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Scenarios of Phosphorus Flow from Agriculture and Domestic Wastewater in Myanmar (2010–2100)

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Received: 6 July 2017; Accepted: 1 August 2017; Published: 4 August 2017

Abstract: Transfer of nutrients from agriculture and wastewater to the hydrosphere attracts attention of policymakers and scientists due to an increasingly important influence on the water environment. Crop and livestock production and fisheries predominantly support the Myanmar economy. However, phosphorus (P), which is used in cultivation and is also present in domestic sewage, is a major source of biogenic pollutants and eutrophication in Myanmar. It is therefore necessary to elucidate P flows from agricultural and domestic wastewaters to formulate a series of cost-effective policies and best-management practices (BMPs). This paper describes P flows to the hydrosphere, as driven by agricultural and domestic wastewater use in Myanmar during 2010–2100. The results reveal that total P flow from farmland and livestock occurred at 55 thousand Mg/year (thousand million grams per annum) in 2010 but is expected to be 128–141 thousand Mg/year in 2100. Urban population growth is the main factor contributing to the gradual increase in P flow from domestic wastewater; however, most of the P flow is derived from agriculture, suggesting that marked reductions in fertilizer use are necessary. This research provides basic information for the appraisal of P utilization and facilitates the identification of important objectives for sustainable P management in Myanmar.

Keywords: sustainable phosphorus management; phosphorus ore depletion; agricultural pollution; fertilizer; sewage

1. Introduction

Myanmar has the fifth largest population in ASEAN (Association of Southeast Asian Nations) and has the second largest land area. Recently, Myanmar opened up as a country after many years of military and junta rule; it is currently embracing democracy. Located between India, Thailand, and China, it has ready access to major Indian shipping routes. Of its people, 70% reside in rural areas, of which 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. According to FAO (Food and Agriculture Organization) estimates, the Myanmar agricultural sector accounts for 37.8% of the gross domestic product (GDP) and for 25–30% of all export earnings [1].

Myanmar has an openly 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, which mainly enter through Muse in Shan State [2]. However, fertilizer use by farmers is insufficient to produce optimum yields. Farmers generally have little knowledge of best agricultural practices and plant nutrition requirements. Consequently, large amounts of nutrients run off from agricultural land to the hydrosphere, causing eutrophication. A lack of research means that these flows have not been quantified and this has hindered awareness of the issue, but the effects are severe.

The FAO (2016) has estimated that over 50% of all phosphate fertilizer around the world will be applied in Asia in 2019, with roughly half of that 50% used in eastern Asia (including all ASEAN countries and China) [3]. The increasing 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 has severe implications for coastal habitats because greater application results in greater runoff; the fraction of fertilizer lost from fields increases with the intensity of fertilizer application. Phosphorus (P) fertilizer use in agriculture has increased to meet the growing demands of feeding an increasing population, which has also increased inflows of P-containing water into the hydrosphere.

In 2016, Chen et al. quantified P flows in an agricultural system and assessed their environmental impact on water based on life cycle analysis [4]. From 1984 to 2008, Ma et al. explored the evolution of P consumption in the main metabolic nodes in China and examined its environmental implications in both surface water and soil [5]. Matsubae-Yokoyama et al. investigated the material flow of P to assess potential P resources within Japan [6]. Considering P scarcity on the global scale, Cordell et al. examined the current and future implications of dependence on a non-renewable P resource [7]. Based on parameters such as economic growth, food demand, harvested area, and urban and rural population shares, future trends in global P flows from 2010 to 2100 were estimated by Lwin et al. [8–10]. However, Myanmar did not fall within the scope of the above research.

Our study specifically examined Myanmar, which has the highest GDP (Gross Domestic Product) growth forecast of the Asia–Pacific Economics [11], and we forecasted P flows from agricultural and domestic wastewater during 2010–2100. Table 1 summarizes the land use, population, GDP, and crop and livestock production in Myanmar.

Table 1. Land use, population, GDP (Gross Domestic Product), crop and livestock production in Myanmar.

Indicator	Unit	Amount
Land use		
Total area	1000 ha	67,659
Share of arable land	%	17.7
Forest area	%	44.5
Population		
Share of rural population	Million	36.5
Share of urban population	million	13.7
GDP		
Share of agricultural GDP	%	37.8
Crop production		
Total sown area	1000 ha	11,950
Livestock production		
Cattle and buffaloes	million heads	14.2
Pigs	million heads	4.5
Sheep and goats	million heads	2.0
Poultry	million heads	57.1

Note: Land use, population, GDP, and crop production data are for 2010 from Ministry of Agriculture and Irrigation [12]. Livestock production data is for 2010 from Livestock Breeding and Veterinary Department, Myanmar [13].

After crop production, Myanmar's fishery and livestock sectors are regarded as the most important in terms of meeting the protein needs of the population, enhancing food security, and providing employment for rural communities. The livestock and fishery sectors account for more than seven percent of the national GDP. Regarding livestock, an increasing urban population plays a significant role in greater livestock demand. Consequently, the increased P flow associated with this increased demand affects society and the hydrosphere, exacerbating environmental pollution in many ways.

As an additional research area, P flow from domestic wastewater is estimated in this study. Myanmar faces considerable challenges in relation to the management of wastewater as a result of increasing income, increasing consumption levels and changing consumption patterns, urban population growth, and a lack of effective wastewater treatment and disposal options. Inadequate wastewater and sanitation services, combined with underinvestment in preventive health care, have resulted in environmental and human health challenges in Myanmar. Currently, there are urban sanitation services as basic functions of urban government in Yangon, Mandalay and Nay Pyi Taw. However, these are below acceptable levels to reach the most difficult areas resulting serious water-borne diseases [14]. With the exception of their central business districts, the three major cities have no conventional central wastewater or sewage collection and treatment systems. Domestic wastewater is usually released into storm water drainage and natural waterways. Nevertheless, environmental impact assessments do not yet emphasize water resource management.

Because of ongoing rapid industrialization in cities, many factories are being built around urbanized areas. There is a need to disseminate knowledge about the proper disposal of wastewater to control the problem of direct wastewater discharge from factories into rivers or streams. Therefore, urgent estimation of P flows to the hydrosphere is necessary, as is the introduction of new wastewater treatment plants and the modification of old wastewater treatment plants in Myanmar.

By quantifying flows to the hydrosphere, this study specifically examines P in agricultural and domestic wastewater and assesses its environmental effects to help formulate relevant wastewater management practices and related policy. Following are the specific objectives of the study:

(1) To calculate the amount of P released into bodies of water from agricultural and domestic wastewater.
(2) To estimate the relative effect 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.

2. Methods and Data

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 flows from agriculture (fertilizer and livestock manure) and domestic wastewater (excrement and gray water) for 2010–2100.

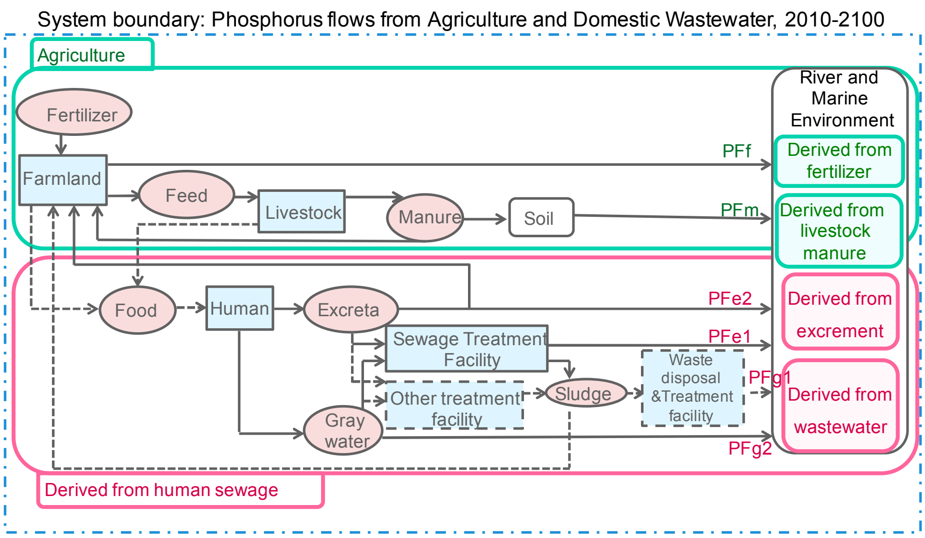

Figure 1. Simplified flows of P (phosphorus) from agriculture and human sewage to hydrosphere.

The annual P flow derived from farmland (PF_f) to water bodies was calculated using Equation (1):

$$PF_f = (\sum_i (P_{CROPi} \times HA_i) + (P_{ls} \times R_{ls}) + (P_e \times R_e)) \times R \quad (1)$$

where P_{CROPi} represents the fertilizer usage by the crop, and HA_i is the harvested crop area. The remaining parameters will be explained later with the other equations and terms used therein.

The *P* flows from livestock manure (PF_m) (tons/year) were calculated using Equations (2) and (3).

$$PF_m = P_{ls} \times (1 - R_{ls}) \times R \quad (2)$$

$$P_{ls} = \sum_i (N_i \times P_{ANIMALi}) \quad (3)$$

where P_{ls} signifies the *P* flow from livestock manure (tons/year); R_{ls} denotes the ratio of *P* return to farmland from livestock manure (–); *R* represents the ratio of outflow to water from the farm (–); N_i represents the number of livestock animals *i* (beef cattle, dairy cattle, pigs, layer chickens, and broiler chickens); and $P_{ANIMALi}$ represents the *P* content in the manure of animal *i* per animal (tons/animal/year).

The *P* flow from human excrement (PF_e) (tons/year) was estimated using Equations (4)–(7):

$$P_e = Pop \times P_{person,e} \quad (4)$$

where P_e is the *P* amount in the excrement (tons/year); *Pop* denotes population (*persons*); and $P_{person,e}$ signifies per-capita *P* contained in the excrement (tons/person/year).

$$PF_{e1} = P_e \times SC \times (1 - PR) \quad (5)$$

where PF_{e1} represents *P* flow from the excrement passing through sewage treatment facilities (STFs) (tons/year); *SC* is the proportion of the urban population with access to STFs (–); and P-removal ratio (*PR*) represents the average P-removal ratio in STFs (–).

$$PF_{e2} = P_e \times (1 - R_e) \times (1 - SC) \quad (6)$$

where PF_{e2} stands for the *P* flow from excrement without passage through STFs (tons/year); and R_e is the ratio of *P* in excrement returned to farmland (–).

$$PF_e = PF_{e1} + PF_{e2} \quad (7)$$

The *P* flow from gray water (PF_g) (tons/year) was calculated using Equations (8)–(11):

$$P_g = Pop \times P_{person,\ g} \quad (8)$$

where $P_{person,g}$ denotes the per-capita *P* contained in domestic gray water (tons/person/year).

$$PF_{g1} = P_g \times SC \times (1 - PR) \quad (9)$$

where PF_{g1} represents the *P* flow from gray water passing through STFs (tons/year).

$$PF_{g2} = P_g \times (1 - SC) \quad (10)$$

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

$$P_g = PF_{g1} + PF_{g2} \quad (11)$$

As a final scenario, the degree to which *P* can be recovered from domestic wastewater systems and reused as fertilizer (P_{rec}) can be calculated using Equation (12):

$$P_{rec} = (Pe + Pg) \times SC \times PR \quad (12)$$

In the following, certain necessary data and clarifications for the equations above are given.

For the estimation of P flow from agriculture, we focus on 41 crop types and these are classified in the same way as the FAO (Food and Agriculture Organization) item aggregated crop data, as shown as in Table 2 [15].

The harvested area data for each target crop for 2010 were obtained from FAOSTAT (Food and Agriculture Organization Statistical Databases) [16]. The total amounts of P fertilizer applied to each crop type were determined from IFA (International Fertilizer Association) data [17]. Although we tried to find and also discuss with agriculture experts from Myanmar, there is no hard data is available regarding with P_{CROPi}, which simply represents the actual fertilizer usage by each crop. Therefore, because of unavoidable difficulties related to data availability, we took the average value of actual of P fertilizer usage per crop in Thailand and Bangladesh [8–10] as shown in Table 3. We accept that the use of fertilizer per hectare likely differs even for the same crop across different countries. Fertilizer use efficiency and intensity vary considerably across a country, reflecting factors such as agro-ecological resources (soil texture, terrain, and climate) and economic incentives. However, the effect of using average values from neighboring countries (Bangladesh and Thailand) for Myanmar might be minimized because these countries use similar technologies and plantation methods along with similar plantation seasons.

Table 2. Classification of crops.

Classification	Crop Name
Cereals	Wheat *(Triticum aestivum)*, rice *(Oryza sativa)*, corn *(Zea mays)*, barley *(Hordeum vulgare)*, rye *(Secale cereale)*, oats *(Avena sativa)*, millet (*Pennisetum glaucum)*, sorghum *(Sorghum bicolor)*, other grains
Roots and tubers	Cassava *(Manihot esculenta)*, potatoes *(Solanum tuberosum)*, sweet potatoes *(Ipomoea batatas)*, yams *(Dioscorea spp.)*, other potatoes
Sugar crops	Sugar cane (*Saccharum officinarum)*, sugar beet *(Beta vulgaris)*
Oilseed crops	Soybean *(Glycine max)*, oil palm *(Elaeis guineensis)*, ground nuts with shell *(Arachis hypogaea)*, sunflower seed *(Helianthus annuus)*, rapeseed *(Brassica napus)*, mustard seed *(Brassica spp.)*, seed cotton *(Gossypium)*, coconuts *(Cocos nucifera)*, sesame seed *(Sesamum indicum)*, olives *(Olea europaea)*, other oilseed crops
Vegetables	Tomatoes *(Solanum lycopersicum)*, onions *(Allium cepa)*, other vegetables
Fruits	Orange/mandarins *(Citrus reticulata)*, lemon/limes *(Citrus aurantifolia)*, grapefruit *(Citrus paradisi)*, other citrus fruits, bananas *(Musa)*, plantains *(Musa paradisiaca)*, apples *(Malus domestica)*, pineapples *(Ananas comosus)*, dates *(Phoenix dactylifera)*, grapes *(Vitis vinifera)*, other fruits

Table 3. Amount of phosphorus fertilizer (P_2O_5) per unit of harvested area (Mg/ha).

	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	0.01	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

Source: FAO, 2010. Note: P_2O_5 stands for phosphorus pentoxide. This research examined only P flows from agriculture to the hydrosphere. Therefore, all data related to P_2O_5 were carefully converted by multiplying a conversion factor of 0.4364 to estimate the P flow from fertilizer to the hydrosphere.

After the harvested area for each crop type in each country for 2010 was obtained from FAOSTAT, a future estimation of the harvested areas from 2020 to 2100 was conducted under three scenarios [18,19]: (1) the harvested area demand for each type of crop estimated by assuming constant global share of each country regarding crop-specific expanded harvested areas; (2) the additional global harvested area demand for specific crops was allocated to countries assuming that they had constant self-sufficiency ratios; and (3) the harvested area demand for each type of crop estimated by assuming a constant global share of each country regarding crop-specific harvested areas. Moreover, other estimated data relating to future demands such as population, gross domestic product (at purchasing power parity) per capita [GDP/cap (In$/cap)], and shares of rural and urban population, were taken from the shared socio-economic 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) [20].

No direct data exist for R_{ls} and R, as used in Equation (1) above. Therefore, we set their definitions and calculated their values. Ratios of P return to farmland from livestock manure (R_{ls}) were obtained by dividing the quantity of P in animal excreta returned to farmland by the total amount of excreta. The ratio of P outflow to water from farms (R) was estimated by dividing the quantity of P in excreta outflowing from farms to water by the total P input to farms. For these two parameters (defined earlier), there is no specific research relevant to Myanmar. Therefore, we applied global data, R_{ls} = 0.533 and R = 0.327 [8–10], allowing us to conduct this research.

Relating to the ratio of P contained in the societal excrement returned to farmland (Re), 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 [21]. For Group I countries, we assumed Re to be zero, but for Groups II and III, we used a value of 0.975 [4] for rural areas and a value of zero for urban areas. The share of the population in urban and rural areas was estimated from the SSP3 scenario of IIASA. Myanmar falls into Group III; therefore, R_e = 0.975 was assigned for rural areas and R_e = 0 was assigned for urban areas.

Regarding the estimation of P flow from livestock, five types of animal were considered: beef cattle, dairy cattle, pigs, layer chickens, and broiler chickens. After taking livestock data from FAO [22,23], the total number of livestock units (equivalent Japan livestock units in 2010), were calculated for Myanmar using the methodology reported by our previous research [8–10]. For future estimation, we referenced the absolute number of livestock units in Myanmar from other research [18,19]. The numbers of livestock units were estimated along with the demand for food. Growth ratios of absolute numbers were calculated for each 10-year study. We then multiplied those ratios by our estimated total number of livestock units (in equivalent livestock units for Japan), starting from 2010. In doing so, the change over time in the number of livestock units was estimated for a study period of 2010–2100.

Per-capita P units in human excrement ($P_{person,e}$) and per-capita phosphorus units in gray water ($P_{person,g}$) vary by diet, location, age, activity, health status, tradition, culture, etc. Few measurements have been reported on the produced amounts and composition of human waste and gray water. Because this research was conducted using "system-wide" strategies, we used available global data on annual per-capita P units contained in human excrement (urine + feces): $P_{person,e}$ = 0.55 kg/cap/year and $P_{person,g}$ = 0.08 kg/cap/year [24].

As used in the above equations, the parameter SC, which is the percentage of the population with access to STFs, was estimated by making the assumption that the ratio of residences connected to an STF is a function of gross domestic product (at purchasing power parity) per-capita (GDP PPP per-capita in In$/cap) [25]. If economic conditions improve and if the population increases, then necessary public environmental utilities such as STFs will be in demand to a greater degree in the hope of raising the standard of the quality of life. In other words, increased resource consumption and increased demand are expected to produce more sophisticated infrastructure requirements. Using such assumptions, the future percentage of the Myanmar population connected to STFs can be estimated under high and low scenarios of sewage diffusion ratios in Myanmar.

The average *PR* (phosphorus removal rate) in STFs was estimated for specific countries [26–28] and per-capita GDP PPP values reported for the respective countries as follows. Based on GDP/cap (GDP per-capita) values in 2010 using US$, countries were categorized as low-income (less than 800 US$), middle-income (between 800 US$ and 13,194 US$), or high-income (over 13,194 US$) [29]. Based on many literature reports related to STFs, we assigned a maximum 30% *PR* in STFs 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 *PR*, we used GDP/cap (In$/cap) values from the SSP3 scenarios. As such, the US$ categories presented above were transformed to GDP/cap (In$/cap) values. We assigned *PR* settings, as shown in Table 4. A country's *PR* was determined based on the GDP/cap (2010 In$/cap) change during the study period (2010–2100). Myanmar fell into the second group throughout the study period. A linear function was used to assess all possible trends in *PR* ratio during 2010–2100. Therefore, the PR of Myanmar shows rates starting from above 30% and ending at about 50%.

Table 4. Average phosphorus removal ratio *(PR)* setting based on per-capita GDP PPP (gross domestic product at purchasing power parity)

Per Capita GDP PPP	Less than 694 [In$/Person]	Between 694 and 11,455 [In$/Person]	Over 11,455 [In$/Person]
	First Group	**Second Group**	**Third Group**
PR	30%	50%	80%

We assigned a crude *PR* scale indexed to a country's income, ignoring the type of wastewater treatment (e.g., mechanical treatment and biological treatment). We regard our work as a top-down assessment and as a first step that is particularly relevant to the analysis of the development pathways of economically developing countries; this currently lacks appropriate amounts of relevant data.

3. Results and Discussion

This section presents an explanation of the extent of P flows to the hydrosphere from farmland, livestock manure, human excreta, and graywater.

3.1. Estimating P Flow from Farmland to the Hydrosphere

Based on the amount of P used in mineral fertilizer in the expanded harvested area, P flows from farmland to the hydrosphere differ. However, as we describe previously, due to a lack of data on fertilizer usage per crop in Myanmar, our estimation had to take average fertilizer usage per crop data for Thailand and Bangladesh.

Figure 2 presents the P flow from fertilizer under Scenarios 1, 2 and 3. The results show that Scenario 2 has the lowest P flow to the hydrosphere. In Scenario 1, the *P* flow from farmland to the hydrosphere shows the highest value by 2100. This indicates that under Scenarios 1, 2 and 3, where the harvested area increased by 37%, 39% and 38%, respectively, the demand for P in mineral fertilizer use increased by approximately 34%, 39% and 37%, respectively, and the total P flow from farmland to the hydrosphere increased by 37%, 42% and 40%, between 2010 and 2100. According to our calculations, the harvested area under Scenario 1 is the highest, indicating that the P demand for Scenario 1 was the largest. Consistently, the amount of P flow from farmland to the hydrosphere is the largest during the study period. Similarly, Scenarios 3 and 2 are, respectively, considered to show the intermediate and lowest P flows to the hydrosphere from farmland.

As shown in Figure 2, total P flow from farmland to the hydrosphere ranges between 104 thousand Mg/year and 117 thousand Mg/year. Based on our previous research [8–10], P flow from the farmland of Malaysia will range between 158 thousand Mg/year to 213 thousand Mg/year in 2100, whereas in the Philippines it will range from 118 thousand Mg/year to 213 thousand Mg/year, and in Vietnam from 333 thousand Mg/year to 417 thousand Mg/year. We have already stated that we used average fertilizer amount per crop of Thailand and Bangladesh, but their total P flow emissions from farmland to hydrosphere are much higher than Myanmar: Thailand emits a P flow from farmland ranging from 115 thousand Mg/year to 254 thousand Mg/year and the Bangladeshi P flow is between 145 thousand Mg/year to 184 thousand Mg/year during the study period. Thus, P flow from Myanmar to the hydrosphere is lower compared with that of neighboring countries. Population level and food demand are likely reasons for this finding; therefore, future studies should conduct decomposition analyses to identify details of the driving factors.

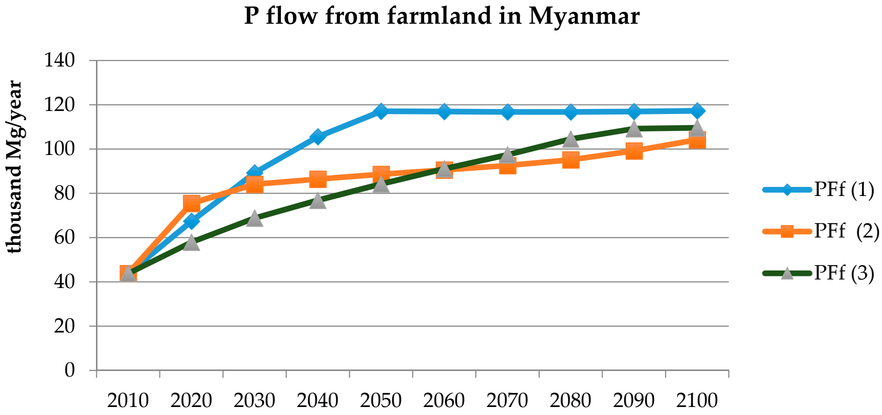

Figure 2. Annual P flows from farmland to the hydrosphere under Scenario 1, Scenario 2, and Scenario 3. Note: PF_f (Scenario 1): P flow from farmland to hydrosphere under Scenario 1 of harvested area estimations; PF_f (Scenario 2): P flow from farmland to hydrosphere under Scenario 2 of harvested area estimations; PF_f (Scenario 3): P flow from farmland to hydrosphere under Scenario 3 of harvested area estimations.

3.2. Estimating P Flow from Livestock Manure to the Hydrosphere

As shown in Figure 3, a marked increasing trend in P flow is especially apparent for livestock during 2010–2100. P flows from livestock in 2010 were 12 thousand Mg/year, but this increases two-fold by 2100. No great change was found in the P flow amount during 2040–2090, when it was about 25 thousand Mg/year. However, over the entire study period (2010–2100), it could be inferred that the two-fold increase is a result of increases in meat intake due to economic growth and income increases. As a consequence, this results in gradually increased P flows from livestock manure to the hydrosphere.

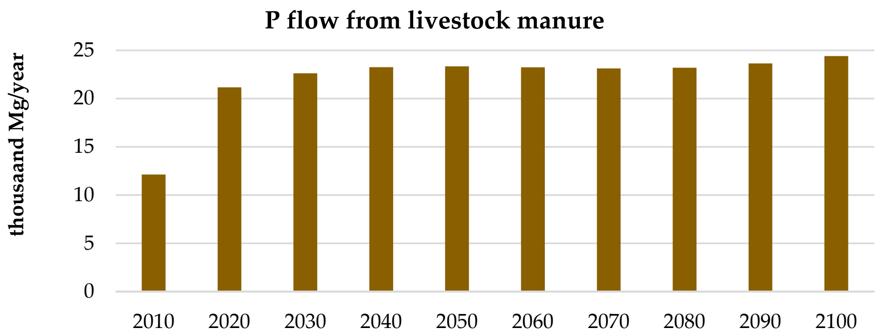

Figure 3. Annual P flow from livestock manure to the hydrosphere.

Our previous research has showed that estimated P flow from livestock manure to the hydrosphere in 2100 will be 16 thousand Mg/year in Malaysia, 26 thousand Mg/year in the Philippines, and 27 thousand Mg/year in Vietnam [8–10]. Thus, P flow from livestock manure in Myanmar will be higher than that in Malaysia but slightly lower than that in the Philippines and Vietnam. Nevertheless, it is considered that to reduce water body pollution in Myanmar, P flows from farmland and livestock manure should be managed properly. One of the main reasons for this is that under the current supervision of the new government, socio economic conditions in Myanmar are expected to improve. Therefore, living standards and consumption patterns will be much more demanding than previously. In addition, the United States' announcement of the reinstatement of preferential tariffs for Myanmar under the Generalized System of Preferences Scheme, which grants Myanmar tax privileges on exports including agricultural products to the world's largest economy, should be considered. Such a condition could potentially increase both crop and meat production to meet not only domestic demand but also that of the US market.

3.3. Estimating P Flow from Domestic Wastewater to the Hydrosphere

The levels of P flow from societal excrement and gray water under high and low sewage connection scenarios are shown in Figure 4. The total P flows from domestic wastewater (societal excrement and gray water) during the study period are around 13–20 thousand Mg/year under the low and high scenarios. The result is overwhelmed by the P flow of direct discharge from human excreta. This is reasonable because only a small share of Myanmar's urban population is connected to an STF and the SC (proportion of the population connected to a sewage treatment system) is expected to reach 5.7% by 2100. Moreover, under our assumptions related to per-capita GDP and PR in STFs, the PR will be between 30% and 50% by 2100. As an overall trend, it is considered that a gradual increase in P flows to the hydrosphere corresponds with an increased urban population.

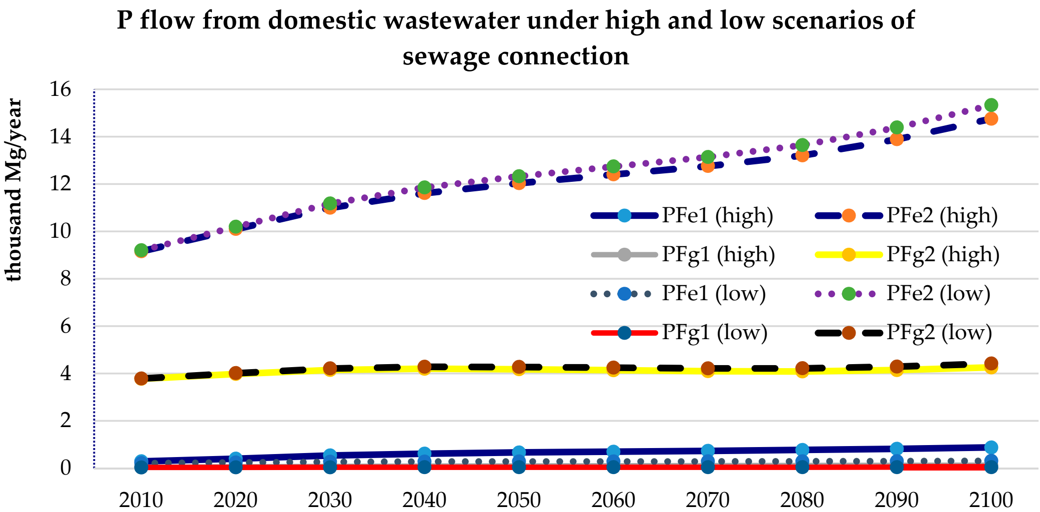

Figure 4. Annual *P* flow from domestic wastewater to the hydrosphere. Note: PF_{e1} (high): P flow from blackwater which is discharged by human beings via STFs (sewage treatment facilities) under assumption of high sewage pipeline diffusion ratio; PF_{e1} (low): P flow from blackwater which is discharged by human beings via STFs (sewage treatment facilities) under assumption of low sewage pipeline diffusion ratio; PF_{e2} (high): P flow from blackwater which is directly discharged by human beings under assumption of high sewage pipeline diffusion ratio; PF_{e2} (low): P flow from blackwater which is directly discharged by human beings under assumption of low sewage pipeline diffusion ratio; PF_{g1} (high): P flow from gray water which is discharged by human beings via STFs and wastewater treatment facilities under assumption of high sewage pipeline diffusion ratio; PF_{g1} (low): P flow from gray water which is discharged by human beings via STFs and wastewater treatment facilities under assumption of low sewage pipeline diffusion ratio; PF_{g2} (high): P flow from gray water which is directly discharged by human beings under assumption of high sewage pipeline diffusion ratio; PF_{g2} (low): P flow from gray water which is directly discharged by human beings under assumption of high sewage pipeline diffusion ratio.

Under a high sewage penetration rate (sewage connection ratio), the total P flow from domestic wastewater in 2100 in Myanmar was estimated to be 20 thousand Mg/year, which is more than that in Malaysia (9 thousand Mg/year) and Vietnam (15 thousand Mg/year), but less than that of the Philippines (43 thousand Mg/year) [8–10]. It was found that although the population of Myanmar is much lower than that of these other countries, the total P flow in Myanmar from the domestic wastewater sector is higher than that of Malaysia and Vietnam. This shows that much less efficient STFs exist in Myanmar and also indicates why the poor sewage connection rate has occurred. The GDP PPP of the Philippines is lower than that of Vietnam and Malaysia. Consequently, a low sewage penetration rate occurred in the Philippines; in addition, this country's high population growth results in more P flow from domestic water to the hydrosphere.

In the near future, the number of proper sewage treatment plants should be increased because the domestic wastewater flow into the hydrosphere results in not only water body pollution but also an increase in health issues. The current sewage network in Yangon was constructed in 1888. In Myanmar, different ministries are responsible for different portions of the urban expansion plan, and collaboration/cooperation among the ministries is very weak. For the mitigation of domestic wastewater flow into the hydrosphere, the integrated management of land, infrastructure, and transport is necessary. In addition, spatial planning is an important factor.

3.4. Combined Scenario Results

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

Table 5. Details 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 Blackwater	P Flow from Gray Water
A	PF_f (Scenario 1)	PF_m	PF_e (high)	PF_g (high)
B	PF_f (Scenario 2)	PF_m	PF_e (high)	PF_g (high)
C	PF_f (Scenario 3)	PF_m	PF_e (high)	PF_g (high)
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)

Note: PF_f (Scenario 1): P flow from farmland to hydrosphere under Scenario 1 of harvested area estimations; PF_f (Scenario 2): P flow from farmland to hydrosphere under Scenario 2 of harvested area estimations; PF_f (Scenario 3): P flow from farmland to hydrosphere under Scenario 3 of harvested area estimations; PF_m: P flow from livestock manure to hydrosphere; PF_e (high): P flow from blackwater to hydrosphere under assumption of high sewage pipeline diffusion ratio; PF_e (low): P flow from blackwater to hydrosphere under assumption of low sewage pipeline diffusion ratio; PF_g (high): P flow from gray water to hydrosphere under assumption of high sewage pipeline diffusion ratio; PF_g (low): P flow from gray water to hydrosphere under assumption of low sewage pipeline diffusion ratio.

In all scenarios resulting in P flows, over 70% of the P flow is accounted for by fertilizer use, mainly because of farmland expansion. Comparison of the results of the six scenarios (Figure 5) demonstrates that Scenario D yields the highest P flow, with Scenario F the lowest.

If the details of Scenario D are analyzed, it can be seen that the highest P flow from farmland under Scenario 1 is included and the low sewage penetration rate in Myanmar is considered. An insufficient proportion of the population being connected to an STF caused a higher P flow to the hydrosphere than did a lower sewer connection rate. As a result, the highest extent of pollution occurred. In a similar way, the other scenarios can be understood.

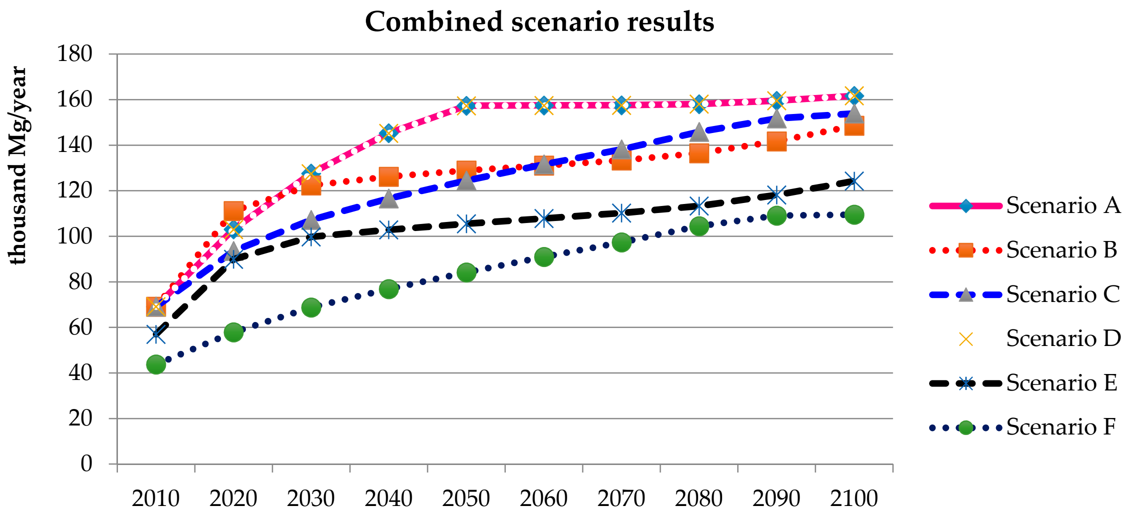

Figure 5. Composite depiction of six scenarios estimating P flow from agricultural and domestic wastewater (2010–2100).

3.5. Amount of Maximum and Minimum P Recovered by Sewage System Introduction

Figure 6 shows the amount of P that could be recovered and reused as mineral fertilizer. Here it is assumed that all P in domestic wastewater is retrievable at STFs. If appropriate P recovery equipment was introduced into STFs, then a maximum of 73 Mg/year of P could potentially have been recovered in 2010 under a high sewage connection scenario, with a minimum of 54 Mg/year recoverable under a low sewage connection scenario (Figure 6). This amount could exceed 571 Mg/year (maximum P recovery amount) and 204 Mg/year (minimum P recovery amount) by 2100 due to improvements in SC. Compared with Malaysia, Vietnam, and the Philippines, the potential amount of P recovery in Myanmar is extremely small. This is because (i) the major P flows to the hydrosphere in Myanmar are from agriculture and (ii) the proportion of the population connected to the sewer system is relatively low. During military rule during 1962–2011, the wastewater network and treatment facilities were neglected and suffered poor maintenance.

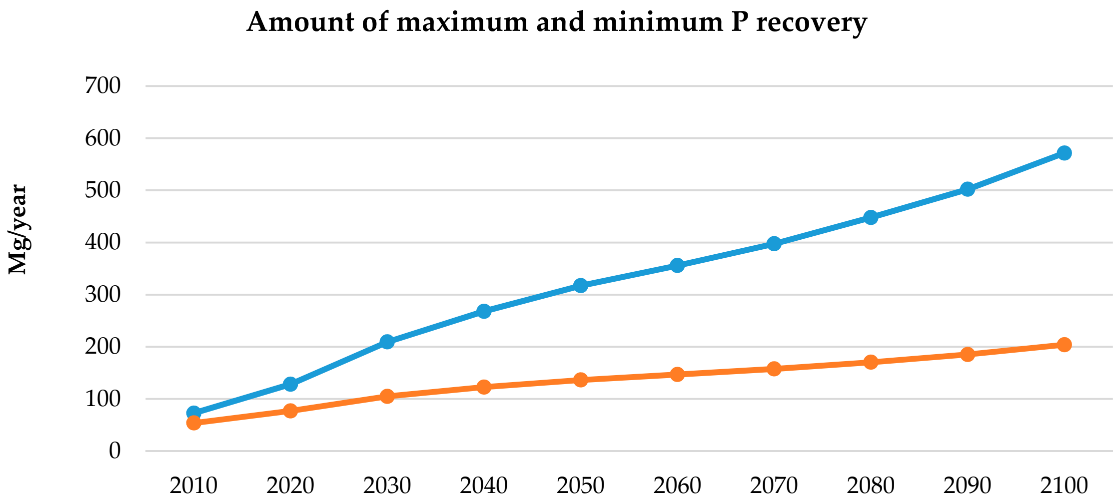

Figure 6. Maximum and minimum P recovery potentials for use as fertilizer.

4. Policy Implications

In Myanmar, one of the least developed countries, it is evident that much needs to be done to address environmental pollution. As such, assessments of P flows from farmland, livestock manure, and wastewater into the hydrosphere are invaluable to further research activities and decision-making processes. Myanmar has a number of regulations related to the protection and conservation of natural resources and the control of pollution. Within the agriculture and irrigation sector, there are four laws: The Embankment Act, 1909; the Pesticide Law, 1990; the Plant Pest Quarantine Law, 1993; and the Fertilizer Law, 2002. Regarding agricultural activities, the Fertilizer Law, 2002, mentions only that suitable fertilizers should be utilized.

Agricultural activities in Myanmar are having an increasingly profound impact on its water bodies, with P from agriculture being the main factor in eutrophication. This work used a methodology to estimate P flows from agriculture, livestock manure, and domestic wastewater up to 2100, thus providing quantitative information to support effective policy making. Hence, it is very important to link data on P flows from agriculture, livestock manure, and domestic wastewater to environmental regulations, thereby guiding practices and behavior.

To reduce the increasingly heavy dependence on imports and the threat to surface water quality, an integrated management of P flows from different sources should be considered. The proportion of the Myanmar population with access to potable water is very low compared to those of other neighboring countries. Estimated P flows into the hydrosphere should be considered when considering suitable water sources in 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 private sector investment. Improving private sector participation in the trade and distribution of fertilizer, coupled with the sharing of 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. Consequently, there is a need to employ more sustainable strategies that can handle nutrient flows from fertilizer usage to the hydrosphere.

Many challenges persist in relation to Myanmar's sewage and sanitation. This is due to a number of factors: (a) the operation of treatment plants remains costly, even when proper treatment plants are available; (b) a lack of budget, technology, and experience remains unavoidable; (c) significant threats to the environment exist because small and medium industrial zones rarely use proper treatment systems for wastewater disposal.

Currently, Myanmar's sewage and sanitation are the responsibility of the government and laws should be applied to the future updating of sewage and sanitation systems. In addition, with aid from INGOs (international non-governmental organizations) and UN (the United Nations) agencies, along with private sector participation, Myanmar's sewage and sanitation must be improved in the future.

5. Conclusions

This study elucidated future trends in P flows from agricultural and domestic wastewater based on scenarios that included numerous parameters such as economic development, population, livestock demand, harvested area, and P-removal rates in improved sanitation facilities in Myanmar during 2010–2100. The results revealed that P flows from agriculture are in the range 104–117 thousand Mg/year. The P flow from livestock was 12 thousand Mg/year in 2010 and is projected to double by 2100. The P flows from domestic wastewater are expected to be 13–20 thousand Mg/year during the study period. It is expected that the recovery of P from sewage sludge can be achieved in the future.

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

P utilization and to facilitate the determination of important objectives for sustainable P management in Myanmar.

Moreover, this study used some components of the SSP3 scenario. Future studies should use other scenarios (SSP1, SSP2, SSP4, and SSP5) and include a comparison of the results. Assessments of the underlying reasons for the results should be carried out to ascertain the relative priorities and to facilitate investigation; this is necessary for policymakers to develop appropriate frameworks for sustainable P management in Myanmar.

Acknowledgments: This research was fully funded by the Grant-in-Aid for Scientific Research (15H02863) of Japan Society for the Promotion of Science. We also thank Hnin Yu Lwin, Department of Agricultural Economics, Yezin Agricultural University, Yezin, Nay Pyi Taw, Myanmar for her kind advice and discussion time on this research. At last, but not at least, we would like to thank anonymous reviewers of this journal for their suggestive comments that conveys great improvement in our research.

Author Contributions: Seiji Hashimoto conceived, designed and supervised the research. Cherry Myo Lwin and Mari Murakami put effort on finding data and methodology preparation. Cherry Myo Lwin conducted the calculation. Cherry Myo Lwin and Kyaw Nyunt Maung analyzed the results. Cherry Myo Lwin drafted the manuscript while Seiji Hashimoto reviewed it.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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