12 | 50 |
| | P | 212 120 | 92 | 5 | 3 |

(Source: FAO, 2004)

As for livestock production, some related regulations are placed on livestock production in several SeA countries, but they are rarely enforced by local governments. Even when livestock waste is collected, a considerable part is lost by leaching or overflow during rainy season, as a result, it causes severe contamination of surface water and groundwater (Gerber and Menzi, 2006).

Aquacultural activities

Aquaculture is another growing source of nutrient pollution. An increasingly negative effect of intensive fish culture is eutrophication of the water bodies receiving aquaculture effluent. Fish excretion and fecal waste combine with nutrients released from the breakdown of excess feed or uneaten foods to raise nutrient levels well above normal, creating an ideal environment for algal blooms. , For every ton of fish, aquaculture operations produce between 42 and 66 kilograms of nitrogen waste and between 7.2 and 10.5 kilograms of phosphorus waste (Selman and Greenhalgh, 2009).

A case study investigated in nutrient pollution in the Thachin River Basin in central Thailand showed that aquaculture is the most critical nutrient pollution source in this basin, contributing roughly 60% of the total net N and P load to the river system. It also revealed that rice production produces a large share of basin nutrient loads. This findings underlines the importance of non-point source pollution control, particularly with its dominant rice production sector (Schaffner et al., 2009a).

**2.2. Driving factors of nutrient pollution in water environment**

Several interrelated socioeconomic factors are believed to drive the increase in nutrient pollution, which is causing increased occurrences of eutrophication. They can be divided into 2 types of drivers. One is indirect drivers, include population growth; economic growth in the developing world, which will impact consumer consumption; and the growth of intensive agriculture. Meanwhile, direct factors of eutrophication include higher energy consumption, increased fertilizer consumption, and land-use change (Selman and Greenhalgh, 2009).

*a. Indirect factors*

+ Population increase

According to UNFPA (2010), total population in this region is expected to reach 760 million by 2050. The demand for food, energy and other natural resources will also increase. Thus, it requires greater agricultural production to meet their growing demands, also increased burning of fossil fuels to satisty improved quality of life such as heating homes, power car and fuel industries

+ Economic growth

Economic growth, rising incomes and urbanization, leads to rapid changes in diets, in favour of more grain-intensive food such as meat, particularly red meat. This leads to a substantial increase in the fertilizer demands for grain to feed livestock for food.

Dargay et al. (2007) esteem that global per capita income will double between 2002 and 2030, with the greatest income growth occuring in developing countries andespecially in SeA. This will lead to changes in consumption patterns, such as increasing energy use and comsumption of foods. Delgado (2003) says that "the amount of meat consumed in developing countries over the past has grown three times as much as it did in the developed countries. Poor people everywhere are eating more animal products as their incomes rise above poverty level and as they become urbanized". It is estimated that by 2020, the share of developing countries in total world meat consumption will expand from 52% currently to 63%. Also, by 2020, developing countries will consume 107 million metric tons (mmt) more meat and 177 mmt more milk than they did in 1996/1998, dwarfing developed-country increases of 19 mmt for meat and 32 mmt for milk. The projected increase in livestock production will require annual feed consumption of cereals to rise by nearly 300 mmt. The income and nutrition of millions of rural poor in developing countries are improving. However, these dietary changes also create environmental and health problems that require active policy involvement to prevent irreversible consequences (Delgado, 2003).

+ Agricultural intensification

The way in which SeA people grow food has changed significantly since the "Green Revolution", which was first launched in Asia in 1960s. "Green Revolution" refers to the big increases in wheat and rice yields by new high-yielding crop strains, combined with the use of fertilizers and agricultural chemicals. The Green Revolution in SeA was a technology package comprising improved high-yielding varieties of rice, irrigation or controlled water supply, improved moisture utilization, fertilizers and pesticides, and associated management skills. However, based on experience from developed countries, this Green Revolution also led to significant unintended environmental impact such as nutrient pollution (Selman and Greenhalgh, 2009).

*b. Direct factors*

+ Growing energy demands

As the income as well as living standard of people in the SeA countries increases, the demand for energy use will be increased. According to the International Energy Agency, in developing Asian countries, energy use is projected to grow by 3% compared with 1.7% for the entire global economy (IEA, 2007). Energy demand is thus expected to double in Asia in the next 20 years, and according to the projections, this increase in regional demand will account for almost 40% of the world total (Sovacool 2009). Fossil fuel sources such as coal, oil and natural gas accounted for 87% of the world's primary energy consumption in 2012 (Gonzalez and Lucky, 2013). Unfortunately, these are considered main sources of $NO_x$ emissions. Eventually, a certain amount of $NO_x$ (specifically $NO_2$) is oxidised to nitric axit vapor ($HNO_3$), which will be absorbed directly at the ground in the form of nitrate-containing particles or dissolved in cloud droplets. However, the contribution of nitrates from this process to nutrient pollution in water environment is normally negligible.

+Increase in fertilizer demands for food and energy

As mentioned above, growing population and income will lead to growing demand for food and energy, including the expanding use of biofuels. Thus, agriculture production, and therefore, fertilizer consumption will be expected to increase to meet the demand-intensive agricultural practices, which are expected to expand in the future of this region.

+ Land-use changes

Natural landscapes, including forests and wetlands, play an important role for capturing and cycling nutrients. Due to land-use conversion, such as loss of wetlands and deforestation in most SeA countries (Sodhi et al., 2004), the ability of these landscapes to capture nutrients is reduced, therefore leading to greater nutrient losses to local water bodies.

## III. Material Flow Analysis as an effective tool for nutrient management planning

Material Flow Analysis (MFA) modeling is a useful tool for nutrient management planning. Numerous studies have dealt with the establishment of the nitrogen and/or phosphorous budget in tropical hydrographic networks in Asia and Africa (Le et al., 2005, 2010; Luu et al., 2012; Schaffner et al., 2009a, 2009b; Do-Thu et al., 2011; Baker et al., 2007; Buranapratheprat et al., 2002).

Unlike other models, the material flow analysis (MFA) model creates visualizations of the material flows, such as nutrients, through human activities, tracing the sources of pollution. It has, been proved to be a suitable instrument for early recognition of environmental problems in developed countries by quantifying material flows in the system and forecasting the impact of possible interventions on the environments (Brunner and Baccini, 1992; Drolc and Konan, 1996; Zessner et al., 1998; Zessner and Kroiss, 1999; Zessner and Gils, 2002). This methodology has been modified to consider the uncertainty in input data sources (Binder et al., 2004). As a result, the modified MFA method has also been successfully applied in developing countries that typically face data scarcity and uncertainty problems.

The Pak Kret municipality, Nonthaburi province, Thailand applied MFA to assess mitigating measures, maximizing nutrient recovery and minimizing environmental pollution (Sinsupan et al., 2005). Results revealed that creating a wastewater treatment plant and composting solid wastes could reduce nitrogen loading by 45%. Therefore, MFA might be effectively applied during environmental sanitation planning in developing countries. MFA was also useful in quantifying N and P flows in urban areas of Hai Phong city, Vietnam, including five urban districts. The aim was to identify weaknesses related to nutrient management in this region (Thuy and Aramaki, 2010). MFA results demonstrated that appropriate management of human excreta and wastewater from households was needed to mitigate the environmental impacts of these nutrients.

The above adapted MFA was also successfully applied in a multi-provincial area like Thachin River Basin, Thailand, including six provinces and a part of Bangkok. This study provided an overview of the origins and flow paths of the various point and non-point pollution sources of the entire area in terms of N and P (Schaffner et al., 2009a,b). The results showed that aquaculture (as a point source) and rice farming (as a non-point source) were the key nutrient (N and P) sources in this river basin. When simulated and measured nutrient concentrations were compared, retention in the river system appeared to be significant and coherent between model and reality.

Do-Thu et al. (2011) proved that the adapted MFA could be used to quantify nutrient flows among environmental sanitation and agriculture systems and to assess the impact of these processes on the surrounding environments. MFA simulation results show critical control sources of nutrients in communes of Hanam province, Vietnam, with overuse of chemical fertilizers in paddy fields, uncontrolled solid waste such as faecal and fish pond sludge, organic solid wastes and on-site sanitation system effluents. Consequently, options for nutrient resource management could be proposed, such as resuse of waste materials as fertilizers in agriculture and on-site sanitation technologies could be further developed and greatly improved. In short, applying MFA as a part of environmental sanitation planning allows decision makers to identify potential problems and simulate the impact of remediation measures on resource consumption and environmental pollution in an integrated way.

MFA modeling was also applied to one of the most polluted river systems in Vietnam, the Day-Nhue River Basin (Do, 2012; Do et al., 2013). Results showed that the main sources of nutrient pollution were overused chemical fertilizers in the paddy fields, and domestic wastewater from the center of Hanoi Capital. The scenario reveals that nitrogen discharge to environments will significantly reduce in 2020, when drainage wastewater can be treated. Nitrogen to the water environment will be decreased by 14.8% and nitrogen load to atmosphere and soil/ groundwater will be reduced 6.3% and 4.8%, respectively. Reducing half of applied chemical fertilizers also makes nitrogen load to all environments decreased significantly. 37.3%, 4.8% and 5.4% of nitrogen discharge to surface water, soil and air will be reduced, respectively. So, in terms of efficiency as well as cost – benefit, cutting half of chemical fertilizer applied will be better for environment than developing wastewater treatment plant. By managing pig manure with biogas systems, air environment quality will be slightly improved with reduction of N load is 7.8%. By contrast, it will increase nitrogen load to soil/ groundwater environment (1.2%). Surprisingly, when agricultural activities are improved, nitrogen load to environments will improve a lot. 76.6% of nitrogen to the water will be reduced and 5.5%, 4.5% for air, and soil/groundwater, respectively. This scenario demonstrates that good agricultural behaviors are the best solution for pollution reduction.

## IV. Why have SeA countries failed to address the issue of nutrient pollution?

Command and control (CAC) regulations or conventional regulatory approaches are the key pollution control policies in SeA region, representing one of the straightforward approaches for water pollution control, including nutrients. It mainly employs standards and emissions/effluent caps as a means to achieve desired water quality standards.

Its principle is to achieve environmentally responsible behaviour and goal by enforceable laws, regulations and standards. Regulatory tools influence environmental outcomes by regulating processes or products, limiting discharge of specified pollutants and by restricting certain polluting activities to specific times or areas. The success rates of CAC instruments largely depends on the enforcement capacity of the regulating agency, for instance, the capacity of the regulator to monitor the emissions, and also on economic and technological strength of the country. One of the drawbacks is that the cost of complying with the regulations is usually unknown or very high (Karn et al., 2001).

In general, it is impossible to determine how much pollution any single farmer or household generates, and to allocate responsibility for ambient concentrations or loads across an agricultural community. Thus, many regulatory programmes and financial incentives that are effective in reducing point souce pollution are not effective in reducing pollution from non-point sources (Balasubramanya and Wichelns, 2012).

In addition to regulatory approach, economic incentives (EIs) have also been taken for water pollution control in many countries, but again many EIs are designed in ways that only address point sources of pollution. EIs can encourage reductions in point souce pollution at a lower aggregate cost than is possible through CAC programmes (Balasubramanya and Wichelns, 2012). Historically, point source pollutants have received the greatest attention, both publicly and scientifically, because of the conspicuous severity of their impacts at a localized point. However, over recent years, public, political, and scientific attention has shifted pollutants that are widespread. This shift reflects an awareness of the scope and potential impact of the non-point source pollution problem (Loague and Corwin, 2005). Unfortunately, due to lack of appropriate monitoring programme, weak institutional capacities, inadequate control and enforcement of environmental regulations, appropriate policies and poor voluntary compliance. As a result, point sources of water pollution are still given more priority and considered the major concern in this region. One estimate suggested that the cost on point source pollution abatement could be 65 times higher than that of non-point source (Nguyen et al., 2006).

Economic incentives, especially emission or pollution charges and per-unit taxes on polluting inputs, have become the most common instruments in this region, as a complement to direct regulation, to address both point and non-point pollution, especially in urban areas in SeA countries such as Vietnam, Indonesia, Malaysia, Thailands, and Singapore (Table 4). In addition, it has been reported that due to difficulty in reducing pollution from dispersed small-scale enterprises through regulatory measures, many local governments in China are shifting their focus from regulatory measures to economic incentives which motivate farmers to assume responsibility for reducing non-point source pollution (Shao, 2010). Meanwhile, in Japan, farmers are rewarded for reducing fertilizer applications, with the goal of improving water quality in lakes across the country. The lakes are an important source of drinking water in many areas within the country, so the public is willing to pay farmers for the service of ensuring that water quality is maintained at high levels (Yamada, 2007).

These market-based instruments create incentives for firms to adopt low-cost technological or process innovations for pollution control. From a theoretical point of view, "…if properly designed and implemented, maket-based instruments allow any desired level of pollution clean-up to be realized at the lowest overall cost to society, by providing incentives for the gretatest reductions in pollution by those firms that can achieve these reductions most cheaply" (Stavinc, 1997).

Table 4. Economic incentives, which have been used for water pollution control in some selected countries in the region

| **Types of Instrument** | **Indonesia** | **Malaysia** | **Myanmar** | **Philippines** | **Singapore** | **Thailand** | **Vietnam** |
|---|---|---|---|---|---|---|---|
| User/Administrative Charge | O | O | O | | O | O | O |
| Charge on water resource extraction & use | O | O | O | | O | O | O |
| Sewage (to sewer) disposal/treatment charge | O | O | O | O | O | O | O |
| Pollution charge/tariff/tax | O | O | O | O | O | O | O |
| Industrial effluent | | O | O | O | O | O | O |
| Institutional/domestic | | | O | O | O | O | O |
| Tax | | O | | | | | |
| Product tax | | | | | O | O | O |
| Sales tax | | | | | | | |
| Tax on raw material/substitution | | | | | | | |
| Liabilities | | O | O | O | O | O | O |
| Compensation/redressing | | | | | | O | O |
| Non-compliance fee | | | | | | O | O |
| Tradable pollution (effluent) permit | X | X | X | X/O | O | X | X |
| Tax subsidies/ Financial Incentives | O | O | O | | | O | O |
| Rebate on custom/excise duty | | O | | O | O | | |
| Accelerated depreciation | | | | | | | |
| Tax subsidies on eco/recycled products | | | O | | | | |
| Grants/ soft loans | O | | O | | | O | |
| On recycling activities | O | | O | | O | | |
| Pollution reduction efforts | O | | O | | | | |
| Suasive/ Voluntary mechanism | O | O | O | O | O | O | O |

Note: O- available; X – not available.

Both regulatory and economic incentive measures taken against water pollution abatement, control and management, can be classified into 4 groups: (i) Legislation and regulatory measures (also referred as to "Command and Control"); (ii) Economic Incentives (sometimes referred as to "market-based instruments"); (iii) Governmental financial assistance such as subsidies or environmental funds; (iv) other supportive measures such as research & development of eco-technologies and goods, public participation in decision making process, voluntary mechanisms. Some measures are aimed at controlling pollution generated directly by any activity or discharged into the environment, therefore can be further categorised as "direct measures" or "direct instruments". Meanwhile, others may indirectly contribute to changing the behaviour or abating pollution sources or quantity, which can be catagorised as "indirect instruments" (Table 5).

Table 5. Commonly used regulatory and EIs for water pollution control in the region

| Type | Direct Instruments | Indirect Instruments |
|---|---|---|
| Legislation and Regulation (also referred as to "Command and Control" measures) | 1. Standards: Ambient water quality and effluents standards (emission regulations◊ source-specific)<br>2. Permits (License) and non-tradable quotas<br>3. Regulations or ban on use and handling of materials (hazardous substances) | 1. Regulation on equipment, products, processes, inputs, and outputs<br>2. Industrial siting and zoning regulation<br>3. Environmental impact assessment system and clearances |
| Economic Incentives | 1. Water pollution tax/charges/fees/tariffs<br>2. User/Service/Effluent charges<br>3. Strict liability rules and performance bonds<br>4. Non-compliance fee | 1. Taxes on products and raw materials<br>2. Tax subsidies on eco-, recycled products<br>3. Tax and price differentiation (public utilities)<br>4. Financial incentives (grants and soft loans)<br>5. Creation of property rights |
| Governmental financial assistance (Subsidies, grant, soft loans and environmental funds) | Regulatory agency expenditures for purification, cleanup, waste recycling, disposal, and pollution reduction efforts. | Development of "Clean" technologies |
| Supportive and other measures | 1. R&D of Eco-technologies and goods<br>2. Public participation in decision making process<br>3. Suasive instruments (replied on voluntary compliance by polluters) | 1. Eco-labeling<br>2. Information disclosure |

(Source: Modified from Karn et al., 2001)

Beside commonly used EIs as mentioned earlier, proven to be helpful in reducing both point and non-point source pollution at a certain level, water pricing is another important policy tool. Higher water prices help to reduce the amount of water use, thus the volumes of effluent dischaged in many settings, particularly in agriculture (Balasubramanya and Wichelns, 2012).

In general, EIs have many advantages, compared to CAP regulations, and have emerged as a potential solution to the trade-offs between economic growth and environmental quality. Although EIs have advantages compared to direct regulation instruments, however, there are also weaknesses, prerequisite factors and barriers which hinder the use and successful implementation of of these instruments in the SeA countries (Table 6).

Despite the attractiveness of EIs for their freedom and market conforming properties, a combination of regulatory instruments and EIs are needed to achieve the desired balance. Whatever the policy mix chosen, problems of implementation arise from a variety of factors: administration, politics, inconsistencies and flaws in design (O'Connor, 1999; Rammont and Amin, 2010). Both Simachaya (2009) and Rammont and Amin (2010) have identified major constraints in initiating and implementing EIs for water pollution control, based on a specific case study in Thailand. These include: (i) complexity in accessing the environment fund or contributory funds due to long approval processes, (ii) personnel problems and loopholes in the law and regulations, (iii) failure to follow up with concrete laws and regulations to support charge implementation, (iv) an apparent disconnect between customer willingness to pay and agency willingness to charge for wastewater services, (v) politicization of the tariff-setting process, (vi) effluent charges set at such a low level that they are not an incentive for abatement, (vii) lack of cooperation between water and wastewater service authorities, (viii) capacity limitations within local government agencies, and (ix) the political will and commitments. These constraints are commonly cited barriers not only in Thailand, but throughout SeA.

Table 6. Strengths, weaknesses and prerequisite factors to ensure the success for implementation of selected commonly used EIs

| EIs | Strengths | Weaknesses | Prerequisite factors |
|---|---|---|---|
| **Charge system** | ♣ Charges proportional to pollution. | ♣ More complex to coordinate with different sources of pollution.<br>♣ Monitoring and enforcement are costly. | ♣ Monitoring data on pollutant must be available.<br>♣ Accurate relationship between estimated emissions and readily observable inputs and site characteristics*.<br>♣ Enforcing compliance.<br>♣ Institutional integrity must be very high. |
| **Taxes** | ♣ Multiple sources of pollution.<br>♣ No need to identify an abatement level.<br>♣ Works even when monitoring data unavailable.<br>♣ Easy to manage.<br>♣ Generate revenues. | ♣ Do not always incentivize adoption of abatement technologies.<br>♣ May affect non- targeted activities.<br>♣ Politically difficult to accept.<br>♣ Distributional impacts can be distortive. | ♣ Enforcing compliance.<br>♣ Institutional integrity must be very high. |
| **Subsidies** | ♣ Incentive to actually change system | ♣ Tax-payer gets part of the pollution burden. | ♣ Monitoring data on pollutant must be available.<br>♣ Enforcing compliance. |
| **Tradable permits** | ♣ Flexibility in their application.<br>♣ Cost savings for the regulator.<br>♣ Less efficient units of production are likely to stop operating. | ♣ Major regulatory requirements.<br>♣ Consistent legal framework.<br>♣ Political resistance. | ♣ Data needed for initial allocation.<br>♣ Tracking system required.<br>♣ Enforcing compliance.<br>♣ Clearly-defined, homogeneous input related to environmental problems*.<br>♣ Sufficient polluters to establish market*. |

(Source: Modified from Ahmed, 2012; *: Weersink et al., 1998)

**Water Quality Trading – An innovative approach for nutrient pollution control**

Water quality trading (WQT) is a market-based instrument which has been gaining attention in watersheds around the world, especially in Australia, Canada, Germany, United Kingdom and United States. It often works along-side water quality regulations to improve water quality by providing flexibility in how regulations are met and lowering regulatory compliance and abatement costs (WRI, 2009). It is based on the idea that the costs to reduce pollution are quite different among individual entities depending on their size, location, scale, management, and overall efficiency. Trading allows sources with high abatement costs, often associated with regulated and point sources, to purchase pollution discharge reductions from sources that have lower abatement costs, often associated with unregulated and non-point sources. Non-point sources are normally sellers of pollution reduction credits and not buyers, since they are often under non-regulatory obligation to reduce their discharge. Practically, trading can occur if there is a large enough difference in the cost of reducing discharges between different sources. This is a necessary condition, but not sufficient on its own. In general, the cost-effectiveness of a trading system will depend on the size of transaction costs, implementation costs and administrative costs (Cartin et al., 2005). For most water quality trading programs established in the United States, the regulatory driver has been the establishment of a

Total Maximum Daily Load (TMDL). Once TMDL has been established, all trading must take place "within a watershed or a defined area for which a TMDL has been approved (Fisher-Vanden and Olmstead, 2013). The US Environmental Protection Agency (2001) estimated that expanded use of water quality trading between point and non-point sources could reduce compliance costs associated with TMDL regulations by $1 billion or more annually between 2000 and 2015.

As many permitted facilities such water treatment plants or industries like food industries in the SeA countries are now facing increased costs to control pollutants due to more and more stringent regulations for this sector, especially pollutants like phosphorus, nitrogen, sediment and salinity; thus, the market demand for pollutant reductions generated by agricultural conservation practices is very large and likely to increase in the near future.

Trading is most commonly applied to nutrient pollutants, such as nitrogen and phosphorus; but has also been applied to temperature, sediments, and even selenium (WRI, 2009). The US EPA also supports the trading of credits for nitrogen, phosphorus, and biological oxygen demand (BOD), but takes a negative attitude towards the credit trading of toxic substances, for these could cause or aggravate local and regional water quality problems (Nishizawa, 2003).

In the world, there are currently about 57 WQT programs. The majority of programs are located in the United States (WRI, 2009). WQT is today considered a proactive approach, and still a voluntary effort, in which farmers have the right to participate or not. Wastewater treatment plants as well as industries are encouraged to get involved in these programs; however, no laws or regulations require them to participate.

There are a number of explainations for the above situation as well as for why WQT is not popupar in many other countries, including the low supply and demand for pollution reduction credits, the fact that non-point sources are not regulated, high transaction costs and lack of trust among stakeholders (Breetz et al., 2005; King, 2005; Cartin et al., 2005). WRI (2009) has identified three factors that have spurred the growth of water quality trading programs in the United States: (1) increased regulatory interest in controlling nutrients as a result of increasing occurrences of eutrophication and hypoxia in US waterbodies; (2) the US Environmental Protection Agency's (EPA) endorsement of water quality trading; (3) the availability of government funding to finance market-based water quality initiatives.

Besides the above factors for considerations, a variety of other factors must be taken into account when introducing this instrument in SeA countries such as target pollutants, policy drivers, allocation of water quality caps, trading ratio, market structure and types of trade. Based on the experiences from all countries that introduce WQT for water pollution control in their countries, for the successful implementation of WQT, a solid foundation of water quality regulations, including water quality standards, total load requirements, and scientific understanding of the water system and watershed dynamics (ADB, 2011) is required. As most SeA countries are still at the early state of environmental legislation development, it is recommended that this approach should focus on agricultural pollutants, specifically nitrogen (N) and phosphorus (P), at this time. As N and P can enter water bodies from several sources, , there could still be a number of potential trading partner with which agricultural producers could trade credits, especially with sources that are likely to be regulated or monitored in the SeA countries such as industrial zones/parks, municipal domestic wastewater treatment plants, and onsite sanitation systems (Table 7). As a precondition for trading, all partners involved in a nutrient trading should located and discharge effluents into the same watershed or water body.

Table 7. Potential trading partners for agricultural pollutants in the SeA countries

| **Agricultural Pollutants** | **Potential Trading Partners in SeA countries** | | | | | |
|---|---|---|---|---|---|---|
| | Municipal wastewater | Industrial wastewater (example: seafood industry) | Septic systems (Onsite sanitation systems) | Forestry | Mining | Urban stormwater runoff |
| | (2nd priority) | (1st priority) | (3rd priority) | | | (4th priority) |
| **Phosphorus** | O | O | O | X | X | O |
| **Nitrogen** | O | O | O | X | X | O |

Note: O- recommended; X – not recommended.

Again, although there are many successful cases of using EIs for nutrient pollution control, these incentives cannot be considered a successful and effective stand-alone measure to solve the problems of nutrient pollution in aquatic ecosystems in the SeA countries. To effectively reduce the nutrient pollutants discharge load into public waters, so that it can meet a national effluent standard or a certain allowable discharge level, a combination of regulatory measures and economic incentives, are essential for the implementation of further improvements in nutrient pollution control.

## V. Conclusion remarks

Given the complexity of nutrient pollution problems in Southeast Asian countries, a single policy approach would not be sufficient to gurantee success in goals of water quality improvement. Experience to date with regulatory measures and economic incentives in the region is mixed but encouraging. It is important to keep in mind that these strategies are not exhaustive. No single policy strategy or approach can be considered a truly successful stand-alone solution.

A comprehensive or combination that integrate the mixed uses of these policies, from planning stage using MFA tool to implementating stage utilizing regulatory and economic incentive measures is believed to be the most effective way for achieving the greatest positive outcomes in nutrient management planning under the given context of Southeast Asian countries.

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