The Implications of Scenarios for Phosphorus flow from Agriculture and Domestic Wastewater in Myanmar

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Abstract
The transfer of nutrients from agriculture (farmland and livestock) and wastewater to the hydrosphere invites the attention of policymakers and scientists because it constitutes an increasingly important factor influencing the water environment. Agriculture, livestock, and fisheries can be regarded as the backbones supporting the Myanmar economy. However, phosphorus (P) used for cultivation and domestic sewage is a major source of organic pollutants and eutrophication in Myanmar coastal waters. It is therefore necessary to elucidate the P flow mainly from agricultural and domestic wastewater to formulate a series of cost-effective policies and best management practices (BMPs). This paper describes P flow to the hydrosphere driven by agricultural and domestic wastewater in Myanmar during 2010–2100. Results reveal that total P flows from farmland and livestock occurred at an annual rate of 55 ktpa (thousand tonnes per annum) in 2010, but they are expected to be 128–141 ktpa in 2100. Moreover, estimated P flows from domestic wastewater are 13 ktpa in 2010 and 20 ktpa in 2100. Urban population growth is a main factor contributing to the gradual increase in P flow from domestic wastewater but most of the P flow derives from agriculture, which indicates that marked reduction of fertilizer use is necessary. Recovery of P from sewage sludge can substitute for a small share of fertilizer use. This research provides a core for the appraisal of P utilization and facilitates determination of important objectives for sustainable P management in Myanmar.

Keywords: Sustainable phosphorus management, phosphorus ore depletion, agricultural pollution, fertilizer, sewage

Introduction

The phenomenal population increase, changes in lifestyle (improved diet and use of phosphorus detergents), and housing (increased household connection to sewage system) in Myanmar, along with the acceleration of urbanization and industry, have drastically raised the urban point release of phosphorus (P) to surface waterbodies. Moreover, agricultural intensification and the widening use of chemicals have dramatically increased P diffuse sources. Varieties of point source and non-point source pollutions transferred from terrestrial to aquatic ecosystems have contributed to the development of eutrophication in surface waters worldwide (De Jonge et al. 2002, EEA 2005).

In 2019, over 50% of all demanded phosphate fertilizer around the world was applied in Asia; roughly half of that 50% was used in eastern Asia, including all ASEAN countries and China (FAO, 2016). The rising demand for fertilizer has arisen from the need to meet the nutritional demands of the region's rapidly increasing human population. The rise in intensive fertilizer use presents severe implications for coastal habitats because greater application results in greater runoff; the fraction of fertilizer lost from fields will increase with the intensity of fertilizer application. Phosphorus (P) fertilizer use for agricultural activities has increased to meet growing demands for feeding of the world's growing population, which has also increased inflows of water containing phosphorous into the hydrosphere. Researchers around the world have conducted material or substance flow analyses of P on a global scale and on the individual country level for the past and current target timing (Chen et al. 2016, Cordell et al. 2009, Ma et al. 2013). Lwin et al. (2016, 2017) also examined global P flows, but Myanmar was not included in their research scope. This study specifically examined Myanmar to forecast P flow from agricultural and domestic wastewater during 2010–2100.

Myanmar has the fifth largest population in ASEAN and the second largest land mass. Recently, Myanmar opened up as a country after many years of military and Junta rule. It is currently embracing democracy. Located among India, Thailand, and China, it has ready access to major Indian shipping routes. Of its people, 70% reside in rural areas; most are engaged in farming. Therefore, it is often said that now is the right time to invest in Myanmar agriculture and that Myanmar is the final frontier in Southeast Asia. In Myanmar, it is estimated that the agricultural sector shares 37.8 percent of the gross domestic product (GDP) and that it accounts for 25–30 percent of all export earnings. Myanmar has an open competitive fertilizer market that is dependent on imports for over 80% of its total market demand, estimated at between 1.2 and 1.4 million product tons per annum. The fertilizer market, which is dominated by urea use, relies mainly on imports from China, entering mainly through Muse in Shan State. However, fertilizer use by farmers is insufficient for optimum yields. Farmers generally have little knowledge of the best agricultural practices and plant nutrition requirements. Consequently, large amounts of nutrients run off from agricultural land to the hydrosphere, causing eutrophication. Lack of research has left flow amounts unknown and has hindered awareness of the issue, but the effects are severe.

In Myanmar, the fishery and livestock sectors are regarded as the most important, after agriculture, to meet the protein needs of the population, to enhance food security, and to provide employment for rural communities. The livestock and fisheries sectors account for more than seven percent of the national GDP. Regarding livestock, increased urban population plays an active role in greater livestock demand. Consequently, increased P flow from increased demand of livestock affects society and the hydrosphere, exacerbating environmental pollution of many types.

As an additional research area, P flow from domestic wastewater is estimated in this study. Myanmar has been facing considerable challenges with the management of wastewater as a result of increasing income, increasing consumption level and changing consumption patterns, urban population growth, and lack of effective wastewater treatment and disposal options. Inadequate wastewater and sanitation services combined with underinvestment in preventive health care, have presented environmental and human health challenges in Myanmar. Although Yangon, Mandalay, and Nay Pyi Taw have urban sanitation services that are well below acceptable levels, the situation is worse in other poor regions and areas of the country. With the exception of central business districts, the three major cities have no conventional central wastewater or sewerage collection and treatment systems. Domestic wastewater is usually released into storm water drainage and natural waterways. Nevertheless, environmental impact assessments do not emphasize water resource management. Because of ongoing rapid industrialization in cities, many factories are being built around urbanized areas. The need persists to disseminate knowledge about the proper disposal of wastewater to control the problems of the direct discharge of wastewater from factories into rivers or streams. Therefore, necessary and emergency estimation of P flow to the hydrosphere is necessary while introducing new wastewater treatment plants and modifying old wastewater treatment plants in Myanmar.

By quantifying amounts of P flow to the hydrosphere, this study specifically examines P in the agricultural and domestic wastewater and their environmental effects to facilitate relevant policy making. Following are the specific objectives.

(1) To calculate the amount of P release from agricultural and domestic wastewater into bodies of water

(2) To estimate the relative effects of efficient and less-efficient fertilizer use and sewage systems on the flow of P to the hydrosphere.

(3) To assess possibilities for P recovery.

Methods and Data

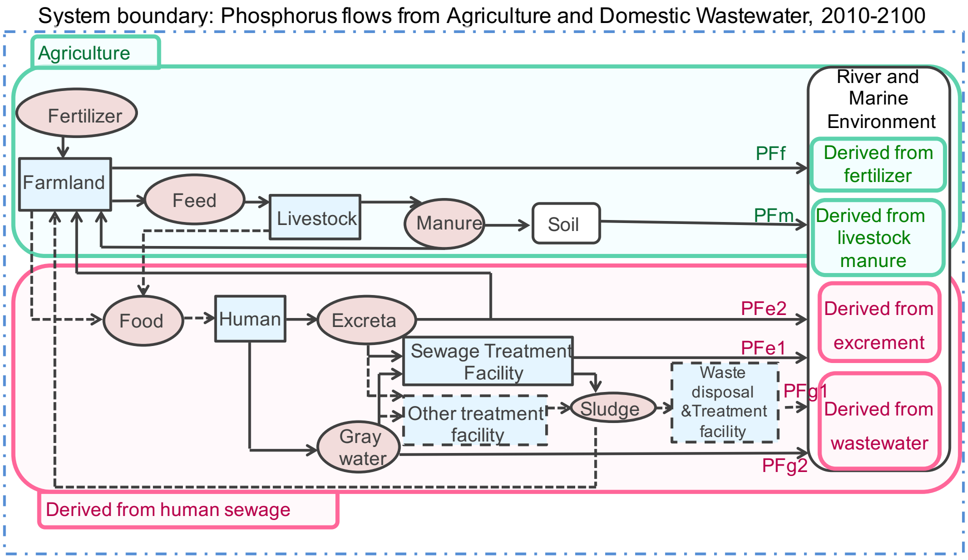

Figure 1: Simplified flows of P from agriculture and human sewage to hydrosphere.

Figure 1 presents our P flow research scope. Flows and systems enclosed in dotted lines were excluded from our research: our system boundary includes P flow from agriculture (fertilizer and livestock manure) and domestic wastewater (excrement and gray water) for 2010–2100.

The annual P flow derived from farmland (PF_f) to water bodies is calculable using the following equation
(1).

$$PF_f = (\sum_i (P_{CROPi} \times HA_i) + (P_{ls} \times R_{ls}) + (P_e \times R_e)) \times R$$

Eq. (1)
The P flows from livestock manure (PF_m) (tonnes/year) were calculated using equations (2)–(3).

$$PF_m = P_{ls} \times (1 - R_{ls}) \times R$$

Eq. (2)

$$P_{ls} = \sum_i (N_i \times P_{ANIMALi})$$

Eq. (3)
In those equations, P_{ls} signifies the P flow from livestock manure (tonnes/year), R_{ls} denotes a ratio of P return to farm from livestock manure (–), R represents the ratio of outflow to water from farm (–), N_i stands for the number of livestock animals i (beef cattle, dairy cattle, pig, layer chicken, and broiler chickens), and $P_{ANIMALi}$ represents the P content in manure of animal i per animal (tonnes/animal/year).
The P flow from human excrement (PF_e) (tonnes/year) was estimated using equations (4)–(7).

$$P_e = Pop \times P_{person,e}$$

Eq. (4)
Therein, P_e is the P amount in excrement (tonnes/year), Pop denotes population (persons), $P_{person,e}$ signifies per-capita P contained in excrement (tonnes/person/year).

$$PF_{e1} = P_e \times SC \times (1 - PR)$$

Eq. (5)

In that equation, PF_{e1} represents P flow from excrement passing through sewer treatment facilities (STF) (tonnes/year), SC is the ratio of urban population with access to STF (–), and PR represents the average P removal ratio in STF (–).

$$PF_{e2} = P_e \times (1 - R_e) \times (1\text{-}SC)$$

Eq. (6)

In that equation, PF_{e2} stands for the P flow from excrement without passage through STF (tonnes/year), R_e is the ratio of P in excrement returned to farmland (–).

$$PF_e = PF_{e1} + PF_{e2}$$

Eq. (7)

The P flow from gray water (PF_g) (tonnes/year) was calculated using the following equations (8)–(11).

$$P_g = Pop \times P_{person,g}$$

Eq. (8)

Therein, $P_{\text{person,g}}$ denotes the per-capita P contained in domestic gray water (tonnes/person/year).

$$PF_{g1} = P_g \times SC \times (1 - PR)$$

Eq. (9)

In that equation, PF_{g1} represents the P flow from gray water passing through STF (tonnes/year).

$$PF_{g2} = P_g \times (1 - SC)$$

Eq. (10)

Therein, PF_{g2} is the P flow from gray water without passing through STF (tonnes/year).

$$PF_g = PF_{g1} + PF_{g2}$$

Eq. (11)

As one ultimate scenario, the degree to which P can be recovered from domestic wastewater system and reused as fertilizer can be calculated using the following equation (12):

$$P_{rec} = \left(Pe + Pg\right) \times SC \times PR$$

Eq. (12)

The following are some necessary data and clarifications for all equation calculations above.

Table 1. Amount of phosphorus fertilizer (P_2O_5) per unit of harvested area

	Cereals				Roots and Tubers	Sugar crops	Oilseed crops			Vegetables	Fruits
	Wheat	Rice	Corn	Others			Soybeans	Oil palm fruits	Others		
Bangladesh (B)	0.021	0.024	0.026	0.025	0.015	0.043	0.034	0.037	0.024	0.023	0.024
Thailand (T)	0.035	0.007	0.018	0.005	0.017	0.052	0.033	0.035	0.010	0.059	0.026
Avg. value of (B and T)	0.028	0.015	0.022	0.015	0.016	0.047	0.033	0.036	0.017	0.041	0.025

(tonnes/ha)

Source: FAO, 2010

Note: P_2O_5 stands for phosphorus pentoxide. This research examines only P flow from agriculture to hydrosphere. Therefore, all data related to P_2O_5 are converted carefully by multiplying a conversion factor of 0.4364 to estimate the P flow from fertilizers to the hydrosphere.

Crops of 41 types are included in this research by classification respective aggregated items provided by FAO, 2010: Cereals (wheat, rice, corn, barley, rye, oats, millet, sorghum and other grains), Roots and Tubers (cassava, potatoes, sweet potatoes, yams and other potatoes), sugar crops (sugar cane and sugar beet), oilseed crops (soybean, oil palm, ground nuts with shell, sunflower seed, rapeseed, mustard seed, seed cotton, coconuts, sesame seed, olives, other oilseed crops), vegetables (tomatoes, onions and other vegetables), and Fruits (orange/mandarins, lemons/limes, grapefruit, other citrus fruits, bananas, plantains, apples, pineapples, dates, grapes and other fruits).

Harvested area data for each targeted crop for 2010 were obtained from the FAOSTAT web site. Total amounts of P fertilizer applied to crops of each type were referred from IFA data (Heffer 2013). Nevertheless, regarding P_{CROPi}, which simply represents the fertilizer usage by crop, no hard data or recorded information of actual usage exist in Myanmar. Therefore, because of unavoidable difficulties related to data availability, we take the average value of actual usage of P fertilizer amount per crop of Thailand and Bangladesh reported by Lwin et al. (2016, 2017). We agree that the use of fertilizer per hectare is expected to differ even for the same crop in different countries. The fertilizer use efficiency and intensity of each country vary considerably, reflecting factors such as agro-ecological resources (soil texture, terrain, and climate) and economic incentives. However, the effects of average values of Myanmar neighboring countries (Bangladesh and Thailand) might be less because they use similar technologies and plantation methods with similar plantation seasons.

After the harvested area for agriculture for crop of each type in each country for 2010 was obtained from FAOSTAT, future estimation of harvested areas during 2020–2100 was conducted under three scenarios as referred from reports of work by Tamura et al. (2015) and Tamura (2016): (1) Additional global harvested area demand for specific crops was allocated to countries assuming constant shares of the countries in expanded harvested areas of the specific crop; (2) Additional global harvested area demand for specific crops was allocated to countries assuming constant self-sufficiency ratios of the countries; and (3) Additional global harvested area demand for specific crop was allocated to countries assuming constant shares of the countries in harvested area of the specific crop. Moreover, other estimated data related to future demand such as population, gross domestic product (at purchasing power parity) per capita [GDP/cap (In$/cap)], and shares of rural and urban population, are taken from some parts of Shared Socioeconomic Pathways Scenario 3 (SSP3) provided by the International Institute for Applied Systems Analysis (IIASA): SSP3 denotes "fragmentation," whereby high population growth and low economic growth occur.

No direct data exist for R_{ls} and R used in equation 1 above. Therefore, we set their respective definitions and calculate respective values based on a review of the literature. Ratios of P return to farm from livestock manure (R_{ls}) were obtainable by dividing the quantity of P in animal excreta returned to farms by the total amount of excreta. The ratio of P outflow to water from farms (R) is estimated by dividing the quantity of P in excreta outflow to water from farms by the total P input to farms. For those two parameters we defined earlier, there is no specific research done yet for Myanmar. Therefore, we apply global data $R_{ls} = 0.533$ and $R = 0.327$ referred by Lwin et al. (2016, 2017) as an option for us to conduct this research.

Related to the ratio of P contained in the societal excrement returned to the farmland (R_e), we divided countries into three groups: Group I countries with developed economies; Group II countries in economic transition; and Group III countries with developing economies (UN 2014). For group 1 countries, we assumed R_e as zero, but for Groups II and Groups III, we use 0.975 of Ma et al. (2013) for rural areas, with R_e set as 0 in urban areas. The shares of population in urban and rural areas are estimated from SSP3 scenarios. Myanmar falls into group III. Therefore, $R_e = 0.975$ is assigned for rural areas and 0 for urban ones.

Regarding P flow from livestock estimation, animals of five kinds were examined: beef cattle, dairy cattle, pig, layer chicken, and broiler chicken. Total numbers of livestock units in equivalent Japan livestock in 2010 were calculated for Myanmar using the methodology reported by Lwin et al. (2016, 2017). For future estimation, we referred the absolute number of livestock units in Myanmar from Tamura et al. (2015) and Tamura (2016). Those numbers of livestock units were estimated along with demand for food. Growth ratios of absolute numbers were calculated for each 10-year study. Then we multiplied those ratios by our estimated total number of livestock units, in equivalent Japan livestock units, starting from 2010. In doing so, the change over time of the number of livestock units was estimated for all study periods (2010–2100).

Per-capita phosphorus units in human excrement ($P_{person,e}$) and per-capita phosphorus units in gray water usage (($P_{person,g}$) vary by type of diet, location, age, activity, health status, tradition and culture, etc. Few measurements have been reported of amounts and compositions of human waste and gray water usage. Because this research was conducted under “system-wide” strategies, we use global conventional data of per-capita P units annually contained in human excrement (urine + feces): $P_{person,e} = 0.55$ kg/cap/yr, $\mathrm{P}_{\mathrm{person,g}} = 0.08$ kg/cap/yr as reported by Otterpohl (2003).

Another parameter SC used in equations, the percentage of population with access to sewage treatment facilities (STF), was referred from our earlier research (Lwin et al. 2015). We made the assumption that the ratio of residence connected to sewage treatment facility is a function of gross domestic product (at purchasing power parity) per capita (GDP PPP per capita in In$/cap). If economic conditions improve and if the population increases, then necessary public environmental utilities such as sewage treatment facilities will be demanded to a greater degree in the hopes of raising the standard of quality of life. In other words, increased resource consumption and increased demand are expected to produce more sophisticated infrastructure requirements. Using such assumptions, future percentages of population connected to sewage treatment facilities can be estimated for individual countries under high scenarios and low scenarios.

The average P removal ratio (PR) in STF was estimated based on literature reviews of studies conducted for specific countries (Liu 2005, JSWA 2009, Stricker and Heduit 2010) and per-capita GDP PPP reported for the respective countries as follows. Based on GDP/cap (GDP per capita) in 2010 current US$, countries were categorized by Anh-Nga Tran-Nguyen and Elkhoury (2010) as low-income (less than 800 US$), middle-income (between 800 US$ and 13,194 US$), or high-income (over 13,194 US$). Based on many reports of the literature related to STF, we assigned the maximum 30% phosphorus removal ratio in STF for low-income countries as the first group, 50% for middle-income countries as the second group, and 80% for high-income countries as the third group. For estimation of the future P removal ratio, we used GDP/cap (In$/cap) from SSP scenarios. Therefore, the current US$ assignments presented above are transformed in GDP/cap (In$/cap). We assign the PR setting as shown in Table 2. Country PR is considered based on the GDP/cap (2010 In$/cap) change during the study period: 2010–2100. However, Myanmar falls into the categories of second group throughout the study period. A linear function is used to assess all possible trends of PR ratio during 2010–2100. Therefore, PR of Myanmar shows rates starting from over 30% and ending at about 50%.

Table 2. Average phosphorus removal ratio (PR) setting based on per-capita GDP PPP

Per capital GDP PPP	Less than 694 [In$/person] First Group	Between 694–11,455 [In$/person] Second Group	Over 11,455 [In$/person] Third Group
PR	30%	50%	80%

We assign a crude P-removal ratio scale indexed to a country's income ignoring types of wastewater treatment such as mechanical treatment, biological treat, etc. We regard our work as a top-down assessment first step that is particularly relevant to analysis of the development paths of economically developing countries, which lack large amounts of relevant data.

Results and discussion

This section presents an explanation of how much P flow from farmland, livestock manure, human excreta, and graywater usage passes to the hydrosphere.

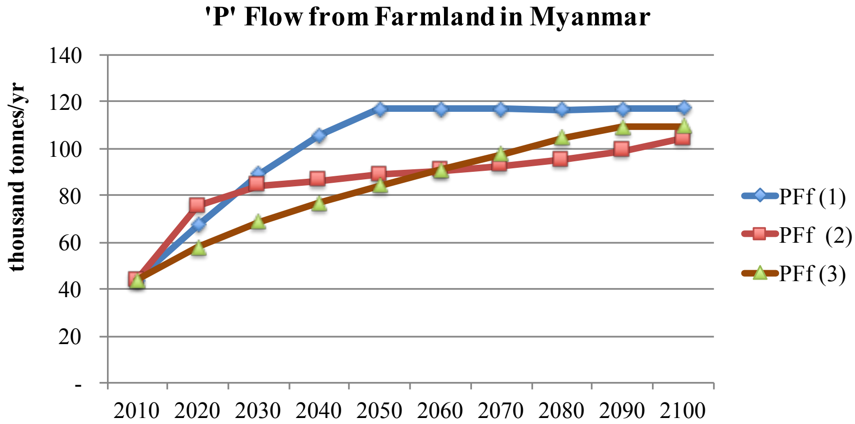

Figure 2: Annual P flow from farmland to the hydrosphere: (a) scenario 1, (b) scenario 2, and (c) scenario 3.

Based on the amount of P used in mineral fertilizer in the expanded harvested area, P flow from farmland to the hydrosphere differs. Figure 2 presents the P flow from fertilizer under Scenarios 1, 2, and 3. Results show that Scenario 2 has the lowest P flow to the hydrosphere. Scenario 1 of P flow from farmland to the hydrosphere stands as the highest. Scenario 2 of P flow from fertilizer to the hydrosphere stands as the lowest, coinciding with the lowest demand of P in mineral fertilizer under Scenario 2.

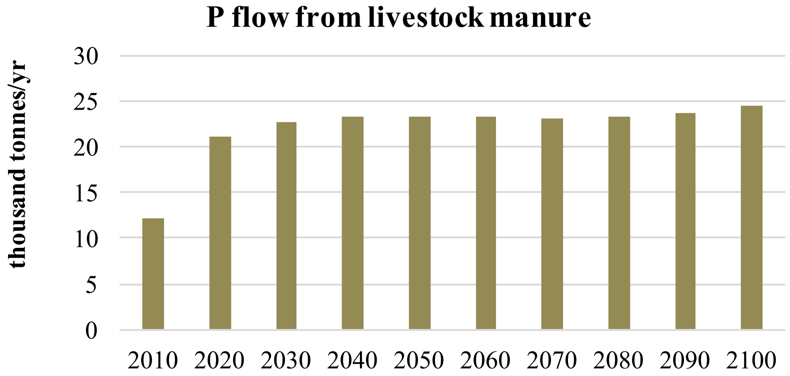

Figure 3: Annual P flow from livestock manure to hydrosphere.

As shown as in Figure 3, a markedly increasing trend is especially apparent for P flow from livestock during 2010–2100. P flows from livestock in 2010 were 12 thousand tones, but it becomes a twofold increase by 2100. No great change was found in the P flow amount during 2040–2090; it is about 25 thousand tonnes. However, from the overall study period (2010–2100), one might infer that, because of economic growth, livestock demand increased. Consequently, it results in gradual enlarged P flow from livestock manure to the hydrosphere.

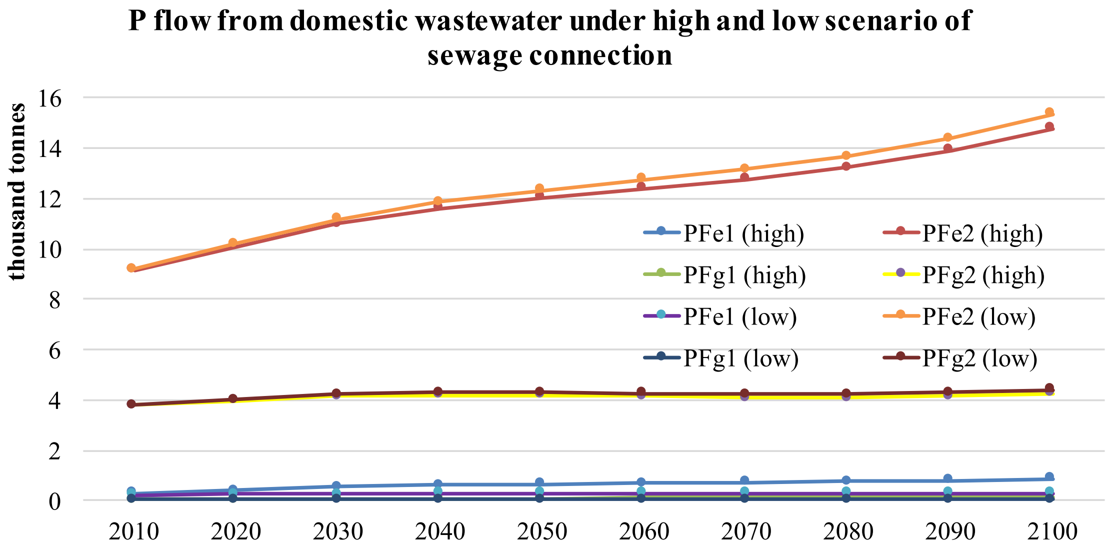

Figure 4: Annual P flow from domestic wastewater to hydrosphere.

The amount of respective P flow from societal excrement and graywater under high and low sewage connection scenarios are portrayed in Figure 4. The total P flows from domestic wastewater (societal excrement and graywater) during the study period are almost 13–20 thousand tonnes under low and high scenarios. The result is overwhelmed by the P flow of direct discharge from human excreta. That is true because, in Myanmar, only a small share of the urban population has access to STF and that the *SC* is expected to be 5.7% by 2100. Moreover, under our assumptions related to per-capita GDP and *PR* in STF, P removal ratio *PR* will be between 30%

and 50% by 2100. As an overall trend, a gradual increase in P flow into the hydrosphere is observed in relation to increased urban population.

Combined scenario results

The P flows from agricultural and domestic wastewater under the six scenarios described in Table 3 are portrayed respectively in Figure 5.

Table 3. Composition of six scenarios estimating P flow from agricultural and domestic wastewater (2010–2100)

Scenario Name	P flow from agriculture		P flow from domestic wastewater	
	P flow from farmland	P flow from livestock manure	P flow from societal excrement	P flow from gray water
A	PF_f (Scenario 1)	PF_m	PF_e (high)	PF_g (low)
B	PF_f (Scenario 2)	PF_m	PF_e (high)	PF_g (low)
C	PF_f (Scenario 3)	PF_m	PF_e (high)	PF_g (low)
D	PF_f (Scenario 1)	PF_m	PF_e (low)	PF_g (low)
E	PF_f (Scenario 2)	PF_m	PF_e (low)	PF_g (low)
F	PF_f (Scenario 3)	PF_m	PF_e (low)	PF_g (low)

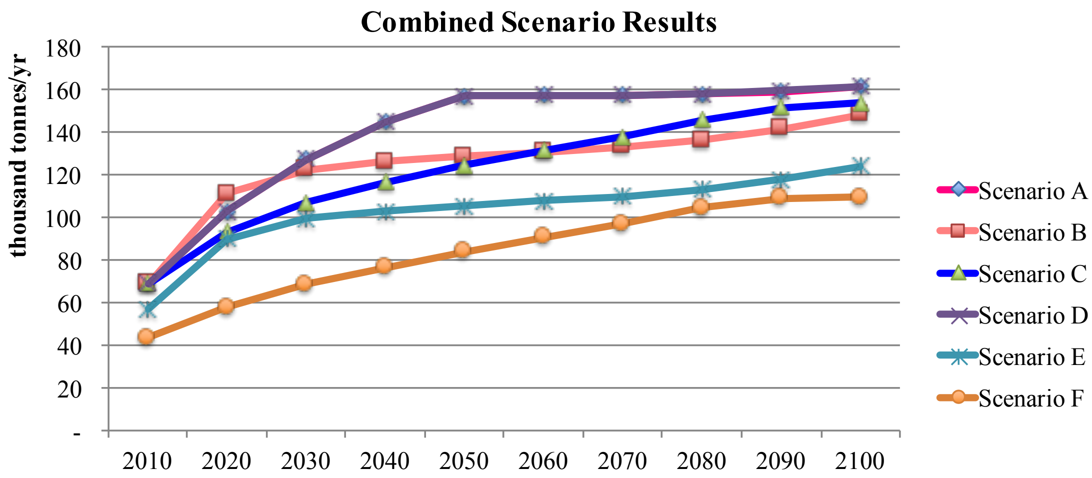

Figure 5: Composite depiction of six scenarios estimating P flow from agricultural and domestic wastewater (2010–2100).

All scenarios resulting in P flows show that over 70% of P flow is accounted for by P flow derived from fertilizer, mainly because of farmland expansion. Comparison of the results of six scenarios (Fig. 5) demonstrates that Scenario D stands as the highest P flow, with Scenario F as the least scenario.

Amount of maximum and minimum P recovered by sewage system introduction

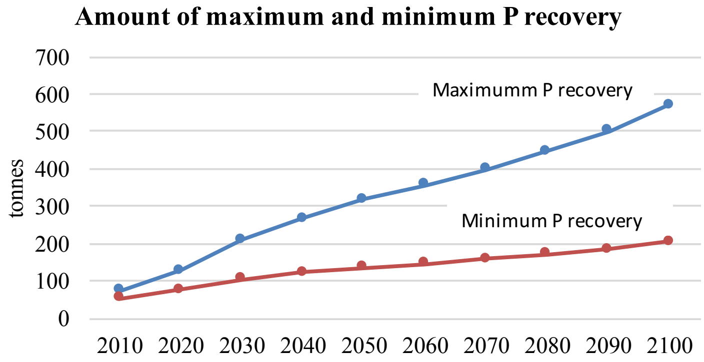

Figure 6. Amount of maximum and minimum P recovery potential to be used as fertilizer

Figure 6 exhibits the amount of P that can be recovered and reused as P in mineral fertilizer. Here, it is assumed that all P in domestic wastewater is collectable at sewer treatment facilities. If proper P recovery equipment was introduced into STFs, then a total of maximum 73 tonnes of P would be potentially recovered in 2010 under high sewage connection condition and minimum 54 tonnes of P under low sewage connection, as shown in Figure 4. That amount could reach over 571 tonnes (maximum P recovery amount) and 204 tonnes (minimum P recovery amount) respectively by 2100 according to the improved SC. The potential amount of P recovery is extremely small because the major P flows to the hydrosphere are from agriculture and population connected to the sewer system by sewer pipes is quite low in Myanmar.

Needs for the future

A main policy objective of the Government of Myanmar is to increase food security and the quantity, quality, and variety of crops through partnerships and through private sector investment. Improving private sector participation in the trade and distribution of fertilizer and sharing agricultural knowledge can reduce fertilizer costs and increase their correct usage, thereby improving farm productivity and food security and also leading to a safer environment. However, the necessity of formulating a series of cost-effective policies and best management practices (BMPs) in agriculture persists to this day. Consequently, the need exists to achieve more sustainable strategies that can handle nutrient flows from fertilizer usage to the hydrosphere.

Many challenges persist in relation to Myanmar sewage and sanitation because of many factors: (a) Operating treatment plants are still costly, even when proper treatment plants are available. (b) Lack of budget, technology, and experience are still unavoidable conditions. (c) High threats to environmental related issues exist because small and medium industrial zones rarely use proper treatment systems for wastewater disposal.

Currently, Myanmar sewage and sanitation must be responsible only to government. Future sewage and sanitation systems should be updated by law. In addition, with aid from INGOs and UN agencies, along with private sector participation, Myanmar sewage and sanitation must be improved in the future.

Conclusion

This study elucidated future trends of phosphorus flows from agricultural and domestic wastewater based on scenarios of numerous parameters that include economic development, population, livestock demand, harvested areas, and phosphorus removal rates in improved sanitation facilities in Myanmar for 2010–2100. Results reveal that phosphorus flow from agriculture exists on the range of 104–117 thousand tonnes. The P flow from livestock is 12 thousand tonnes in 2010: it is expected to double by 2100. Phosphorus flows from domestic wastewater are expected to be 13–20 thousand tonnes during the study period. It is expected that recovery of phosphorous from sewage sludge can be managed in the future.

As pioneer research for Myanmar, P flow from agricultural and domestic wastewater was estimated. As described earlier, in general, no hard data are available for fertilizer usage by crop in Myanmar. Development of estimates (if not guestimates) requires expert knowledge, i.e. communication with agronomists with extension services and fertilizer suppliers. Producing a P flow database for Myanmar is our ultimate mission. By collaborating with agricultural experts and considering actual usage amounts of phosphorus fertilizer usage by crop type, future national research is expected to provide a core for the appraisal of P utilization and to facilitate determination of important objectives for sustainable P management for Myanmar.

Moreover, this study mainly uses some parts of SSP3 scenarios. Future studies should use other scenarios (SSP1, SSP2, SSP4, and SSP5) with mutual comparison of their results. Inference of the underlying reasons for the results should be done to ascertain the relative priorities and to facilitate investigation, which is necessary for policymakers to elaborate appropriate frameworks for sustainable P management in Myanmar.

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