Phosphorus budget in the low-income, peri-urban area of Kibera in Nairobi (Kenya)

P. Kelderman, D. K. Koech, B. Gumbo and J. O’Keeffe

ABSTRACT

Kibera, located in Nairobi, Kenya is one of the largest (235,000 inhabitants) low-income areas in East Africa. Surface waters in Kibera show high pollution levels with respect to SRP (soluble reactive phosphorus; range: 2–10 mg P/L), coming from the uncontrolled wastewater discharges in the area. The different P production and consumption values in Kibera were estimated using interviews (155 interviewed) as well as detailed P house-keeping for five representative families. The results show that highest P consumption comes from food, in particular cereals. Highest P production came from urine (55% of the total) and faeces (31%), with relatively lower contributions from grey water and solid wastes. The overall P budget in Kibera amounted to around 9 × 10³ kg P/month. This is equivalent to 0.47 g P/person yr, both for P production and consumption, with a relative error of 20%. Comparing with the estimated P outflows via the Kibera surface waters, around 65% of the P produced in Kibera will leave the area. In future ECOSAN techniques such as urine separation could well be applied for efficient recycling of these waste sources.

Key words | households, Kenya, low-income, mass budget, Millennium Development Goals, peri-urban, phosphorus

INTRODUCTION

The United Nations Millennium Development Goals (MDGs), agreed upon by 189 countries, have set out different goals, amongst others to alleviate poverty, to improve the lives of slum dwellers and to protect the environment (UN 2005). One of the key items for developing countries is to address urgently the nutrient depletion in soils. Inputs of nutrients are essential for agricultural production. At the same time, a surplus of nutrients, in particular phosphorus (P) can cause environmental damage to surface waters, e.g. in the form of lake eutrophication (Wetzel 1983).

In many developing countries, phosphorus deficiency in soils is responsible for poor crop yields. In Kenya, the rate of P depletion in the soil is estimated at 2 – 3 kg/ha yr (Smaling 1993). Use of commercial fertilisers is a less preferred solution because of the high prices involved and limited global fertiliser resources. According to the 1996 Bellagio principles, the pressure of humanity on fragile water resources and the corresponding need for environmental and water protection requires that human excreta and societal wastes be recycled and used as a resource. In Kenya, however, usage of manure is not a common practice yet and manure quality is often low, amongst others due to inadequate management (Probert et al. 1995).

Kibera in Nairobi, Kenya, is one of the largest and most densely populated peri-urban areas in East Africa (see Figure 1). The present environmental situation in Kibera is certainly not up to the MDGs: the inhabitants hardly have access to reliable drinking water and sanitation is virtually non-existent. Wastewater discharges have led to deterioration of the Kibera surface waters, especially to eutrophication due to overloading with nutrients like phosphorus and nitrogen (Chapman 1996).
Mass budgets have often been applied as a reliable method for assessment of material fluxes in systems, e.g. for phosphorus in lakes and heavy metals in urban systems (Dillon & Evans 1993; Søndergaard et al. 1999; Kelderman et al. 2000; Kelderman et al. 2005). Gumbo et al. (2004) developed a P calculator model for assessment of both the water budget and the household and agricultural P budgets for urban ecosystems in Zimbabwe. The main objective of the present study is to determine the overall P budget in Kibera. Phosphorus is generated from household activities such as food consumption and washing, and released as wastes, viz. as yellow water (urine), brown water (faeces), grey water (washing and cleaning) and solid wastes. In order to assess the different P fluxes, use will be made of inventories and detailed “house-keeping” of the P fluxes for representative sub-groups and families in Kibera. The results for the Kibera P budget will also be compared with the P fluxes out of the system, via the Kibera River and streams. Thus more insight will be attained on the magnitudes of the different P fluxes in Kibera, leading to possible options for short-cutting the P cycle in this, and other urban environments in developing countries.

METHODS

Description of the area

Kibera (Lat. 1° 19’14” S; Long. 36° 47’34” E) is situated about 10 km SW of the centre of Nairobi, Kenya at an altitude of around 1,800 m (see Figure 1). In 2005/06, Kibera had a population of about 235,000, based on the 1995 census (184,000, with a growth rate of around 5% per year (Koech 2006)). The houses in Kibera are usually made of mud and either roofed with corrugated iron sheets or covered with polythene sheets. There are virtually no sewered toilets in the area. About 80% of the latrines are emptied manually by directing wastewater into the open drainage channels to the streams while other latrines are simply covered and abandoned (Koech 2006). There is also no regular solid waste collection system; most residents dispose of their solid wastes in the open space. The study area is part of the wet tropical zone; the average rainfall amounts to 970 mm per year, mainly from November to May. Temperatures are rather constant throughout the year, with daily maxima of 22–27°C and minima of 11–15°C.

Motoine River (see Figure 1) is, with its 27 km length, the largest river in the area. It has an average flow of 0.7 m/s
with low and high flows of 0.2 m/s and 1.0 m/s, respectively; during the rainy season Motoine River often becomes impassable (Koech 2006). The river originates from a high-lying forest zone and passes through agricultural farms and other settlements before entering Kibera. Here the river gets highly polluted with e.g. organic matter and nutrients. Apart from the Motoine River, there are other streams passing through Kibera of which only two major ones, Stream 1 and Stream 2, will be considered here (see Figure 1).

The Nairobi Dam reservoir was commissioned in 1953 for Nairobi’s water supply and recreation. Its original surface area amounted to 356,000 m², with an average water depth of 2.8 m (Koech 2006). The reservoir is currently heavily silted due to upstream erosion; it also receives high solid waste, organic and nutrient loadings from Kibera. Consequently it has been invaded by aquatic plants such as water hyacinths. Recently, plans have been developed for restoration of the Nairobi Dam involving removal of water hyacinths and solid wastes. However it will be apparent that such restoration plans can only be successful after proper sanitation of the incoming waste streams.

Water analysis

In total 45 water samples were taken, all on 17 November 2005. There had been heavy rains the previous night and water discharges were relatively high. This may have had a diluting effect on the various water quality parameters (see later). The monitoring stations for surface water quality assessment (see Figure 1) were located on the Motoine River (M1–M9); on Stream 1 (A1–A12); on Stream 2 and a small stream in Soweto East (B1–B6); open drains in Kibera (D1–D7) and in the Nairobi Dam (N1–N6) (Koech 2006). Additionally five representative samples were taken from the groundwater spring. Water samples were collected manually in 100 mL polythene bottles, were filtered over a 0.45 μm filter and stored at 4°C. Subsequent analyses generally took place within 2 days at the laboratory of the Kenya Bureau of Standards in Nairobi; this laboratory has been accredited according to ISO 17025 Standards by the United Kingdom Accreditation Services (UKAS). Water samples were analysed for Soluble Reactive Phosphorus (SRP) according to the ammonium molybdate method (Eaton et al. 2005; for details, see Koech 2006). Quality Assurance and Control (QA/QC) comprised analyses of a limited number of reference samples, of blanks (one sample) and duplicate samples (one per 10 samples) (acceptance criteria of the duplicates ±10% of the arithmetic mean). Due to logistic and budget restrictions, no analyses were carried out on total-phosphorus ($P_{\text{tot.}}$); $P_{\text{tot.}}$ values were estimated from literature data on $\text{SRP}/P_{\text{tot.}}$ ratios Tchobanoglous (1991).

Phosphorus cycle in Kibera

A research approach was chosen much in line with the detailed P cycle study in urban ecosystems in Zimbabwe (Gumbo 2005). The materials considered in the Kibera P cycle included food and beverages, soaps and detergents, wastewater and solid wastes. A two-way approach was used, one involving questionnaires on 200 interviewed, the other the monitoring of five selected, representative families (Koech 2006). For these surveys, three research assistants were recruited, based on their educational qualifications and experience in similar surveys. One of the assistants was born and brought up in Kibera; all three lived in the area at the time of the research.

**Questionnaires** - In total 200 adults (>18 years old), representing 200 families, were approached to fill out a questionnaire; 155 filled-out questionnaires were received back (78% response). No financial rewarding was offered to the interviewed. The questions emphasised the following items (for details, see Koech 2006): personal data (age, sex, family structure, income, etc.); consumption of food and beverages; water consumption and disposal; usage of soaps and detergents; solid waste production, collection and disposal; faeces and urine disposal techniques; agricultural practises including reuse of (human) wastes and perceptions with respect to this reuse. Questions were usually in a multiple-choice format. The results of the interviews were analysed on a personal computer using SPSS and Microsoft EXCEL for finding parameter values such as mean value, standard deviation and 95% Confidence Intervals (Wernimont & Spendley 1993).

**Monitoring of five selected families** (for details, see Koech 2006) - The different water usages by each family
were monitored during one month based on daily water uses, with the help of inventory lists. The water usages were subdivided into categories such as water for bathing and for drinking. The food consumption was determined by daily monitoring of the consumption in the five households in Kibera, according to the following food types: cereals; meat and fish; milk and eggs; vegetables; nuts; starchy roots; pulses; beverages. The values for the P_{tot} contents of each food type were taken from the earlier mentioned Zimbabwe study (Gumbo 2005). A similar approach was chosen with respect to the use of soaps and detergents. Since the five families had a somewhat different age structure than the Kibera population (viz. 26% vs. 36% < 14 years old), an Age correction factor of 0.82 was taken into account, implicating that all P consumption values found here were multiplied with this value (Gumbo 2005; Koech 2006).

The amounts of P excreted through urine and faeces were also derived from the Zimbabwe study (Gumbo 2005). Again, above Age correction factor of 0.82 was taken into account. The amounts of water released through bathing and cleaning (“grey water”) were calculated using the daily grey water production (see before) and its P content; the latter was based on the P contents of the types of soaps and detergents used (Gumbo 2005; Koech 2006). Finally, P production via solid waste was monitored by weighing (a spring balance was provided to each family) and using waste categories; only the P content in the organic fraction was taken into account assuming a P content of 1.6 g P per kg organic waste (Gumbo 2005).

RESULTS AND DISCUSSION

P contents in Kibera surface waters

The data on the SRP contents in the Motoine River (see Figure 2A) indicate that the river reaches Kibera in a quite unpolluted state, followed by a gradual increase, up to 5 mg P/L within Kibera. Similar results were found for the two Kibera streams (see Figure 2C-D), with maximum SRP values up to 10 mg P/L and a gradual decrease towards Kibera Dam, probably due to dilution. As mentioned before, heavy rains had occurred the night before sampling; the observed P data could thus be an underestimation of the regular values. SRP contents in the drains (see Figure 2B) show that the grey water had a constant and somewhat lower SRP content than the previous surface
waters, *viz.* $2.2 + 0.1 \text{ mg P/L} \ (n = 7; \ 95\% \ \text{Confidence Intervals will be used here}).

Homogeneous P contents were found in the Nairobi Dam, with high SRP contents, *viz.* $5.8 + 0.3 \text{ mg P/L} \ (n = 6).$ Compared to this the spring water (see Figure 1) was found to be of excellent quality, with SRP contents close to the P detection limit (*viz.* $0.01 + 0.005 \text{ mg P/L}; \ n = 5).$

Above data indicate that the SRP contents in the Kibera river and streams are far above the common international standards for surface waters, *viz.* typically $0.01 - 0.1 \text{ mg P/L}$ in the European Union, Canada and Russia (*Chapman 1996; Buijs 2003*) (N. B. Kenya water quality criteria mainly aim at effluent discharge standards; for phosphorus $1 - 5 \text{ mg P/L}$ (unpublished 2007 Report)). As a consequence, the Kibera Dam is in a hyper eutrophic state, receiving an estimated phosphorus loading $> 150 \text{ g P/m² yr}$ (*Koech 2006*). It will need $>99\%$ P reduction to reach an acceptable, mesotrophic or even oligotrophic condition (*Wetzel 1985*).

A crude estimation can be made of the mass of $P_{\text{tot}}$ flowing out of Kibera via the Motoine River and the two streams. At the Kibera Dam outlet, we determined an average water discharge of $0.2 \text{ m³/s}$ (*Koech 2006*). Assuming 30% evaporation in the Kibera Dam (*Kadlec & Knight 1996*), this would imply a water input into the Kibera Dam of $9.0 \times 10^6 \text{ m³/yr}$. As mentioned before, we did not carry out $P_{\text{tot}}$ analyses. However, from an inflowing SRP content of around $5 \text{ mg P/L}$ (see Figure 2), we can deduce -using an overall SRP/$P_{\text{tot}}$ ratio in practice- a $P_{\text{tot}}$ content of around $7 \text{ mg P/L}$ (*Tchobanoglous 1991*). Thus it can be estimated that around $6.3 \times 10^4 \text{ kg P/yr}$ will be transported out of Kibera via the Motoine River and streams. This value is probably an underestimation since the actual water discharge during our monitoring day (17 November 2005) will have been higher than average, having led to P dilution. Indeed regular floods can be expected to wash out accumulated materials out of Kibera.

### Results for the 155 questionnaires

The filled-out questionnaires from the 155 respondents (for details, see *Koech 2006*) showed that the majority (60%) was employed whereas 30% had an own business; only 1% was full-time farmer. Some 50% of the respondents had a monthly income of 50–100 US$/month; 20% were found in both the 20–50 and 100–200 US$/month ranges.

The total water consumption per respondent amounted to 22 l/cap.day, mostly used for washing (60%) and bathing (27%). Drinking water was mainly (81%) bought at vendors for an average price of around 3 US$/m³. For the remaining group, 9% used communal taps and 9% piped water. Food consumption characteristics showed the following features: cereals, vegetables, milk and eggs, and beverages were consumed generally (65–87%) on a daily basis; for the other food categories, the consumption mostly (55–80%) took place 2–3 times per week. Disposal of excreta occurred for 66% in the open space; 32% used latrines or septic tanks and only 2% flushing toilets. Solid waste was mostly disposed of in open spaces; solid waste collection only took place for 7% of the respondents.

### P budget in Kibera

The outcomes for the detailed research on the five selected families were in line with above results (see *Koech 2006*). The food category with highest consumption rates was formed by cereals (see Table 1), with an average monthly quantity of 10.9 kg/cap.month (range 7–14 kg/cap.month, dependent on family composition, income, etc.); consumption values for the other food categories were much lower. Usage of soaps and detergents amounted, on average, to 1.4 kg/cap.month. With the help of the P contents of above products, the monthly P consumption in Kibera could thus be calculated (see Table 2).

With respect to P production (see Table 2), highest contributions came from urine (55%) and faeces (31%). The remaining categories were phosphorus in the grey water (6%) and in solid waste (7%). The P production values in Kibera were derived assuming a total population of 235,000 and using an Age correction factor of 0.82 (see before).

The overall P budget in Kibera (see Table 2) shows a good fit between the consumption and production (relative error: 20%), especially when we take into account the different assumptions and simplifications made. *Gumbo (2005)*, in his detailed research on P fluxes in households in Zimbabwe, found a relative error of 8%. In Table 2, the estimated P production/consumption of around $9 \times 10^3 \text{ kg P/month}$ over whole Kibera is equivalent to about $0.47 \text{ kg P/cap yr}$.
P contents in the different food groups (Table 1) will be dependent on climate, soil characteristics, fertiliser application, etc. (FAO 2005); these P contents will directly determine the P contents of the urine and faeces (Jönsson et al. 2004; Gumbo 2005). In Table 2, P consumption through soaps and detergents were derived from the actual P contents of the commercial products; wide variations exist in this respect (Patterson 2001; Gumbo 2005). The estimated P production values for urine and faeces in Kibera are equivalent to 0.22 and 0.13 kg P/cap yr, for urine and faeces, respectively. These values are well comparable with reported data for India, Haiti and Uganda, and are somewhat lower than found in South Africa and China P.R. (Jönsson et al. 2004). Grey water composition, finally, will much be influenced by lifestyle, customs and washing habits (Jefferson et al. 2004).

Comparing above P production of \(8.0 \times 10^3\) kg P/month with the earlier calculated P outflow via surface waters \((6.3 \times 10^4\) kg P/year = \(5.3 \times 10^3\) kg P/month), we can see that around 65% of the P produced will flow out of the Kibera system, via the Motoine River and the streams. The remainder will be stored in the soil (e.g. in pit latrines), dumped as solid waste in the open space, etc. As mentioned before, much of this material may eventually be washed out of Kibera, through the regularly occurring floods in the region.

Globally, it can be expected that P resources for fertilisers will be depleted within the coming 100–200 years; this necessitates a “paradigm shift” in the perception of waste products, as valuable, still largely un-used material sources (Gumbo 2005). The 1996 World Food Summit in Rome gave priority to development of urban and peri-urban agriculture. Potentially, the “wastes” produced in Kibera all constitute valuable resources for agricultural production for, ideally, 235,000 people (viz. the population of Kibera, assuming a closed P budget). In case of serious spatial planning problems, export of (stabilized) urine may be the next best option (Gumbo 2005). Waste recycling is also a vital component in the 2006–2010 UNESCO-IHE SWITCH Project (Sustainable Water Management Improves Tomorrow’s Cities’ Health) (http://www.unesco-ihe.org/Project-activities/Project-database; accessed 23 August 2009).

Ecological Sanitation (ECOSAN) techniques deserve special attention such as waste treatment in wetlands, composting and urine and faeces separation (Jönsson et al. 1997; Werner et al. 2004; Gumbo 2005); these ECOSAN techniques have rapidly evolved during the last decades. Urine separation will probably be the most promising

### Table 1

<table>
<thead>
<tr>
<th>Food group</th>
<th>Consumption (kg/cap.month)</th>
<th>P content (g/kg)</th>
<th>P cons. (g P/cap.month)</th>
<th>P cons. in Kibera ((\times 10^3) kg P/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td>10.9</td>
<td>1.85</td>
<td>20.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Meat and fish</td>
<td>1.9</td>
<td>1.55</td>
<td>3.0</td>
<td>0.64</td>
</tr>
<tr>
<td>Milk and eggs</td>
<td>3.2</td>
<td>0.93</td>
<td>3.0</td>
<td>0.64</td>
</tr>
<tr>
<td>Vegetables</td>
<td>3.0</td>
<td>0.85</td>
<td>2.5</td>
<td>0.55</td>
</tr>
<tr>
<td>Nuts</td>
<td>0.6</td>
<td>4.05</td>
<td>2.3</td>
<td>0.53</td>
</tr>
<tr>
<td>Starchy roots</td>
<td>1.9</td>
<td>0.46</td>
<td>0.9</td>
<td>0.19</td>
</tr>
<tr>
<td>Pulses</td>
<td>2.1</td>
<td>4.62</td>
<td>9.7</td>
<td>2.1</td>
</tr>
<tr>
<td>Beverages</td>
<td>3.4</td>
<td>0.13</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>27.0</td>
<td>42.1</td>
<td>9.2</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>ITEM</th>
<th>P Consumption ((\times 10^3) kg P/month)</th>
<th>P Production ((\times 10^3) kg P/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food and beverages</td>
<td>9.2</td>
<td>4.4</td>
</tr>
<tr>
<td>Soaps and detergents</td>
<td>0.63</td>
<td>2.5</td>
</tr>
<tr>
<td>Urine</td>
<td></td>
<td>0.52</td>
</tr>
<tr>
<td>Faeces</td>
<td></td>
<td>0.59</td>
</tr>
<tr>
<td>Grey water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9.8</td>
<td>8.0</td>
</tr>
</tbody>
</table>
technique since urine constitutes >50% of all P produced (see Table 2); it has been a technique used for millennia in e.g. large parts of China P.R. where still today >50% of all human excreta are used for agricultural production (Gumxi 2005). Thus in 2001, an ECOSAN Project in Guanxi used 30,000 urine diversion squatting pans, patented in China P.R. itself.

In Kenya and many other countries, there may be large objections on the direct usage of human excreta (Gibson & Apostolidis 2001; Jefferson et al. 2004; Gumbo 2005). From the 153 respondents interviewed in our research, 55% indicated that they would not consume food grown using sewage water. At the same time, however, from the group of respondents with farming activities (about 65%) 91% did use wastewater for irrigation (Koech 2006). Therefore, education and awareness projects must form essential elements in the successful implementation of ECOSAN projects, both in developed and developing countries.

CONCLUSIONS

In this phosphorus budget study for Kibera (235,000 inhabitants) we estimated P production and consumption values of about 10^4 kg P/yr. In spite of the assumptions and simplifications made, the relative small difference (20%) between the estimated P consumption and production values is a support for the validity of the approach chosen. Some 65% of the phosphorus will be exported out of the area. P recycling in urban agriculture would be beneficial for the community, both from environmental and economic points of view. This would necessitate a “paradigm shift” in the perception of waste products, as valuable, still largely un-used material sources.

REFERENCES


