Global potential of phosphorus recovery from human urine and feces

James R. Mihelcic, Lauren M. Fry, Ryan Shaw

Abstract

This study geospatially quantifies the mass of an essential fertilizer element, phosphorus, available from human urine and feces, globally, regionally, and by specific country. The analysis is performed over two population scenarios (2009 and 2050). This important material flow is related to the presence of improved sanitation facilities and also considers the global trend of urbanization. Results show that in 2009 the phosphorus available from urine is approximately 1.68 million metric tons (with similar mass available from feces). If collected, the phosphorus available from urine and feces could account for 22% of the total global phosphorus demand. In 2050 the available phosphorus from urine that is associated with population increases only will increase to 2.16 million metric tons (with similar mass available from feces). The available phosphorus from urine and feces produced in urban settings is currently approximately 0.88 million metric tons and will increase with population growth to over 1.5 million metric tons by 2050. Results point to the large potential source of human-derived phosphorus in developing regions like Africa and Asia that have a large population currently unserved by improved sanitation facilities. These regions have great potential to implement urine diversion and reuse and composting or recovery of biosolids, because innovative technologies can be integrated with improvements in sanitation coverage. In contrast, other regions with extensive sanitation coverage like Europe and North America need to determine how to retrofit existing sanitation technology combined that is combined with human behavioral changes to recover phosphorus and other valuable nutrients.

Keywords: Phosphorus, Material flow, Human excrement, Ecosanitation, Wastewater, Sanitation

1. Introduction

Management of human waste is a critical part of daily life, and it is an important factor in human health (Esrey et al., 2001). The goals of most modern day sanitation systems are to prevent exposure of humans to harmful pathogens that are found in excrement and to minimize adverse impact on aquatic ecosystems from the input of oxygen consuming pollutants and nutrients such as nitrogen and phosphorus. Most sanitation systems in the developed world seek to carry away waste via a sewer collection system, remove pathogens and pollutants in an energy and material intensive treatment system, and then release the contents back into nature, often in large volumes of dilute waste that can cause water quality problems (Muga and Mihelcic, 2008). In the developing world, various types of latrines are often proposed as an appropriate technology to concentrate and contain the excrement (Mihelcic et al., 2009). Furthermore, when sewers are used in the developing world, because of limited resources, they often focus more on carrying away waste than providing adequate treatment (WHO, 2008). In addition, sewers may not be an appropriate technology in areas of the world that are water stressed (Fry et al., 2008) and centralized treatment systems that require large and expensive collection systems may not be the most appropriate technology for communities that are looking for sanitation coverage beyond latrines (Fuchs and Mihelcic, 2011).

Globally 2.6 billion people, 72% who live in Asia, still do not have access to improved sanitation facilities (WHO and UNICEF, 2010). Furthermore, while open defecation has decreased globally from 25% in 1990 to 17% in 2008, it is still widely practiced in Sub-Saharan Africa by 27% of the population and in Southern Asia by 44% of the population (WHO/UNICEF, 2010). Also, nutrient discharges (phosphorus and nitrogen) to surface waters are expected to increase substantially between 2000 and 2050 from the combined impact of increasing population, urbanization, and provision of sewers. This increase is especially great in southern Asia where phosphorus discharges are expected to increase by a factor of 4-5 (Van Drecht et al., 2009).

Improved sanitation can improve health by limiting contact between humans and their excreta. It is defined by the Joint Monitoring Programme for Water Supply and Sanitation through the World Health Organization and UNICEF (WHO/UNICEF, 2010) as...
a connection to a public sewer, connection to a septic system, or use of a pour-flush latrine, ventilated improved pit latrine, composting latrine, and simple pit latrine. When integrated with treatment or appropriate containment, current human waste collection systems found in the developed and developing world do much to minimize human contact with the pathogens in excrement, but little to ensure that nutrients will be recovered and returned to agricultural and natural systems in a way that benefits food production and aquatic ecosystems.

There is however growing awareness of the valuable nutrients being lost in human excreta collection, containment, and treatment systems. For example, it has been reported that for Swedish diets, 88% of the excreted nitrogen and 67% of the excreted P are present in urine (Jönsson et al., 2004). The remainder is discharged with the feces. In countries where the diet is less digestible (as might be expected in the developing world), urine will contain a smaller percent of the total nutrients with more subsequently present in the feces. For example, data from a Chinese diet reported urine contained approximately 70% of the excreted nitrogen and 25–60% of the excreted phosphorus (Gao et al., 2002). The nitrogen initially present in urine consists of approximately 75–90% urea with the remainder being mostly ammonium ion. Urea breaks down rapidly to ammonium ion and carbon dioxide in the present of water and urease. Ninety-five to 100% of the phosphorus in urine exists as inorganic phosphate ions. Also present are potassium and sulfate ions. This overall chemical composition makes urine a preferable fertilizer because the nutrients are available in plant-available chemical forms (Jönsson et al., 2004). In regards to the nutrients found in feces, the beneficial reuse of wastewater biosolids in agricultural settings is already widely recognized for improving of soil properties.

In terms of phosphorus, it has been estimated that globally there are 0.3–1.5 million metric tons of phosphorus reused annually from the 3 to 3.3 million metric tons of phosphorus generated in human excreta (i.e., feces and urine) and graywater (Liu et al., 2008; Cordell et al., 2009a). In regards to national material flows, it is estimated that 8000 metric tons of phosphorus are discharged with human excreta annually in Australia and 40–50% of that phosphorus reaching a treatment plant is applied to agricultural soils as biosolids (Cordell and White, 2009). Furthermore, the potential production of phosphorus from urine in Europe has been estimated as 0.3 kg phosphorus per person per year (Lienert et al., 2003). Re-use of these nutrients currently occurs primarily through wastewater reuse (i.e., water reclamation) and land application of biosolids. The available phosphorus from human excreta is reported to also be split near equally between rural and urban areas (i.e., 1.6 million metric tons excreted in urban environments, 1.7 million metric tons excreted in rural environments) (Liu et al., 2008). This split is likely to become more urban in the future because an estimated 70% of the world’s population is expected to reside in cities by the year 2050 (UNEP, 2007).

Closing the nutrient loop related to sanitation is now especially important because of the critical need to address the looming phosphorus crisis (see Vaccari (2009) and other articles in this special issue). Also, a new paradigm emerging in water and wastewater management is to emphasize the resources (water, energy, and nutrients) that can be recovered from wastewater in addition to the constituents that must be removed (Guest et al., 2009). Given all this information, there is thus a tremendous opportunity to not only provide appropriate and sustainable technology to the 2.6 billion people that lack improved sanitation that incorporates efficient nutrient recycling, but also integrate new ideas and technology with existing sanitation collection and treatment systems.

Accordingly, the objective of this study is to geospatially quantify the mass of phosphorus available from human urine and feces on a global, developing region, and country specific basis, taking care to integrate the results with availability of sanitation technology. The analysis is performed for two scenarios of population (2009 and 2050) and on a country specific basis. This important material flow is related to the presence or absence of improved sanitation technologies and also considers the global trend of urbanization. We also present our results using the United Nation’s regional grouping of countries in terms of their development status.

Of the main sources of available phosphorus (phosphate rock, animal manure, human excreta), human excreta makes up the smallest mass (Cordell et al., 2009a). However phosphorus material flows from human excreta should increase in the future as population and affluence (as measured by individual protein consumption) both increase, while greater demand for total food calories and protein will also increase the need for phosphorus fertilizer. And while others have reported global phosphorus material flows from human excreta (e.g., Liu et al., 2008; Cordell et al., 2009a), no one has geospatially related this information on a country and regional basis in terms of current development status and the availability of improved sanitation facilities. This information is important because proposed methods to remove phosphorus from wastewater are still largely based on biological and chemical removal from the dissolved to particulate form (de-Bashan and Bashan, 2004). However, new perspectives, technologies and behaviors are needed to drive innovations in providing infrastructure required to meet the future needs of increasing population and affluence along with an urbanizing world (Boyle et al., 2010).

One perspective that has been used by humans for centuries and is gaining renewed attention as a method to recover nutrients from human excreta is urine diversion. This contrasts with the more established technologies of processing and returning biosolids to agricultural settings. Urine diversion and reuse has been shown to be technologically feasible in both the developed and developing world settings (Maurer et al., 2003; Rauch et al., 2003; Wilsenach et al., 2007; Shaw, 2010; Shaw et al., 2010). The average human produces 0.8–1.6 L of urine per day (Lentner et al., 1981) which makes up less than 1% of total wastewater flow in developing country wastewater collection systems. The mass of phosphorus produced annually in this urine on a per capita basis is reported to range from 0.2 to 0.4 kg (Drangert, 1998; Kvarnström et al., 2006).

Human urine contains very few, if any, pathogens but contains significant nutrients. Few diseases are transferred through urine, and the risk of transfer for these through the use of urine fertilizer is insignificant, with the exceptions being: (1) schistosomiasis or (2) the possible contamination of urine with feces, both of which can be eliminated or minimized by appropriate collection, storage, and application (WHO, 2006). Unwanted micropolliutants in urine are primarily steroidal hormones and pharmaceuticals which can be removed to different degrees through natural attenuation or with existing engineering treatment technologies (Jönsson et al., 2004; Escher et al., 2006) which are energy and material intensive, and thus may not be appropriate in all areas of the world.

Understanding the potential for nutrient reuse on a geospatial basis is also important. For example, some agricultural practices do not always replace the nutrients lost in the system from harvesting crops. In addition, soils are losing nutrients at an alarming rate, especially in Africa (Connor, 2006) where three-quarters of Africa’s farmland is plagued by severe soil degradation caused by wind and soil erosion and the loss of vital mineral nutrients. This degradation partly explains why agricultural productivity in Africa has remained largely stagnant for 40 years while Asia’s productivity has increased threefold. African farmers must have access to affordable mineral and organic fertilizers if they are to stand any chance of reversing the decline of soil fertility (Connor, 2006). Urine and feces are two such sources of affordable fertilizer. In fact,
Sub-Saharan Africa provides an immediate opportunity for use of sanitation derived fertilizers because it already has very low levels of chemical fertilizer use (Rosemarin et al., 2008). In addition, Asia with its expanding population, lack of freshwater reserves relative to global population, and large population not served by improved sanitation facilities provides a realistic opportunity to introduce a

---

**Fig. 1.** Data used in development of this study’s results. 2009 and 2050 population (United Nations Environment Programme, 2010), total protein intake, and the percent protein that is derived from vegetable sources (Food and Agriculture Organization of the United Nations 2010a,b).
new perspective for nutrient recovery from human excrement and wastewaters.

2. Methods and data

A few studies have determined the precise nutrient content of urine (e.g., see Esrey et al., 2001; Gao et al., 2002; Jönsson et al., 2004). The problem is compounded because the chemical content of urine and feces depends on the digestible content of an individual’s diet. This is because digested nutrients enter the metabolism and are excreted with urine, while undigested fractions are excreted with feces. The Food and Agriculture Organization of the United Nations (FAO) provides per capita protein consumption data on a country specific basis. This data can be used to estimate the phosphorus excreted by an individual on a country specific basis as follows (Jönsson et al., 2004):

\[
\text{Phosphorus} = 0.011 \times (\text{total food protein} + \text{plant food protein})
\]

Eq. (1) was developed from data collected in Sweden on the mass of urine and feces excreted on a per capita basis, the nitrogen and phosphorus content of these two items, and country specific food intake information (Vinnerås, 2002; Jönsson and Vinnerås, 2004). And because plant protein contains approximately twice as much phosphorus per gram of protein than animal protein (Jönsson et al., 2004), the amount of phosphorus in the excreta (urine plus feces) is obtained from the sum of animal protein intake and two times the plant protein.

Results were then modified to determine the phosphorus present in urine and feces. For this we used a value of 50%, assuming equal distribution of phosphorus in urine and feces. One study conducted in Sweden suggested that urine will contain somewhat less than 67% of total excreted phosphorus (Jönsson and Vinnerås, 2004) and Chinese data (Gao et al., 2002) indicates that urine contains approximately 25–60% of human excreted phosphorus. And as was previously discussed, in countries where the diet is less digestible, urine should contain a smaller percent of the excreted phosphorus excreted with subsequently more present in the feces.

The most current average national total protein and vegetable protein consumption data (g/capita/day) that are available (from 2007) were drawn from FAO food balance sheets where available (FAO, 2010a). If 2007 data were not available, the next available 2005 data were drawn from the FAO’s Nutrition Country Profiles (FAO, 2010b). Urban, rural, and total population by country in

![Fig. 2. (Upper left) national sanitation coverage in 2008. (Upper right) total phosphorus produced in urine and feces annually per capita in 2009. (Lower left and right) total phosphorus produced in urine and feces on a country specific basis in years 2009 and 2050. Note the different scale representing the 2050 scenario.](image-url)
2009 and 2050 (projected) were obtained from the United Nations Environment Programme (UNEP, 2010). The data used to produce our results are provided in Fig. 1. Note that in this figure vegetable protein consumption data were converted to percent protein obtained from vegetable sources to make the data more visually clear. Protein consumption data were available for 180 countries, representing 98% of the global population in 2009. Countries were grouped into specific “developing regions” as developed by the United Nations and listed in the most current Joint Monitoring Report (WHO/UNICEF, 2010). This report also provided 2008 information on availability of improved sanitation coverage (as defined in the Introduction).

3. Results and discussion

Results varied by region, according to total protein intake, percentage of protein from vegetable sources, and total population. The total phosphorus produced each year (for the years 2009 and 2050) in specific countries on a per capita basis and a total produced on a country basis is shown in Fig. 2. Fig. 2 shows that depending on their protein intake, the mass of phosphorus produced annually on a capita basis in their combined urine and feces ranges from 0.18 (Democratic Republic of Congo) to 0.73 kg (Israel). The lower row of this figure shows that the total phosphorus discharged in combined urine and feces for individual countries ranges from 18.4 metric tonnes (Lichtenstein) to 7.87 × 10^8 metric tonnes (China). The specific mass of phosphorus available specifically from human urine or feces can be obtained by taking the values in Fig. 2 and multiplying by an assumed percent of the nutrient expected to be excreted in urine or feces (assumed to be 50% in this study). This is an important consideration in identifying the types of technology and behavior changes required to recover the nutrients. The potential phosphorus recovery from urine and feces increases under the 2050 population scenario because of population increases (our results assume no change in diet).

Table 1 shows results of the analysis using the regional grouping of countries in terms of their “development status” as defined by the United Nations and used in the WHO/UNICEF Joint Monitoring Report along with the percent of population served by improved sanitation in 2008. This table shows there are large regional sources of human-derived phosphorus that are available for agricultural reuse and could be derived from either urine or composted feces or digested biosolids. This is especially important for Sub-Saharan Africa and the three development regions of Asia that have large numbers of population currently unserved by improved sanitation facilities. For example three developing regions of Asia alone have the potential to recover over 1 million metric tons of phosphorus from urine in the year 2050 (and a similar value from composted or digested feces). This value will be even higher if protein consumption increases by 2050 (though increases in protein production will require greater phosphorus fertilizer inputs). Regions like Africa and Asia have great potential to immediately implement urine diversion, composting of feces, and/or biosolids recovery via new and existing technologies as sanitation coverage is provided over the next several decades. Other regions with extensive existing sanitation coverage (e.g., Europe and North America) would need to determine how to retrofit existing wastewater collection and treatment technology (e.g., addition of struvite precipitation).

Fig. 3 geospatially shows similar data as Table 1. Again phosphorus data is presented on a per capita basis and also a regional basis using groupings of countries in terms of their development status (specific regions are listed in Table 1). Fig. 3 also provides 2008 sanitation coverage averaged for each developing region (WHO/UNICEF, 2010). In addition to the opportunities for recovery of phosphorus in Africa and Asia which are currently implementing sanitation coverage on a broad scale, Fig. 3 also shows the large potential for recovering phosphorus from human excrement (currently and in future years) in the Americas and Europe. The data provided in this figure on existing sanitation coverage is important because it provides information on whether implementing urine and feces collection on a large scale will require retrofitting existing technology, using new technology, and/or consideration of what type of specific household behavioral changes might be needed.

Table 2 shows that in 2009 the global phosphorus available from urine (and similar mass from feces) is 0.88 million metric tonnes in urban areas and 0.80 metric tonnes in rural areas (results are supported by those of Liu et al., 2008). In 2050 the available phosphorus in urban areas from urine and feces that is due to only population growth will increase to over 1.5 million metric tons. However, the available phosphorus in urine and feces in rural areas will decrease to 0.64 million metric tones because of projected decreases in population. This data points to an important challenge, that is, the world is urbanizing with most population growth over this century projected to occur in urban areas, thus presenting challenges related to spatially connecting urban sources of human-excrement derived phosphorus with rural areas of agricultural activity.

It is important to note that our estimates do not take into account future changes in diet (i.e., total protein intake and per capita consumption of vegetable sources of protein). Table 1 shows results of the analysis using the regional grouping of countries in terms of their “development status” as defined by the United Nations and used in the WHO/UNICEF Joint Monitoring Report along with the percent of population served by improved sanitation in 2008. This table shows there are large regional sources of human-derived phosphorus that are available for agricultural reuse and could be derived from either urine or composted feces or digested biosolids. This is especially important for Sub-Saharan Africa and the three development regions of Asia that have large numbers of population currently unserved by improved sanitation facilities. For example three developing regions of Asia alone have the potential to recover over 1 million metric tons of phosphorus from urine in the year 2050 (and a similar value from composted or digested feces). This value will be even higher if protein consumption increases by 2050 (though increases in protein production will require greater phosphorus fertilizer inputs). Regions like Africa and Asia have great potential to immediately implement urine diversion, composting of feces, and/or biosolids recovery via new and existing technologies as sanitation coverage is provided over the next several decades. Other regions with extensive existing sanitation coverage (e.g., Europe and North America) would need to determine how to retrofit existing wastewater collection and treatment technology (e.g., addition of struvite precipitation).
pita protein intake from vegetable sources is assumed the same in 2009 and 2050). In reality, it is likely that diets will change as countries develop and food intake changes on a global level (WHO, FAO, 2003). Increases in food intake and shifting of calories from staples of roots and tubers towards livestock products and to meat, poultry, milk, and other dairy products will increase demand for phosphorus fertilizers. Urbanization also results in a more varied diet richer in animal proteins and fat (WHO, FAO, 2003). Changes in global diets will also drive the demand for phosphorus fertilizers.

Furthermore, while dietary energy and protein intake have been steadily increasing on a global basis; the change is not equal across regions. That is, the per capita supply of vegetable protein is slightly higher than that of animal protein in developing countries, while the supply of animal protein is three times higher than that of vegetable protein in industrialized countries. In addition, per capita food energy supply has declined from both animal and vegetable sources in the countries in economic transition, while it has increased in the developing and industrialized countries (WHO, FAO, 2003). In global terms, the WHO/FAO reported that the supply of calories has remained relatively constant in Sub-Saharan Africa while caloric intake has increased by almost 1000 kcal/capita-day in East Asia, primarily in China.

Global phosphorus demand is currently approximately 15 million metric tons. Future scenarios for 2050 suggest the demand could range from 4 to 110 million metric tons with a likely demand of 67 million metric tons (Cordell, 2010). Our calculations show that the total phosphorus available in excreted human waste (urine and feces) in 2009 is therefore approximately 22% of global phosphorus demand. This is supported by other estimations (Liu et al., 2008; Cordell et al., 2009a) The phosphorus available in urine alone could account for 11% of the total global phosphorus demand assuming 50% of phosphorus is present in urine. Importantly, only 0.3–1.5 million metric tons of phosphorus are estimated to be cur-

Table 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Total P in excreta (metric tons)</th>
<th>Total P in urine (metric tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Total 3358 048</td>
<td>1678 744</td>
</tr>
<tr>
<td></td>
<td>Urban 1755 942</td>
<td>877 691</td>
</tr>
<tr>
<td></td>
<td>Rural 1601 546</td>
<td>800 493</td>
</tr>
<tr>
<td>2050</td>
<td>Total 4329 417</td>
<td>2164 429</td>
</tr>
<tr>
<td></td>
<td>Urban 3055 623</td>
<td>1527 532</td>
</tr>
<tr>
<td></td>
<td>Rural 1273 234</td>
<td>636 337</td>
</tr>
</tbody>
</table>

Fig. 3. Results depicted according to “developing region” defined by the United Nations. (Upper left) national sanitation coverage in 2008. (Upper right) total phosphorus produced in urine and feces annually per capita in 2009. (Lower left and right) total phosphorus produced in urine and feces on a regional basis in years 2009 and 2050. Note the different scale representing the 2050 scenario.

Table 2

Total phosphorus in human excreta and in urine in urban and rural areas of the world in 2009 and 2050 (50% of phosphorus is estimated to be in the urine of human excreta; thus, the mass of phosphorus in feces would equal the mass listed in urine).
ently recovered from human waste annually by wastewater reuse and reclamation and biosolids application (Liu et al., 2008; Cordell et al., 2009a). In addition, our discussion does not take into consideration the many inefficiencies and losses that occur in the whole system of mining phosphate reserves and producing agricultural commodities (see Cordell et al. (2009b) for discussion on this topic). Also, our comparisons do not account for scenarios where demand for phosphorus demand increases 2% per year until 2050 from increases in population, demand for meat and dairy demand, and cultivation of biofuels (Cordell et al., 2009b).

Our 2009 estimates of potential global phosphorus derived from human urine and feces was approximately 3.4 million metric tons of phosphorus available per year. If this value is assumed to remain constant over the next 90 years (resulting in 2.9 million metric tons globally in 2050), it represents only 2% of the approximately 15,000 million metric tons of phosphorus in phosphate rock that are economically recoverable with current technology and represent approximately 50–100 years of readily available phosphorus mining reserves (Cordell et al., 2009a; Vaccari, 2009). However, all the urine collected from one individual has been reported to provide enough useful nutrients (phosphorus, nitrogen) to fertilizer 300–400 square meters of crops per year (Jönsson et al., 2004). Furthermore, the World Health Organization has stated that nutrients obtained from recycled excreta can help to relieve poverty through: (1) reductions in malnutrition through improved nutritional variety and household food security, (2) increased income from sale of surplus crops, and, (3) money saved on fertilizer which can be put to other productive uses (WHO, 2006). Recovery of phosphorus (and nitrogen) from urine and pollution prevention efforts that reduce phosphorus from laundry and dish detergents also have the potential to greatly reduce phosphorus (and nitrogen) loadings to wastewater treatment plants and the environment. Obviously consideration of the potential to recover nitrogen from human excrement (especially urine) is important.

In recent decades, closed-loop sanitation systems have received attention as a way to reduce health risks while at the same time recovering useful nutrients and returning them back to food systems quickly (Esrey et al., 2001). Closed-loop sanitation uses excreta collection methods that facilitate the decomposition of pathogens and other excreted material into beneficial products that can be used directly for crop production, which can then help alleviate malnutrition and possibly increase income (WHO, 2006). One important component of closed-loop sanitation technology such as a compost latrine is the diversion of urine from the collection of feces, which keeps moisture levels low, promoting oxygenated conditions and speeding up destruction of pathogens through desiccation (WHO, 2006; Mehl et al., 2011). Urine diversion is also a technology that addresses the need for an alternative means for providing sanitation coverage in urban areas of developing countries. Urine diversion (e.g. urine-separating compost toilets) is currently used more frequently in rural rather than urban settings. However, urine diversion has many advantages in urban settings. For example, removing urine from the wastewater collection system reduces energy and materials requirements at the treatment plant, reduces peak ammonia loadings to the treatment plant which can act as a substitute for plant expansion, and 3) reduces the impact of combined sewer overflows on aquatic environments (Rauch et al., 2003). In addition, urine diversion technology has been shown to be feasible in several urban developed country settings. This includes a Swiss study which measured attitudes in a small focus group towards a Swedish based technology implemented at the household level (Pahl-Wostl et al., 2003). In that study, acceptance of urine diversion toilets was quite high (assuming no increase in cost) with the majority of participants expressing interest in moving to an apartment with the technology and purchasing food fertilizer with urine.

Table 2 demonstrated the important role urbanization will play in the distribution of phosphorus produced from urine. Currently, slightly over 50% of the global population is urban, whereas in 2050, the percentage of the population that is urban is projected to grow to nearly 70% (UNFPA, 2007). Accordingly, much of the world's future population that will be unserved by improved sanitation will be situated in the world's cities. In terms of the current situation in regards to reuse of human wastes in urban and rural areas, Liu et al. (2008) suggests that "it could be appropriate to assume" that about 20% of urban human wastes are currently reused and 70% of rural human wastes are currently reused. Traditionally, water-consuming sewers where urine is mixed and diluted with solid excreta and graywater are thought to be the most feasible option for managing human waste in urban environments. However, even in developing world cities where sewers exist, few are connected to wastewater treatment facilities that can recover nutrients from the waste. In these situations oxygen depleting pollutants and nutrients can cause localized water quality problems which in turn harm the ability of the world's poor to generate needed income through employment as fishers. Additionally, water-intensive sanitation technologies may not be appropriate for many of the world's cities which are under water stress or will be in the future (Fry et al., 2008). The combined importance of water conservation and nutrient recovery from human excreta in these urban areas of developing countries suggests the need for an alternative strategy for providing sanitation coverage. This study geospatially quantified the mass of phosphorus available from human urine globally, regionally, and by specific country. The analysis was performed over two scenarios of population (2009 and 2050). This important material flow was related to the presence or absence of improved sanitation technologies and also considers the global trend of urbanization. The potential for obtaining needed phosphorus from human urine is in its infancy, yet has great potential as a source or phosphorus. This is especially important because as the world moves toward meeting the Millennium Development Goal sanitation target, engineers and urban planners might consider designing urine diversion systems appropriate for urban areas.

Acknowledgment

We thank the US Peace Corps for assistance provided through the Master's International Program in Civil & Environmental Engineering.

References


