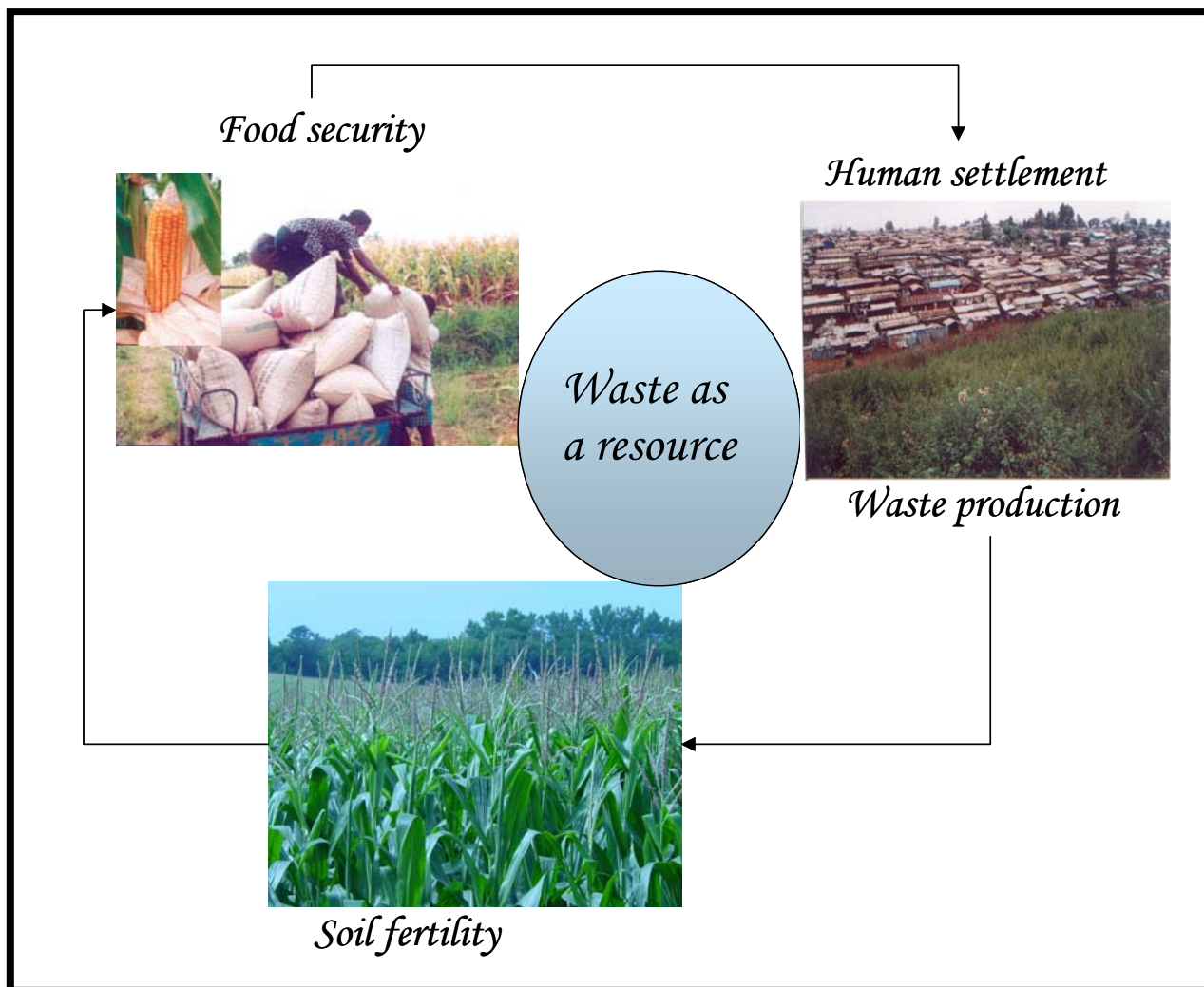


# UNESCO-IHE INSTITUTE FOR WATER EDUCATION



## Phosphorus budget of a household system in a low-income peri-urban area. Case study: Kibera, Kenya

David Kipngetich Koech

MSc Thesis WM 06.11  
April 2006



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The findings, interpretations and conclusions expressed in this study do neither necessarily reflect the views of the UNESCO-IHE Institute for Water Education, nor of the individual members of the MSc committee, nor of their respective employers.

## Dedication

To my dear wife, Veska and the children, Clenice, Collins and Milan for their patience and support during the entire period of my studies.



## Abstract

Phosphorus is an essential element to both plants and animals. The phosphorus mainly occurs as rock phosphates in the earth's crust and is mined for making fertilisers. These reserves are finite and other potential sources need to be explored. Household wastes contain phosphorus which can be recycled into agricultural use while at the same time reduce environmental pollution from these wastes.

The aim of this thesis is to quantify the amount of phosphorus from household wastes. This is based on a study in the low-income area of Kibera in Nairobi, Kenya. Weekly mapping of the food consumed together with soaps and detergents used by five selected families was done for a period of two months. The total amount of phosphorus in the material flow and the wastes was estimated on the basis of the composition of each group. In order to assess the phosphorus losses to the environment, water and soil samples were taken and analysed. A social survey was done using structured and semi-structured interviews to get as many respondents as possible.

The inflow of phosphorus through foods and soaps amounted to 42.2 g P/p. month and 2.2 g P/p.month respectively. Cereals in the food groups contributed the highest phosphorus (20.3 g P/p.month) whereas in the soaps and detergents group, detergents contributed the most (1.3 g P/p.month).

The P-outflow through urine, faeces, grey water, and solid waste was 25, 8.3, 2.2 and 2.5 g P/p.month respectively. Urine was the largest contributor to the P loadings whereas grey water was the lowest. It was estimated that in total, a person consumes 44.4 g of Phosphorus per month and generates 38 g Phosphorus per month as waste.

The P- concentration of the streams and Motoine river ranged from 1 to 9 mg P/l against the Kenyan guidelines of a maximum of 0.1mg P/l. The P concentration was found to decrease downstream towards the Nairobi Dam, which could be attributed to sedimentation and dilution effect in the surface water. The Nairobi dam is a reservoir of all the wastes transported via the streams and Motoine river. This research established that the P-concentration of the dam was 5.8 mg P/l with the total P-loading of 166g P/m<sup>2</sup>.yr. The dam was found to be highly eutrophic which explains the invasion of water hyacinth plants in the dam. The residence time of water in the lake was estimated at 6 days less than the original design time of 10-20 days.

The P-loading should be reduced by 98 % if the dam is to be restored to a desired oligotrophic state.

*Key words: Eutrophication, Food and beverages, Faeces, Grey water, Phosphorus loadings, Residence time, Soaps and detergents, Solid wastes.*



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Thanks to the almighty God for his love, care and gift of life given unto me during my entire period of my study.

I wish to thank the Government of Netherlands and the Government of Kenya, through my employer; Kenya Bureau of Standards for the assistance given to me in terms of finances, logistical support, time, moral and material support which have seen me through this worthy course.

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I salute Prof. Pieter Van der Zaag, Dr. Andrejea Jonoski, Ir. Daniel Schotanus and the Water Mill family for selecting me to represent the water mill group in *the 4<sup>th</sup> World water Forum in Mexico*. It was a great opportunity for me and an eye opener, to the many global challenges facing the world on water and sanitation. I realised that it may require only one person to bring a change, not necessarily a collective responsibility.

My colleagues and friends, whom I have come to know in my entire life, I know you always stood by me, encouraged me to aim higher. Your contributions are highly appreciated.

I will not forget my parents, brothers and sisters. It was hard for you to imagine my one and half years of absence. Your patience, prayers and greetings have seen me through and I say a big thank you.

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## List of Acronyms.

BOD	Biochemical Oxygen Demand
CBS	Central Bureau of Statistics
EBRP	Enhanced Biological Phosphorus Removal
FAO	Food and Agricultural Organisation
FAOSTAT	Food and Agricultural Organisation Statistic Database
ISO	International Organization for Standardizations
JICA	Japan International Cooperation Agency
KWAHO	Kenya Water for Health and Organisation
NETWAS	Network for Water and Sanitation
SPSS	Statistical Package for Social Sciences
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UK	United Kingdom
UNEP	United Nations Environment Programme
UN MDG	United Nations Millennium Developments Goals
USA	United States of America
USEPA	United States Environmental Protection Agency



# 1 Introduction

## 1.1 Background

The Millennium Development goals and targets agreed upon by 189 countries, including 147 Heads of state, in September 2000 set out different goals aimed at, among other things, alleviation of poverty, improving the lives of slum dwellers and environmental protection.

One of the quick wins in the report is for the developing countries to urgently address nutrient depletion in the soil. The leaching away of nutrients such as P and N reduces the fertility of soils in many countries, leading to poor yields in crop production (UN Millennium project 2005).

Inputs of nutrients, such as nitrogen and phosphorus, are essential to agricultural production and integral to raising productivity. At the same time, a surplus of nutrients in excess of immediate crop needs can be a source of potential environmental damage to both surface and ground water e.g. in the form of eutrophication. This is a condition in which a surplus of nutrients causes excessive growth of algae and other aquatic plants. Phosphorus is the key element primarily responsible for the eutrophication of fresh water ecosystems and its control is an effective means of eutrophication abatement (Kelderman 2005).

Phosphorus (P) in lakes and streams comes from both point sources (industrial and domestic wastes) and non point sources mainly agriculture. Non-point sources contribute a higher proportion of P during the wet season whereas during dry periods, P is mainly from point sources (Report on Minnesota's surface water)<sup>a</sup>. As a result of these human activities, phosphorus is lost into the river and finally to the deep sea where it is difficult to recover (Hootsman 2005). This has caused a deficiency of P in soil nutrients and eutrophication of lakes.

In many developing countries the phosphorus deficiency in the soil is responsible for poor crop yields. Many small-scale farmers cannot afford to pay for expensive fertilisers. In Kenya, the rate of depletion of Phosphorus in the soil is estimated at 2-3 kg/ha/yr (Smaling 1993, FAO 2006). It has been shown that human wastes contain nutrients, which are sufficient for crop productivity (Gumbo 2005).

According to the Bellagio principles (1996), the pressure of humanity on fragile water resource base, and the corresponding need for the environmental and fresh water protection requires that human excreta and societal wastes (solid and liquid) be recycled and used as a resource.

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<sup>a</sup> <http://www.pca.state.mn.us/publications/reports/pstudy-section1.pdf>

## 1.2 Problem statement

Human settlement around water systems, has caused such waters to be either polluted or to be over-abstracted leading to serious environmental degradation.

The settlement of people in Kibera in Nairobi, Kenya has led to deterioration of the adjacent streams, rivers and lakes (Nairobi Dam).

Nairobi Dam, which was constructed to boost the water supply to the Nairobi citizens, have become home to water hyacinths and other water plants. One part is already becoming a dry land where people grow fodder for their cattle (Plate 1-1). This has been caused by a high loading of nutrients and solid wastes from the adjacent Kibera settlements. The source of these nutrients is related to the household activities aimed at cleaning and nourishing (Gumbo 2005). This has been accelerated by the lack of proper sanitation and poor solid waste collection and disposal system.

The Kibera settlement is crowded with unplanned tin-roofed structures without proper sanitation. People use latrines which are often overflowing and the solid wastes are dumped anywhere where there is space (Howard 2003). As a result the dam downstream becomes a reservoir for all these wastes.



Plate 1-1: Napier grass growing at the inlet of the Nairobi Dam

## 1.3 Millennium development perspectives

This study will give an insight of the amount of Phosphorus flow from household waste and biodegradable solid wastes in a high-density area. Based on the results, a proposal is made on the possibility of diverting these wastes into agriculture to replenish the nutrient deficient soils. By so doing, the farmers will be able to improve on their yields and therefore reduce hunger while at the same time the pollution of the environment (eutrophication) will be reduced. This is the focus of the UN Millennium development goals:

- Goal 1 “Eradicate extreme poverty and hunger”  
Target 1 “Halve, between 1990 and 2015, the proportion of people who suffer from hunger”
- Goal 7 “Ensure environmental sustainability”  
Target 10 “Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation”

## **1.4 Objectives**

The main objective of this study is to determine the total amount of phosphorus generated from household activities and released as wastes, namely: yellow water (urine), black water (faeces), grey water and solid waste.

The specific objectives of the study will be:

- ❑ To quantify the amount of food and beverages consumed and the total amount of soaps and detergents used by each inhabitant in Kibera.
- ❑ To establish the phosphorus trend in the river, springs and streams within the study area.
- ❑ To determine the Phosphorus level in soils of different farms and gardens within/ outside the Kibera area.
- ❑ To determine the P-loading in, and the trophic status of, the Nairobi Dam
- ❑ To establish the potentiality of wastes as a source of fertilisers in agriculture.

In order to achieve the above stated objectives, the following questions were formulated.

## **1.6 Research questions**

- ❑ What is the average size of a family in the study area?
- ❑ How much material (food and soaps) does each family use per day?
- ❑ What kind of wastes is generated per household?
- ❑ How do people dispose of their wastes?
- ❑ Which farming activities exist in the study area?
- ❑ How much phosphorus does the soil in the garden have?
- ❑ How much water is approximately used per household?
- ❑ What is the phosphorus concentration of surface water in Kibera (drains, river springs and streams)?
- ❑ What is the trophic status of the Nairobi dam?
- ❑ What is the perception of the people about re-use of waste?
- ❑ What size of agricultural land is needed if all these wastes were to be recycled?



## 2 Literature Review

### 2.1 Phosphorus occurrences

#### 2.1.1 Phosphorus in the Bio-geosphere

Phosphorus is rare in total bio-geosphere compared to its abundance in biomass (Gumbo 2005). It is widely present on the earth's surface, in rocks, soils, waters, and in living organisms.

Phosphorus does not exist in its gaseous phase under the prevailing conditions on earth. Under most conditions it is exclusively combined in four oxygen molecules, forming the phosphate oxyanion (Valsami-Jones 2004).

Table 2-1 below shows the distribution of Phosphorus in the environment.

*Table 2-1 Phosphorus in the environment, and in natural and anthropogenic materials (% P w/w)*

Environment		Natural materials		Anthropogenic materials	
Air	0.00	Plants	0.05-1.0	Concrete	0.01-0.05
Sea water	0.0001-0.001	Body	1.0	Window glass	<0.01
Rain water	0-0.001	Blood	0.04	Wood ash	4.0-9.0
Igneous rocks	0.1	Bones	12.0	Wrought iron	0.1-0.2
Phosphate rock	10.5-15.0	Teeth	8.0	Steel	0.02-0.05
Soil	0.02-0.50	Brain	0.3	Sewage sludge	2.6
Meteorites	0.2	Milk (cow)	0.1	(dried)	
		Brewer's			
		Yeast	1.8		

*Source: (Valsami-Jones 2004)*

Phosphorus is ranked the eleventh element in abundance in the earth's crust mainly in the igneous rocks. The main types of rocks of importance are igneous and sedimentary rocks. These rocks are commercially mined for Phosphorus in many countries in the world. The main commercial markets are at present in the U.S.A, Morocco, China, Russia and South Africa (see table 2-3) (United States Geological Survey website)<sup>a</sup>.

The world reserve for Phosphorus is somewhat declining due to over-mining for various purposes (Gumbo 2005). The biggest reserve base is in Morocco with an estimated base of 42 % (Table 2-2). It is estimated that the current reserves that can be exploited vary from 100 – 250 years depending on the level of human activities. The continued phosphorus production without any means of recycling will likely stop to exist within 50 years (Gumbo 2005, Ecosanres website<sup>b</sup>).

<sup>a</sup> [http://minerals.usgs.gov/minerals/pubs/commodity/phosphate\\_rock/phospmcs05.pdf](http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/phospmcs05.pdf) (Accessed on 2005 august 6)

<sup>b</sup> <http://www.ecosanres.org> (Accessed on 11/2/2006)

Table 2-2 below shows the world reserve in the year 2004.

Table 2-2: Phosphorus production & reserves based on 2004 estimates.

	<i>Production</i>	<i>Reserves</i>	<i>Reserve base</i>
USA	37000	1,400,000	4,000,000
Morocco and Western Sahara	23,000	5,700,000	21,000,000
China	25,000	6,600,000	13,000,000
Russia	11,000	200,000	1,000,000
Israel and Jordan	9,800	1,080,000	2,500,000
Tunisia	8,000	100,000	600,000
Brazil	5,650	260,000	370,000
South Africa	2,600	1,500,000	2,500
Others	15,950	1,160,000	5,030,000
World total (rounded)	138,000	18,000,000	50,000,000

(Source: United States Geological Survey website)<sup>c</sup>

From Table 2-2 above, USA produces 27 % of the total world production of Phosphorus followed by China and Morocco, each producing about 18 % of the total Phosphorus.

### 2.1.2 Phosphorus in the environment

The elemental Phosphorus combines spontaneously and vigorously with oxygen to form  $P_2O_5$ , which combines with water to form ortho-phosphoric acid.

There are many different forms or complexes of Phosphorus, which are normally considered. These include:

- Dissolved orthophosphate expressed as DP- $PO_4$  (which include  $H_3PO_4$ ,  $H_2PO_4^-$ ,  $HPO_4^{2-}$  and  $PO_4^{3-}$ ).
- Total Dissolved Phosphorus (including DP- $PO_4$ , Poly phosphate from detergents and dissolved organic Phosphate).
- Particulate organic Phosphorus (POP).
- Particulate inorganic Phosphorus (PIP).
- Total Phosphorus (refers to total dissolved phosphorus plus Particulate Phosphorus).

Particulate organic phosphorus and particulate inorganic phosphorus are rarely considered in P budgets. Orthophosphates are commonly analysed and form the basis of P budgets. The level of these phosphates in natural water is low ranging between 1 and 24 mg P/m<sup>3</sup> (Gumbo 2005).

<sup>c</sup> [http://minerals.usgs.gov/minerals/pubs/commodity/phosphate\\_rock/phospmcs05.pdf](http://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/phospmcs05.pdf) (Accessed on 2005 August 6)

## 2.2 Phosphorus cycle

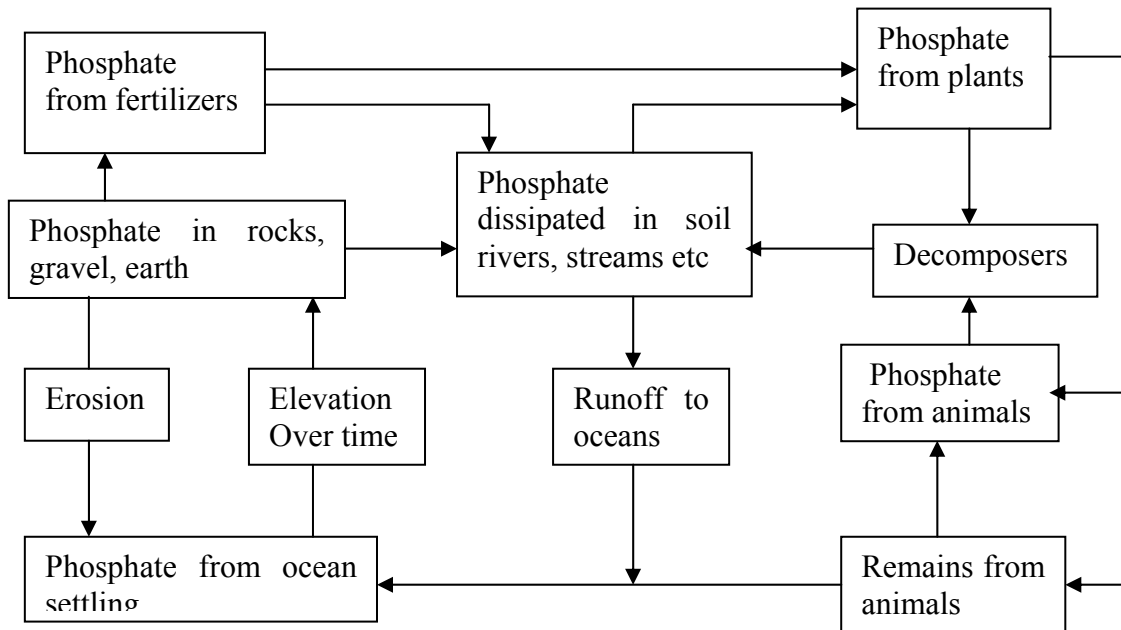


Figure 2-1: Phosphorus cycle (Source: Mississippi state university website (msu) <sup>d</sup>)

From Fig 2-2, the Phosphorus from the rocks, gravel and minerals is released to the environment through weathering, erosion and dissolution. The dissolution process requires the presence of  $H^+$ , which can originate from the soil itself or from the roots or the microbes.

Phosphate rocks can also be mined to make fertilisers, which are applied to the farms as source of nutrients.

Phosphates taken up by the biota are transformed into the organic form of Phosphorus. In the food chain the plants are eaten by grazers such as herbivorous who in turn are eaten by the carnivores. Herbivores and carnivores excrete phosphorus as a waste product in urine and faeces. Phosphorus is released back to the soil when plants or animal matter decomposes and the cycle repeats.

Phosphorus in the soil may be transported via rivers and streams into the oceans where they accumulate in form of insoluble Phosphate. In the deep sea, the phosphorus may be buried and become less available to plants. The phosphorus can only be retrieved again through major geological events such as mountain formation, followed by renewed weathering (Hootsmans 2005).

<sup>d</sup> <http://msuare.com/crops/soils/images/phosphorus.gif> (Accessed 2005 on August 6)

## 2.3 Phosphorus in the soil

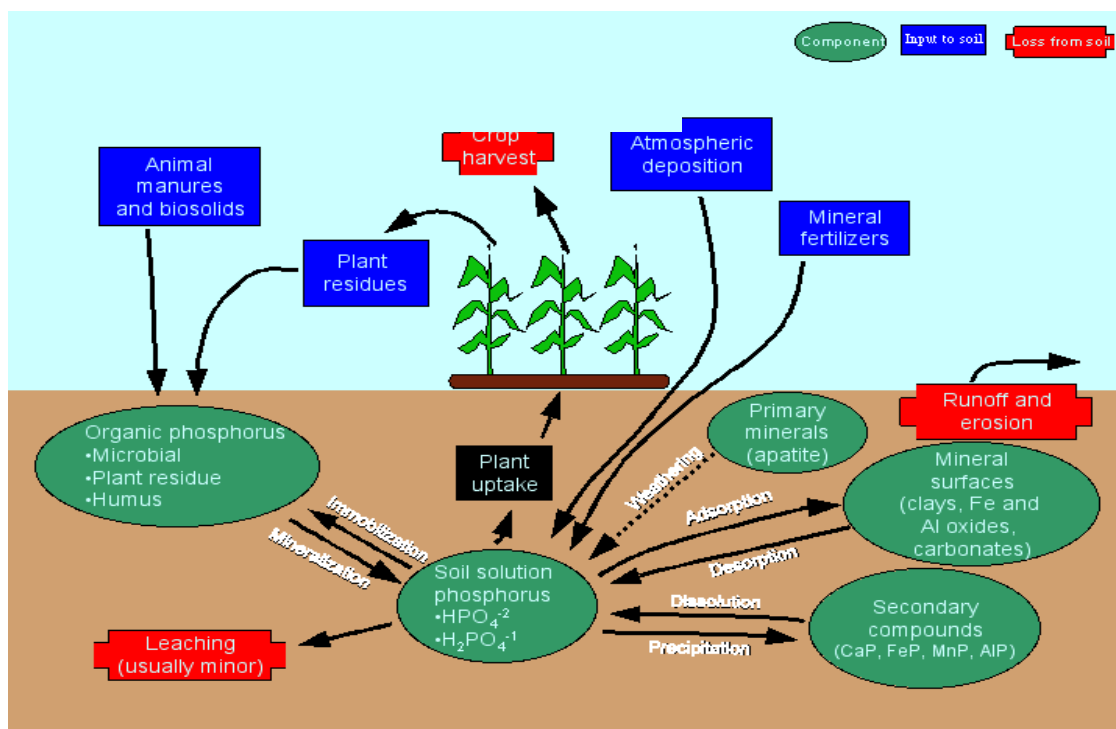


Figure 2-2: Phosphorus cycle in the soil

Source: Mississippi state university website (msu) <sup>e</sup>

Figure 2-1 gives the Phosphorus dynamics in the soil profile.

Phosphorus exists in soils in inorganic and organic forms. From Fig 2-1 above the organic forms of P are found in humus and other organic materials (or recently added organic debris coming from plants or animals). In natural conditions Phosphorus in the soil is present at relatively low concentrations, 100-3000 mg/kg (Valsami 2004) and its availability to plants is controlled by the sparingly soluble properties of Phosphorus.

When water-soluble phosphorus is added to the soil in form of fertilisers or manures, it goes first into the soil solution and then distribute between the readily available and the less readily available pools of P (Valsami-Jones 2004).

The readily available- P is taken up by plants and the remainder becomes adsorbed to soil particles. Where this adsorption is weak, the phosphorus can transfer back into the soil solution. Further reactions lead to absorption (assimilation) with stronger bonds making the phosphorus less readily available. These reactions depend on the type and size of the mineral particles, the presence of the other elements such as Al, Fe and Ca, soil acidity and organic matter.

<sup>e</sup> <http://msuaires.com/crops/soils/images/phosphorus.gif> (Accessed 2005 on August 6)

The organic matter in the soil contains phosphorus in a form, which is not readily available for use by the plants. The organic matter can be associated either with soil organic matter (humus) or recently added organic debris coming from plants or animals. The organically bound phosphorus becomes available to the plants through soil microbes and cultivation. An enzyme, phosphatase is responsible for hydrolysing complex organic phosphates (Gumbo 2004, Miller et al 1990).

The inorganic form may be either as phosphate minerals (Ca, Fe or Al) or adsorbed in soil particles (clay). There are more than 179 Phosphate minerals that have been identified in the soil. In all its natural forms, including organic forms, the Phosphorus is very stable or insoluble (Holford 1997).

The behaviour of P in the soil can be explained by adsorption –desorption reactions (Valsami-Jones 2004). Inorganic Phosphorus is negatively charged in moist soils. Phosphorus reacts readily with positively charged iron (Fe), Aluminium (Al) and Calcium (Ca) ions to form relatively insoluble compounds. When this occurs, the phosphorus is considered fixed and less available for plant uptake. This reaction is influenced by the pH of the soil. At low pH, the reaction favours the formation of insoluble Phosphates whereas at high pH, the Phosphorus exists as orthophosphates ( $\text{HPO}_4^{2-}$ ,  $\text{H}_2\text{PO}_4^-$ ), which are readily available to plants.

Soil Phosphorus is mostly available to plants at pH values of 6 to 7. At higher pH (above 7.3), the phosphorus is increasingly made unavailable by fixation with calcium to form calcium phosphates. At lower (less than 6), the Phosphorus is fixed by the reactions with Aluminium (Al) and Iron (Fe) to form aluminium phosphate and iron phosphates respectively (Miller et al 1990).

Studies (Sahrawat et al 1996) have shown that Phosphorus becomes less available to plants such as rice in acidic soil (low pH). However when urea is added to acidic soil, the P availability increases until the soil pH reaches 6.5 where the availability of the same decreases. (Ouyang et al 1999, Otto et al 2001, Kogbe et al 2003).

## **2.4 Importance of phosphorus to organisms**

Phosphorus is an essential part of nucleoproteins in the cell nuclei, which control cell division and growth and the deoxyribonucleic acid (DNA) molecules, which carry the genetic make up in living organisms.

In plants, phosphorus is essential for stimulation of early root growth, hastening plant maturity, in energy transformation within the cells and in fruiting and seed production. In animals that get phosphorus by eating the plants, phosphorus is critical for bones and teeth, which are mostly calcium phosphates (Miller et al 1990, Valsami-Jones 2004).

In the human body Phosphorus provides a variety of functions such as nerve conduction, muscle contraction, and act as cofactors in enzyme-catalysed reactions and also as a structural element in the body. Since it is found as calcium phosphate crystal, in bones and teeth, it forms the cement that contributes to the physical strength of these structures.

The body of an average man weighing 70 kg contains about 780 g of P, of which about 700 g are present as bone apatite (bone, dentine and tooth enamel) (Valsami-Jones 2004). This translate to 1.1 % of our body is made up of phosphorus of which 90 % is in bones.

Table 2-3: Recommended daily intake of phosphorus for humans

Group	Age (years)	g P/p.day
Infants	up to 1yr	0.2-0.5
Children	1-10	0.7-1.0
Males	10-18	1.2-1.4
	18-75	0.8
Females	10-18	1.2-1.3
	18-75	0.8
Pregnancy		+0.4
Lactation		+0.5

Source: Griffith et al 1973, Gumbo 2005

## 2.5 Phosphorus in household systems

### 2.5.1 Foods and Beverages.

It has been established that the main source of Phosphorus in household system is food and beverages. Different food components have different P contents. A comparison of P contents in food components also varies from country to country (Griffith et al 1973, Gumbo 2005). Table 2-4 shows the P contents of different food components in USA and Zimbabwe.

Table 2-4: Phosphorus content of representative foods

Food group	Types	USA (g P/kg)	ZIMBABWE (g P/kg)
Cereals	Maize flour	0.57	2.20
	Rice	0.28	-
	Bread (whole wheat)	2.58	1.21
Eggs		2.05	2.1
Milk	whole milk	0.93	0.95
Meat	beef	2.5	1.94
Fish	all kinds	1.9-2.48	1.13
Starchy roots	potatoes	0.53	0.51-0.56
Vegetables	peas	0.99	0.63
Nuts	groundnut - dried & roasted	-	3.54
Pulses	beans	1.35	5.41
Beverages	Beer from maize & sorghum (2% alcohol, w/w)	-	0.13

Source:

(Griffith et al 1973)

(Gumbo 2005)

## 2.5.2 Phosphorus in faeces and urine.

The amount of faeces and urine depends on a person's age, diet and health (Jonsson et al (2004). A less digestible diet will have more faeces than the urine and vice versa. The amount of urine excreted by a person depends on the time, food consumed, person's physiological activity and environmental conditions. For example excessive sweating during a hot season results in concentrated urine.

The average volumetric urine excretion rate is 0.4 l/d. This rate is increased when there is a high water and salt intakes and a protein rich diet. The volume rate is lower during the night than during the day (Gumbo 2005).

The amount of faeces is also dependent on the transit time (from mouth to anus). The daily stool mass may be as high as 260 g/pd in a mixed diet. It may even come as low as 10-22 g/pd after prolonged fasting (Palmquist et al 2003, Gumbo 2005).

The total amount of nutrients excreted by humans (urine and faeces) can be estimated using the following equations:

$$N = 0.13 * \text{Total food protein}$$

$$P = 0.011 * (\text{Total food protein} + \text{vegetal food protein})$$

The above equation was developed by Jonsson et al (2004) based on Food and Agricultural Organization statistics.

Urine represents only 1% of the volumes flow in the household wastes but contributes 80 % of nitrogen, 50-90 % of phosphorus and 80-90 % of potassium (Maure et al 2002, Vinneras 2002). Faeces are the second highest contributor of the nutrients in the household wastes.

Phosphorus in faeces and urine ranges from 0.1-0.2 to 0.3-0.4 kg P/ca.yr (Maure et al 2002, Palmquist et al 2003, Jonsson and Vinerras 2004, Gumbo 2005) (Table 2-5, Table 2-5)

Table 2-5: Typical values for the major nutrients in urine

Element	% in urine	g/ Pd	Conc (g/m <sup>3</sup> )	Conc mmol/l
N	80	8.8	8180	584
P	50-80	0.7	670	21.6
K	80-90	2.3	2160	55.2

Source: Maure et al 2002.

Even though faeces contain less nutrients than urine, the humus produced from faeces contains higher concentration of phosphorus and potassium (Winblad et al 2004). The amount of nutrients (N, P, K) in faeces and urine varies from country to country as this is largely influenced by the diet (Table 2-6) According to Gumbo (2005), an average adult of 60 kg excrete phosphorus in urine at a rate of 0.76 g/d (0.277 kg/y/capita). The amount of phosphorus in urine depends on the diet and this has been shown to vary from countries to countries (Table 2-6).

Table 2-6 below shows the different loadings of nutrients from faeces and urine in different.

Table 2-6: Estimated excretion of nutrients per capita in different countries.

Country		Nitrogen kg/cap, yr	Phosphorus kg/cap, yr	Potassium kg/cap, yr
China, total		4.0	0.6	1.8
	Urine	3.5	0.4	1.3
	Faeces	0.5	0.2	0.5
Haiti, total		2.1	0.3	1.2
	Urine	1.9	0.2	0.9
	Faeces	0.3	0.1	0.3
India, total		2.7	0.4	1.5
	Urine	2.3	0.3	1.1
	Faeces	0.3	0.1	0.4
South Africa, total		3.4	0.5	1.6
	Urine	3.0	0.3	1.2
	Faeces	0.4	0.2	0.4
Uganda, total		2.5	0.4	1.4
	Urine	2.2	0.3	1.0
	Faeces	0.3	0.1	0.4

Source: (Jonsson and Vinerras 2004).

More than 95 % of phosphorus in urine is in the form of inorganic phosphates. The other nutrients are; nitrogen as urea, phosphorus as super-phosphate and potassium in ionic form. These ionic compounds are the correct forms required by the plants.

### 2.5.3 Phosphorus in grey water

Grey water is defined as wastewater without any input from toilets, which means that it corresponds to wastewater produced in bathtubs, showers, hand basins, laundry machines and kitchen sinks, in households, office buildings, schools etc. The total grey wastewater has been estimated to account to about 75 % v/v of the combined sewage (Erikson et al 2002).

The exact composition of grey water is influenced by the users' behaviour (e.g. type and amount of soaps), water-saving measures and the source of grey water (bath and shower, kitchen) (Eriksson et al 2001).

Studies (Nolde 2000) in Berlin, Germany have shown that untreated grey water (composed of wastewater from bath tubs, showers but excluding toilet flushing and kitchen wastewater) contained low nutrients with phosphorus concentration of 0.2-0.6 mg P/l and nitrogen concentration of 5-10 mg P/l.

Similar studies by Erikson et al (2002) and Carden et al (2005) found the total nitrogen in grey water (including kitchen wastewater) to be in the range of 0.6-74 mg/l and the phosphate levels of 1-5 mg P/l. The kitchen wastewaters contributed the highest levels of nitrogen ranging from 40-74 mg N/l.

The main source of phosphorus found in grey water is from washing detergents. In countries where detergents containing phosphorus are being used, the P-concentration in waste water ranges from 6 -23 mg Tot P/l as compared to a range of 4-14 mg/l where the use has been banned (Erikson et al 2002).

In the Netherlands, the composition of grey water has low concentration of nutrients with Kj-N and total PO<sub>4</sub>-P amounting to 19.6 and 3.3 mg/l respectively (Elmitwalli et al 2003).

#### 2.5.4 Phosphorus in solid waste

Solid waste from households consists of paper and polythene bags, organic materials, textile, wood products and metals. A high percentage of the solid waste is composed of organic material, mainly the remnants of food materials.

The organic materials in the solid waste are responsible for the P- loading to the environment (Gumbo 2005).

In solid waste, the biodegradable fraction can be composted in order to recover valuable nutrients for use in agriculture.

Similar studies done in different cities in China show an average municipal waste generated per capita amounted to 1.0 kg/ day. According to Gumbo (2005), the average solid waste per capita in Zimbabwe is quite low (0.2 kg/day) and this was comparable to the solid generation rate in Sweden (0.22 kg/p day) (Vineras et al 2002).

Solid waste generated amount to about 5480 kg P/ years whereas detergents contributed 1860 kg/ year (Gumbo et al 2001).

## 2.6 Re-use option of waste containing Phosphorus.

### 2.6.1 Introduction

Conventional treatment of municipal and industrial waste is effective in removal of suspended solids and BOD to a magnitude of 90 % but it is much less effective in N and P removal, estimated at between 20-40 %. Treated water should meet the limits of the intended use (Table 2-7).

Table 2-7: Typical treatment as function of intended use

Contaminant	Discharge surface water quality		Discharge in waters sensitive to eutrophication	Effluent use in irrigation & aquaculture
	High quality	Low quality		
BOD mg/l	20	50	10	100
TSS mg/l	20	50	10	<50
Kjeldahl-N mg/l	10	-	5	-
Total N mg/l	-	-	10	-
Total P mg/l	1	-	0.1	-
TDS mg/l	-	-	-	< 500
F.Coliforms/100ml	-	-	-	<10 <sup>3</sup>

Source: Veenstra (2002)

Other methods include

- Phosphorus removal by chemical precipitation with salts of iron (e.g. ferric chloride) or aluminium (e.g. alum).
- Enhanced biological phosphorus removal (EBPR) technique. This process use specific bacteria, called polyphosphate-accumulating organisms, which are

selectively enriched and capable of accumulating large quantities of phosphorus within their cells. Their biomasses have a high fertiliser value.

Recent studies have shown that the EBPR technique shows 3 to 4 fold enhanced levels of P uptake by the bacteria and the bi-product might serve as a potential raw material for P-recycling in fertilizer or detergent industries (Mcgrath et al 2000)<sup>f</sup>.

The cost of conventional treatment is high making it not feasible to be applied in household systems without sewer system.

The option available is either to avoid pollution or to explore a possibility of re- use of nutrients and probably close the loop (Gumbo 2005).

### **2.6.2 Grey water**

Grey water reuse is getting a wider attention in different parts of the world. It is emerging as an integral part of water management. Grey water is now widely in use in many countries such as Japan, Germany and Australia (Jefferson et al 2000, Nolde 2000).

Common water reuse applications include agricultural and landscape irrigation, industrial recirculation of process waters and ground water recharge. In Canada, grey water is mainly used for agricultural irrigation applications (Exall 2004).

Wastewater should be treated before reuse to avoid adverse effects of pathogens or pollutants. Crops that have been irrigated with untreated grey water should not be eaten raw. This is strongly advocated in France in order to protect people from any potential health hazards (Bountoux et al 1996).

Treatment of grey water is being done in UK using coarse filtrations plus disinfections systems. This treatment option removes all indicator organisms making it potentially safe for reuse. Further more recovery and reuse of the grey water has been shown to safe up to 33 % of water (Jefferson et al 1999).

Processes for wastewater recycling ranges from simple systems in single houses to very advanced treatment systems for large scale re-use. In U.K coarse filtration plus disinfections system is widely in use. This technology could safe water in the range of 3.4-33.4 %. It was also observed that even though there was less or no removal of chemical/biological pollutants, the treated water was free of all indicator organisms making it potentially safe for reuse (Jefferson et al 1999).

### **2.6.3 Human Excreta**

In human waste, faeces (black water) and urine (yellow water) are normally considered for re-use due to their nutrients contents. They are usually separated into their fractions before being re-used in agriculture. Each fraction of the excreta requires different ways of handling, storage and treatment before re-use.

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<sup>f</sup> [http://questor.qub.ac.uk/webpages/questortools/projects/E\\_phosphorus/](http://questor.qub.ac.uk/webpages/questortools/projects/E_phosphorus/) ( Accessed 2005 August 18)

### 2.6.3.1 Faeces and urine

Faeces and urine may contain a variety of pathogens that can be a health hazard when applied directly to crops. Care must be taken to ensure that such pathogens are not transferred to the farms and eventually to the crops.

In a healthy individual the urine is sterile in the bladder. When transported out of the body different types of dermal bacteria are picked. Freshly excreted urine contains bacteria at levels not considered to constitute a significant health problem (Schonning 2002). However, prolonging the storage period (Table 2-8) makes it potential for reuse without little risks (Schonning 2003).

Faeces contain most of the pathogens in human excreta and are the main source for transmission of enteric infectious diseases and parasites (Winblad et al 2004).

Table 2-8 provides the storage period for urine recommend before reuse.

Table 2-8: Storage period for urine

<b>Storage crops Temperature</b>	<b>Storage Period</b>	<b>Presence of pathogens in the urine mixture</b>	<b>Recommended</b>
4 °C	≥ 1 month	Viruses, protozoa	Forage and food crops that are to be processed.
4 °C	≥ 6 months	Viruses	“
20 °C	≥ 1 month	Viruses	“
20 °C	≥ 6 months	Probably none	All crops

(Source: Schonning 2003)

Urine is being used for crop fertilisation in a number of countries like Mexico, Germany, USA, Sweden, Denmark and Zimbabwe. In some countries like South Africa, urine is still not being widely accepted to be used in agriculture owing to different perception of the people (Winbad et al 2004).

The concentration of urine and the frequency of application in farms influence the yield of certain crops. Studies carried out by Mnkeni et al (2005) revealed that there is a highest yield for spinach and cabbage when urine diluted at a ratio of 1:3 (urine: water) was applied once a week for about one month. They further observed that application of urine lowers the yield as it makes the soil saline. According to Oldenburg et al (2003), urine needs to be mixed with animal manure before being applied on the farmlands if maximum yield is to be realised. The nutrients in the urine are in the ionic forms which are readily available to plants (Degaard 2003, Gumbo 2005).

The faeces have to be treated by storage, composting to elevate the temperature, addition of ash or other material to increase the pH and incineration where the ash may be used as a fertiliser (Schonning 2003). Composting of faeces has been done using different techniques.

In Ghana, different methods of composting of faeces such as, barrel composting, brick built composting bin, is being used by communities in Peri-urban areas (Bradford et al 2003, Danso et al 2003). There are also composting toilets which have been developed

and applied. In Germany composting toilets are offered since 1980 and are mainly installed in family houses (Berger 2003). Another approach is the use of “Arbaloo” type of toilet. This is a portable toilet structure, which is placed over a shallow pit (0.6-1m deep). Once it is nearly full, it is moved to a different site and a tree or banana is planted in soil and placed over the pit contents (Morgan 2003).

Human faeces and urine needs to be separated from the source to minimize contamination. Many methods are available for separating faeces from urine; solid-liquid separation.

- Separation by Aquatron (a method which separates solids from the liquid using a combination of a whirlpool effect, surface tension and gravity), filtration, floatation and sedimentation were investigated for their efficacy in recovery of faecal nutrients. The Aquatron and filtration gave a fraction of separated solids with 10 % dry matter, which contain 70-80 % plant nutrients (N, P, and K).
- Use of urine-diverting toilets, the potential of recovery of local nutrients from household wastewater is 88 %N, 75 % P, and 55% K mainly in the form of directly plant available nutrients (Vinneras et al 2002).

Flotation and sedimentation are not functional techniques for local separation of faecal plant nutrients from flush water.

The methods of application are (i) either direct application on the crops or top application after fermentation in a ditch for certain period (ii) composting with crop stalk for basal application and (iii) direct usage as feed for fish in ponds (Shiming 2001).

In all these types of techniques, the nutrients are recovered and reused as a source of fertilisers to the plants. It has been shown that collection and reuse of faeces and urine can recover up to 85 % N, 75 % P, and 75 % K from the household system (Vinneras et al 2002).

## **2.7 Benefits of Recycling of P containing wastes**

Improved recycling of phosphorus in wastes from urban areas and refuse from animal production to agricultural land would help to close the nutrient loop in the soil-crop-animal-human-soil cycle. Phosphorus, which is released, as waste can be re-used hence reduce the effect of pollution in the environment (Günther 1995).

Over application of phosphorus materials may exceed the binding capacity of the soil as it has happened in other countries such as Netherlands, where this capacity has already been exceeded (Kelderman 2005).

Excess application of phosphorus accumulates in the soil and become a source of non-point pollution. It is therefore necessary to ensure that the treated wastewater meets set guidelines depending on their intended use.

### 3 Materials and Methods

#### 3.1 Introduction

The research was conducted in Kibera from October to December 2005. The methodology used to collect the necessary data for this research included:

- Desktop study to get information about the study area (baseline information).
- Household interviews
- Analysis of water and soil samples
- Direct observations.

#### 3.2 Baseline information

During the three months study, several visits to a number of institutions including government bodies/ agencies, were done to get data or information necessary to conduct the research. The following is a detailed list of data collected, which formed a baseline for the Kibera study.

*Table 3-1: desk study*

No	Document/information	Source	Information obtained
1	Census report	Central bureau of statistics (CBS)	- Population size - Age structure - Area in sq. km - Male/female ratio - Population density
2	Rainfall pattern	Meteorological department	- Annual precipitation over the study area
3	Environmental guidelines	Kenya bureau of standards	- National and international Standard guideline documents
4	Administrative/social arrangement	Divisional office, Kibera	- Social organization - Authority to access the study area

### 3.3 Description of the study area (Kibera Slum)

#### 3.3.1 Kibera in general

Kibera is one of the largest low-income areas in East Africa. It is located at Lat  $1^{\circ} 19'14''$  South, Long  $36^{\circ} 47'34''60$  E at an altitude of 1785 m.



(c) Map of Nairobi showing the study area, Kibera,

Figure 3-1: The location of the study area in the map of Nairobi Kenya

Source: Hass Consult website<sup>g</sup>

<sup>g</sup> <http://www.hassconsult.co.ke> (Accessed on 2006, April 4)

**A SKETCH OF SAMPLING LOCATIONS IN KIBERA**

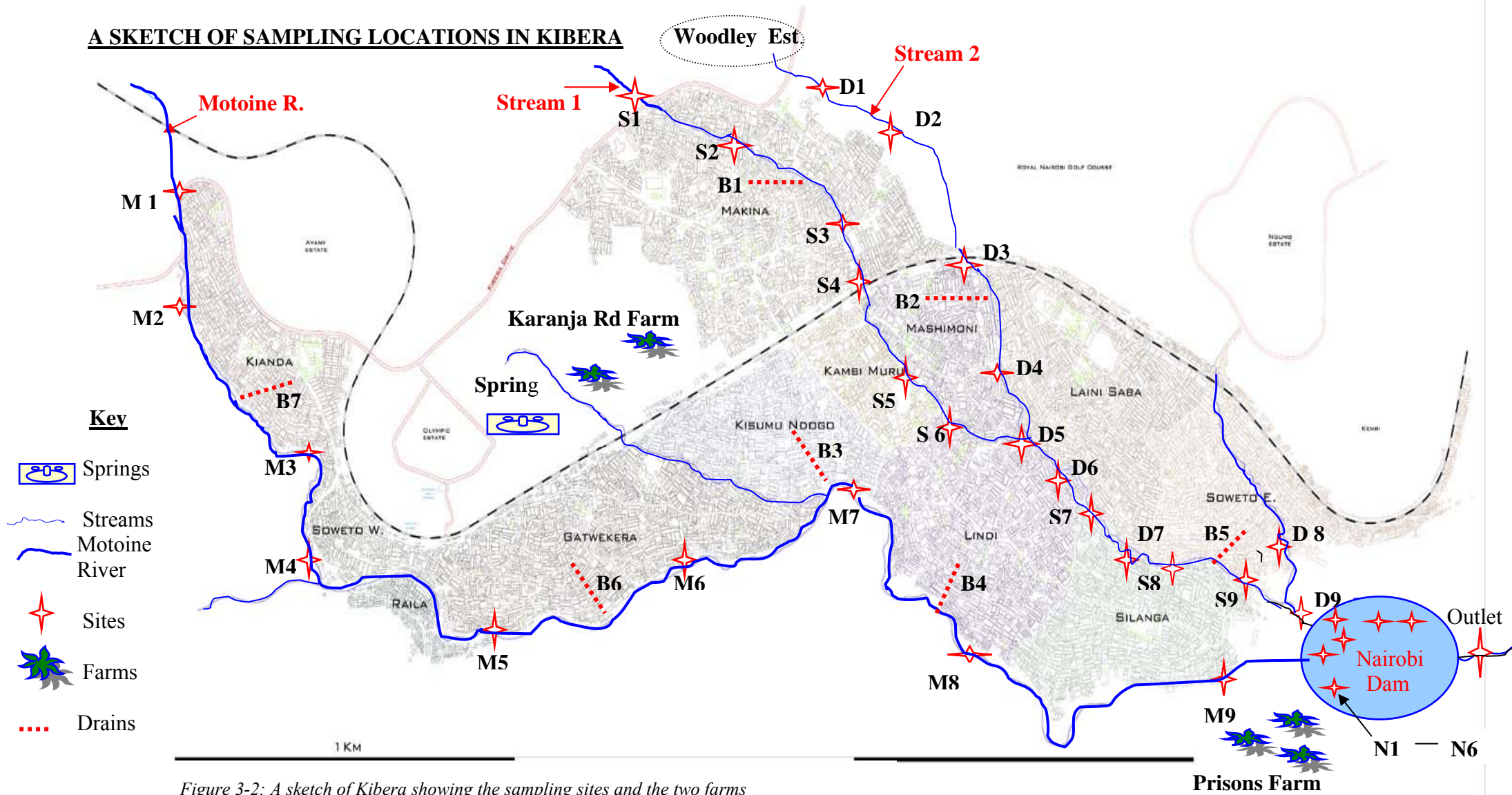


Figure 3-2: A sketch of Kibera showing the sampling sites and the two farms

Source: <http://www.csgkibera.org/maps.html> (Accessed on 2006 April 5)

BY ALESSANDRO PERINELLI - TECHNICAL UNIVERSITY OF VIENNA - BASED ON 2003 AERIAL PHOTOGRAPHY

“Kibera” is a word derived from Nubian language to mean “forest”. This was a place ‘where Nubian soldiers from Nubian highlands in Sudan who were serving in the British army were settled. The place is now direct opposite of the forest that it was, due to a highly congested slum with no proper sanitation. It is situated approximately 10 km from the capital city, Nairobi (see Fig3-1). The houses are unplanned and are crowded with hardly any space to allow for access roads (see Plate 3-1, 3-2 below).



Plate 3-1: *Queuing for water in front of a pipe*



Plate 3-2: *Crowded settlement in Kibera*

The settlement developed along the Motoine River and near the Nairobi dam, which was a source of water for domestic and agricultural needs to the Nairobi residents.

Most of the houses are made of mud and roofed with either corrugated iron sheets or covered with polythene papers.

There are no sewerage toilets in a larger part of the area except in a few estates (Karanja Rd, and Olympic estates) served with a sewer system. About 80 % of the latrines are emptied manually by directing wastewater into the drainage channels directly into the river while others are simply covered and abandoned (Krhoda 2002).

The drainage system in the settlement comprises; shallow open natural drains, man-made drains and combination of both. Drains are often used as dumping points of solid waste and sludge and in a few cases open channels are used for emptying sewage from latrines.

There is no regular solid waste collection within the settlement. Most residents dispose off solid waste by dumping it in open drains that end up in the stream.

According to a study carried out by NETWAS (2002)<sup>h</sup> the stream is extremely polluted by uncontrolled disposal of human excreta and solid waste from the slum. The residence cannot afford to engage in farming for food in the surrounding areas due to high cost of fertilizers (Dennry 1995, KWAHO 2005)<sup>i</sup>.

### 3.3.2 Climatic conditions

The meteorological information describing the Kibera area has been derived from records held at the Wilson Airport and the Dagoretti K. Meteorological stations. The

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<sup>h</sup> [http://www.unep.org/roa/Nairobi\\_River/docs/ms\\_word/NETWAS%20document1.doc](http://www.unep.org/roa/Nairobi_River/docs/ms_word/NETWAS%20document1.doc) (Accessed on 2005, August 5)

<sup>i</sup> Kenya water for Health and Organisation (KWAHO 2005) <http://www.kwaho.org/loc-d-kibera.html> (Accessed on 2005, October 6)

two stations are located at about 10 km from Kibera. These records span over a long period of time dating back to 1955 up to 1980 (Appendix A).

The study area (Kibera) falls under a wet climatic zone. The average rainfall is 970 mm per annum (ranging from 900-1000 mm/yr). Long rains fall between April and May with the short rains coming between November and December. The daily maximum temperatures range from 20.6 °C in July to 25.6 °C in March. The minimum temperatures range from 10.1°C to 14°C according to the Dagoretti Meteorological stations. The relative humidity ranges from a daily maximum of 88 % in May to a daily minimum of 36 % in April.

### **3.3.3 Population distribution**

Kibera has an estimated population of 200,000 (based on the 1999 census report; see Appendix A). The population has been growing at 5 % due to urban migration. There are eight villages indicated in the last (1999) census report, though another estate called Raila estate is coming up. Some of the villages (Silanga and Gatwekeira) have high population density than the others ( Mashimoni and Makina) (see Fig 3.2, Appendix A).

### **3.3.4 Nairobi dam**

Nairobi dam was commissioned in 1953 as a reservoir for water supply to the city of Nairobi (Fig 3-2). It was designed for a total water surface area of 356,000 m<sup>2</sup> at an average depth of 2.76 m. The dam inlet is at about 1700 m while the dam crest is about 1680 m above sea level (Khroda 2002).

It is currently heavily silted with sediments from erosion and solid waste dumping. Consequently it has been invaded by water plants such as water hyacinth and is no longer suitable for recreational activities such as diving, sailing, sport fishing and water sports activities (Howard, 2003).

During the period of the study, it was evident that the dam is choked with solid waste and some highlands have developed where people grow arrowroots and fodder (Napier grass) for animal feed.

### **3.3.5 Motoine River**

Motoine River flows through the Nairobi showground into the slum through Gatweikira slum and cutting across Olympic village all the way to the dam (Fig 3-2). Motoine River is the biggest river in this area often swelling and becoming impassable during rainy season. It originates from the Motoine swamp and Dagoretti forest and passes through agricultural farms and other settlements before entering Kibera slum.

The river basin up to the dam is 26.7 km long and not more than 5 km wide (Khroda 2002). The river marks the boundary between Kibera and the middle class Langata estates. It is along this river where people grow sugarcane, fodder, arrowroots and vegetables especially on the Langata side. The river however is highly polluted with a high nutrients and high coliform counts (NETWAS 2002) <sup>f</sup>.

### **3.3.6 Other streams**

There are many other small streams passing across the study area (Kibera) but only two major ones were considered in this study (see Fig 3-2).

#### **Stream 1**

This is a stream, which enters the slum at Makina village and meanders through the Kericho Ndogo (a name referred to by the residents), passing Mashimoni village, Laini saba, Silanga and finally to the Nairobi dam (Fig 3-2).

#### **Stream 2**

This second stream enters the study area from Woodley estate through a site adjacent to the district officer's office, and then enters through Kabarnet garden, golf course before re-emerging at Laini saba village. From here it flows downstream and joins stream 1 at Lindi, before finally entering the dam (Fig 3-2).

#### **Open drains**

As you crisscross the slum, one sees dirty water flowing in open drains arising from bathrooms or washing (Fig 3-2). The bathrooms are just structures of corrugated iron sheets built outside the houses. These wastes flow freely into the streams or rivers and obviously contribute to the loading of nutrients in the dam.

## **3.4 Methodology**

### **3.4.1 Introduction**

The aim of this study was to collect data on materials flows within a household system. The materials considered included food and beverages, soaps and detergents; water and solid wastes. A series of interviews were conducted on a sample of the population deemed to be representative. A two way approach was used; one involving monitoring of five selected families and the other using questionnaires on a wider sampling area.

### **3.4.2 Selection of the Research assistants**

Three research assistants were recruited for the surveys. The team was selected based on their educational qualifications (certificate and diploma level) and experience on similar surveys. One of the assistants was born and brought up in Kibera. In order to ensure proper survey was done, a two-day preliminary survey with the research assistants was carried out and the outcome evaluated. The details of their personal profiles are given Appendix C.

### **3.4.3 Selection of families**

Five families were selected from five villages namely; Makina, Gatweikera, Silanga, Mashimoni and Kibera. The details of the selected families are given in Table3-2 below. The villages were chosen based on their population and the location within Kibera.

Table 3-2: Details of the selected families

		Family 1	Family 2	Family 3	Family 4	Family 5
Size		1	7	6	3	6
Gender structure	Male	1	5	3	2	4
	Female		2	3	1	2
Age structure	< 14 yrs		3	2	1	
	15-65 yrs	1	4	4	2	6
	Above 65 yrs					
Source of income	Head of family	Employed	Business	Employed	Employed	Employed
	Other members		Dependants	Business		2 - working
Monthly Income (in Euro)		60	250	150	120	200
Farming, if any		None	Garden (plot size)	None	None	None

An initial random survey was conducted in the five villages in order to select households meeting the set criteria and also those who were willing to participate in the survey. The criteria for selection of the families and the detailed profiles of the families are given in Appendix C.

#### 3.4.4 Monitoring of selected families.

The five selected families were briefed on the aim of the study in order to minimise the possibility of wrong information given. It was noted that a number of people were only willing to give information in exchange of money. It was an initial challenge to convince interviewees that the study was purely for academic purposes.

The families were asked to indicate the type and quantity of food they consume, the amount of water they use and the type of soaps and detergents they use on a daily or weekly basis.

They were also provided with disposable polythene bags for solid waste disposal. An inventory detailing the food and materials in each household was designed and given to them. All the research assistants were living in these areas and therefore the daily and weekly (solid waste) monitoring was possible.

Summary of the material inventory used by the families is given in Appendix D.

#### Household interviews

In the structured interviews, w8 villages were covered (Kibera, Makina, Silanga,Lindi, Laini Saba,Gatwekeira,Olympic and Mashimoni) (Fig 3-2). We interviewed people in the villages according to the population. In an attempt to give equal chances to all the families, a systematic sampling technique was used whereby, for every 200 houses one household was chosen. A total of 155 people were interviewed and a number of observations were made.

Most questions were closed questions in a multiple-choice format, so that the respondents had only to tick for the answer they deemed appropriate.

The results of the interviews were analysed using SPSS and Excel spreadsheet.

Table 3-3: Overview of questions from the questionnaire

Data group	Description
Personal data	Sex, age structure, household size, income
Food and beverage	Frequency of consumption per week.
Water	Source, daily usage, disposal of waste (grey) water
Soaps and detergents	Common type of soaps and detergents, the amount used per week, different uses.
Solid waste	Most common type of solid waste, approximate amount generated per week and where they dispose.
Re-use option of wastes	Whether they grow crops, crop yields, fertilisers they use, how much they spend to buy, knowledge of re-use of these wastes and finally their perception about the re-use.

### 3.5 Laboratory measurements

#### 3.5.1 General

Different water and soil samples were taken, from different sites and locations, and transported to the laboratory for measurements of ortho-phosphates. The first sampling was done on 22/10/ 2005 and subsequent analysis done one day later.

Analysis was done at Kenya Bureau of Standards' laboratories in Nairobi, which are accredited to ISO 17025 standards by United Kingdom accreditation services (UKAS). This is a standard, which certify that a testing laboratory is technically competent to carry out tests.

#### 3.5.2 Water samples and the stations

##### Sampling sites

A random sampling was done on 22/10/05 covering various sites within the entire study area. The results were used to select the best location to set the sampling sites. However there were other considerations taken into account in setting the sampling sites

Other factors considered include:

- i. Accessibility of the sampling point
- ii. Tributaries joining the river
- iii. Cost effectiveness of collection, transportation and analysis
- iv. Grey water from washing in the homesteads
- v. The kind of vegetation growing along the river/ streams

The sampling points were set in different sites of the river, streams, open drains and finally within the dam. The description of the locations of the sites is given in Fig 3-2.

- a) Motoine river passing through Gatweikira to the Nairobi dam; sites M1-M9
- b) Stream 1; sites S1-S9
- c) Stream 2; sites D1-D9

- d) Open drains; B1-B7
- e) Different sites within the Nairobi dam itself (N1-N4)

### **3.5.3 Water sampling and handling**

Water sampling was done on 17/11/2005 in all the sampling points. On this particular day, there had been heavy rains the previous night and the volume of water in the streams and runoff was quite high.

Water samples were drawn and put into 100ml plastic containers. The first 20ml was used to rinse the container before they were completely filled. The samples were stoppered and stored in cool boxes before they were transported to the laboratory. In the laboratory, the samples were preserved in 2 ml conc.  $H_2SO_4$  and stored in the refrigerator maintained at 4 °C.

### **3.5.4 Soil sampling**

Soil samples were taken from Karanja Rd and Prisons farms study area (see Fig. 3-2). The soil samples were taken, using scooping spoons, from the top 20 cm into 100 ml plastic containers and transported to the laboratory. Samples were taken from different parts of the farm with; maize, sweet potatoes and tomatoes grown and also where the farm was bare without any vegetation cover. A composite sample was taken at each sampling site. In total 10 samples were collected from the farms and transported to Kenya Bureau of Standards laboratories.

### **3.5.5 Test methods**

#### **3.5.5.1 Water analysis procedure:**

Water samples were analysed for orthophosphate ( $PO_4-P$ ) using the ammonium molybdate spectrophotometric method. Samples were treated with 1ml ascorbic acid followed by 2 ml of acid molybdate containing antimony. The antimony-phosphomolybdate complex formed is reduced by the ascorbic acid to form a strongly coloured molybdenum blue complex. The concentration of orthophosphate in the sample was determined by measuring the absorbance of this complex using a spectrophotometer at 880 nm. The reading was done after every 10 to 30 minutes of the development of the colour. The method used could only measure samples within the range of 0.005 to 0.8 mg P/L without the necessity of dilution (USEPA 1983, ISO 6878: 1998).

#### **3.5.5.2 Analysis of soil samples**

1±0.05 g of the dried Soil sample was weighed accurately and put in a 250ml Erlenmeyer flask. 20 ml of extracting solution (0.5 N Sodium hydrogen carbonate solution adjusted to pH of 8.5) was added and the mixture was shaken for 30 minutes. The extracts were filtered using Whatman filter paper 2 into a beaker. A 5 ml aliquot was taken and transferred into a 50 ml volumetric flask. The concentration of Phosphorus was measured using the procedure above. The method has a detection limit of 1.0 mg/kg (soil basis) and is generally reproducible within 8 % (Olsen method) (ISO 11263: 1994).

### 3.5.5.3 Precision and Accuracy

The accuracy and precision of my analysis was achieved using the following quality control checks:

- For each batch of ten samples there was a duplicate sample (acceptance criteria of the duplicates  $\pm 10\%$  of the arithmetic mean)
- Analysis of the samples together with one sample of known concentration ( $Q_c = 3 \pm 0.3$  mg P/l)
- Using a reagent blank in each analysis
- Water used for rinsing and making the solutions was demineralised.

## 3.6 Food and materials flows

### 3.6.1 Food and beverage

The types of food consumed by the people were determined by monitoring the daily consumption of the five households (sec 3.5.2 above) in Kibera slum. The food types were grouped into eight categories according to the FAO database food groups namely: Cereals, Meat and fish, Milk and eggs, Vegetables, Nuts, Pulses, Starchy roots and Beverages (see Appendix D) (FAOSTAT (2002)<sup>j</sup>).

An inventory was made for the quantity of each food category on daily basis for each family (Appendix D).

The value of Phosphorus of each class of food was taken from literature study (sec 2.10.1 above, Gumbo 2005).

Using the P value of each food group, the corresponding P- influx per month was calculated for each family. The average P per capita was then computed using the equation below

$$P_{fb} = \frac{1}{K} \sum_{i=1}^n M_{fb,i} \times \sigma_{fb,i} \quad \text{Equation 3-1}$$

Where

$P_{fb}$  P-influx per capita per month. (g P/p. month)

$M_{fb}$  The quantity of food and beverage per food group consumed by each family per month (kg/ month)

$\sigma_{fb}$  Phosphorus content as P in food or beverage material expressed as a ratio (g P/kg).

K Adjustment factor according to age structure of the family members (see Appendix D).

n Total number of the food groups.

<sup>j</sup> <http://faostat.fao.org> (Accessed on 2005,September 9)

### 3.6.2 Soaps and detergents

The daily use of soaps and detergents for washing of clothes, cleaning and bathing were recorded on weekly basis for the selected families. The families were asked to keep track on the period it took to use the soaps or detergents they purchased. The categorisation of soaps were done based on their use in terms of washing clothes, cleaning of utensils, kitchen wash, mopping of the floor and finally bathing.

The P- content of each soap and detergent, based on literature studies (Gumbo 2005), was used to calculate the P-influx based on the quantities of soaps used. The P value for each category of soap and detergent is given in Appendix D.

The total amount of Phosphorus in the soaps and detergents was then calculated using the expression below:

$$P_{sd} = \frac{1}{h} \sum_{i=1}^n M_{sd,i} \times \sigma_{sd,i} \quad \text{Equation 3-2}$$

Where

$P_{sd}$	P-influx per capita per month. (g P/p. month)
$M_{sd}$	The quantity of soap and detergent used by each family per month (kg/ month)
$\sigma_{sd}$	Phosphorus content as P in soap or detergent material expressed as a ratio (g P/Kg)
n	Total number of soaps and detergents
h	Size of the family (Table 3-2 above)

### 3.6.3 Water consumption

The total amount of water used by each family was monitored based on their daily use.

The families were given an inventory to record (Appendix C) the amount of water used for different purposes namely:

- i. Water for use in taking a bath
- ii. Water being used for domestic purposes such as drinking and cooking
- iii. Water for use in any type of washing including clothes, utensils, kitchen wash and any other cleaning.



Plate 3-3: A queue for water in Kibera.

### 3.6.4 Estimation of P in urine and Faeces

The amount of Phosphorus excreted through urine and faeces was estimated using values from different studies done in various countries in the world as shown in Table 2-5 (Maure et al 2002) and Table 2-6 (Jonsson and Vinerras 2004).

In this study I chose to use P- value of 0.3 kg/p.yr for urine and 0.1 kg/p.yr for faeces; this is the value for Uganda (Jonsson and Vinerras 2004) since the people in the two countries share common socio-economic and climatic conditions. The general income level and diet in their food type are similar.

$$P \text{ (tot) kg/yr} = P\text{-value (Urine or Faeces) (kg P/p.yr)} * \text{Age corr. Factor} * \text{Population}$$

For the age correction factor, see Appendix A

### 3.6.5 Grey water.

The amount of water released as grey water was established based on daily water consumption of the selected families and the people interviewed. A water consumption budget was then computed showing what is received and what is used. From this budget, the volume of water out flowing as grey water was then estimated

Analysis of grey water (water which was emanating from different houses through open drenches) was done.

P loading from grey water was assumed to be emanating from soaps and detergents:

$$P \text{ (Grey water)} = P \text{ (soaps and detergents)}$$

### 3.6.6 Solid waste

Each family was provided with polythene bags to store their solid waste before any disposal was done. Every week and particularly on Saturdays, the waste collected was sorted into various categories.

The solid wastes were categorised into eight types; paper and cardboard, organic material, plastics, glass, metals, wood, textiles and finally Inert materials (JICA 1998, Gumbo 2005).

Each fraction was weighed using a spring balance capable of weighing 100 g and put into the bags for disposal.

The weight of each type of waste was recorded in the inventory provided (Appendix D) and the total amount per month was calculated.

The organic fraction was estimated and the P value calculated using the expression below:

$$P_{sw} \text{ (kg/p. month)} = \lambda \frac{1}{h} \sigma_{sw} \quad \text{Equation 3-3}$$

Where:

- $P_{sw}$  P-influx per capita per month. (g P/p. month)
- $h$  Size of the selected family (Table 3-2)
- $\lambda$  The quantity of dry organic or biodegradable solid waste fraction generated per family per month ( kg/month)
- $\sigma_{sw}$  Is the phosphorus content as P in the organic fraction of solid waste expressed as a ratio (0.0016 kg P/kg) (Appendix D, Gumbo 2005).

The moisture content was not measured but was assumed to be 64 % (JICA 1998).

The contribution of solid wastes for the entire population of Kibera was estimated by multiplying with the population.

### 3.7 Phosphorus loading in the Nairobi Dam

The concentration of Phosphorus in the dam was determined from the laboratory measurements of samples taken from the dam (composite samples were taken from different sites of the dam) see Fig 3-2.

The amount of phosphorus loading into the dam was determined with the use of Vollenweider model equation:

$$[P] = \frac{w^1}{q + 10} \quad \text{Equation 3-4}$$

Where

- $[P]$  Phosphorus concentration (g /m<sup>3</sup>)
- $w^1$  Annual phosphorus loading per unit area (g/ m<sup>2</sup> /yr)
- $q$  Water discharge per unit area (m/yr)

Source: (Kelderman 2005)

The discharge from the spillway down the dam was obtained from studies done earlier in the dam (Krhoda 2002).





## 4 P- Calculator Model

Fig 4-1 above describes the P-calculator model (Gumbo 2005) used to estimate the water and P balances in four systems: rainfall, municipal, household and agriculture. The P-calculator model is a Stella based model build using stocks, flows, converters and connectors blocks) Details of the on the use of Stella software is not included in this thesis.

In this section the monthly water balance for rainfall and municipal systems and the P balance for household and agriculture were estimated.

A guide of the balances in the four systems is given below:

### Rainfall water balance

The water budget from the rainfall is estimated using the P-calculator model.

$$\text{Average monthly rainfall (R)} = Tr + I + Qs + Qg \quad \text{Equation 4-1}$$

Where

- Tr is the transpiration from the rainfall (Potential transpiration (Tpot) for arable crops assumed as 6mm/day)
- I is the interception (Daily interception threshold (D) taken as 3 mm/day)
- Qs is the surface run-off (Surface run off coeff (C ) taken as 0.24)
- Qg is the ground water seepage (Reff-Tr-Qs )

NB. -The effective rainfall, Reff, is calculated as R-I

- Transpiration arising from garden irrigation using municipal water supplies is also computed from the model.

### Municipal water balance

The water balance from municipal supply in a month was estimated using the model.

In household water is used for the following functions:

$$\text{Municipal water supply (W)} = Wc + Wi + Wg + Ws \quad \text{Equation 4-2}$$

Where

- Wc is water consumed by the population either directly or contained in ingested food products
- Wi is total municipal water used for garden irrigation  $Wi = aW + eWg$
- Wg is the grey water generated from activities related to nourishing and cleaning (kitchen, bathroom and laundry).
- Ws is the foul sewage or 'black water' flux which is a combination of yellow, brown, and a proportion of grey water

## Household P balance

The total phosphorus budget for a household is based on the sources and the sinks  
Sources = Sinks

$$P_{fb} + P_{sd} = P_y + P_g + P_b + P_{sw} \quad \text{Equation 4-3}$$

Where

- $P_{fb}$  is the P from foods and beverages
- $P_{sd}$  is P from soaps and detergents
- $P_y$  is P from yellow water (urine)
- $P_b$  is P from the brown water from toilet flushing
- $P_{sw}$  is P from solid wastes

In estimating the P in all the materials, the quantities as well were estimated.

## Agricultural P balance

The P – budget in agriculture is based on the equation below

$$P_{ss} + P_{ma} + P_{mf} + eP_g = P_{sr} + P_{sl} + P_{le} + P_{bu} \quad \text{Equation 4-4}$$

Where

- $P_{ss}$  is the initial bio available P in the soil stock
- $P_{ma}$  is the P imported from organic manure
- $P_{mf}$  is the P- applied from commercial fertilisers
- $eP_g$  is the fraction of P-flux from grey water applied for irrigation
- $P_{sr}$  is the P losses from surface run-off
- $P_{sl}$  is the P losses as a result of soil erosion
- $P_{le}$  is the leaching P-flux due to percolation and groundwater flow
- $P_{bu}$  is the P taken up by the plants

Nb. -In this model the P from organic manure ( $P_{ma}$ ) has been assumed to be from household wastes; urine, faeces, and solid wastes. It is assumed that the commercial fertilisers will not be applied.

- The Area required (New Ac) to absorb the different fractions of wastes can be estimated using this model.



## 5 RESULTS

### 5.1 Phosphorus trend in different surface waters

#### 5.1.1 Trend analysis

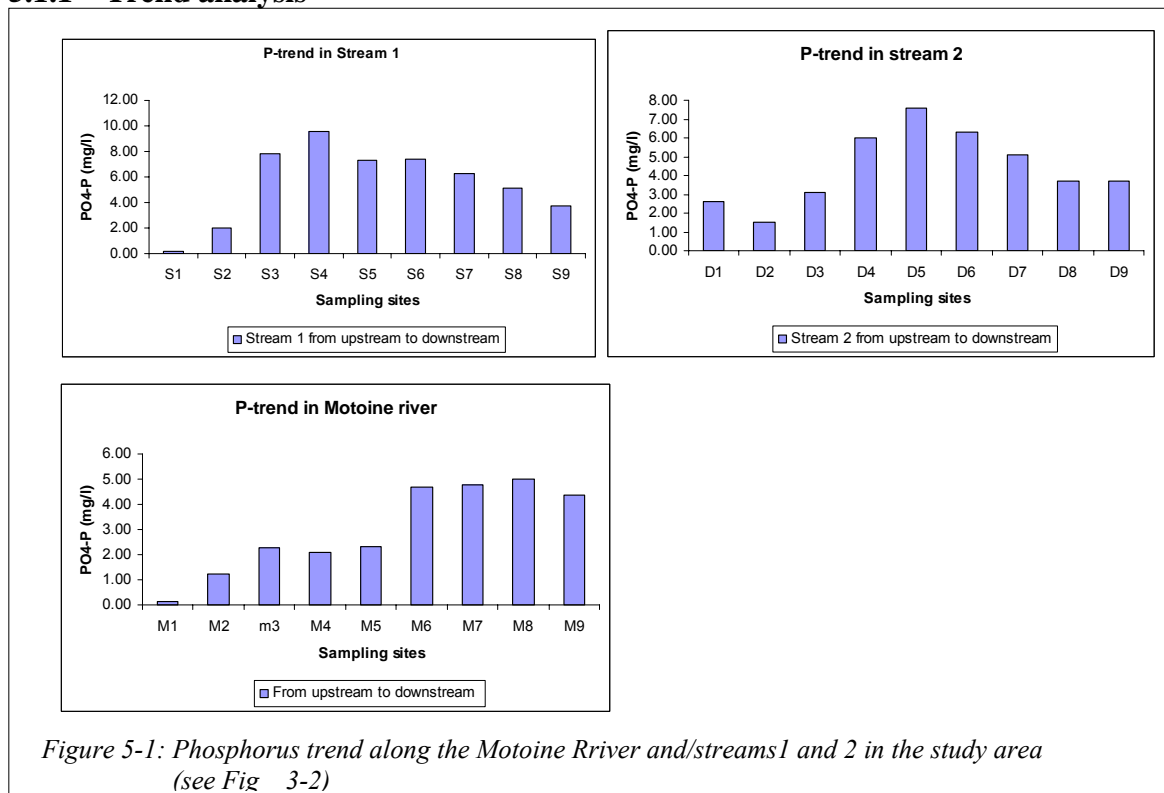


Figure 5-1: Phosphorus trend along the Motoine River and/streams 1 and 2 in the study area (see Fig 3-2)

#### Stream 1

From Fig 5-1 (a) above the P- concentration of the stream1 as it enters the study area (S1) is low (0.1Pmg/l) but rises sharply immediately it enters the village (S2). This continues to rise until at Site 4 where it decreases gently until it enters the dam (S9). The most likely reason for the sharp increase in P is the input of P from the villages. This may come from wastes dumping into the stream. As the water flows, there is a dilution effect, which reduces the concentration of phosphorus in the water. The population density decreases downstream and probably the P input through wastes decreases.

#### Stream 2

The concentration of P in stream 2 (Fig 5-1(b)) is high (2.5 mg/l) at initial sampling point (D1) but dropped at the second site, D2 (1.5 mg/l). There is a school and an estate (Woodley), adjacent to where the stream enters the Village and there is a possibility that the stream is contaminated from the activities in these areas or further upstream. The stream leaves the village and enters the Golf field where there is less P-input since they have a sewer line and no waste is likely to enter the stream directly. Also there is natural purification due to sedimentation and adsorption of P, which will reduce the P concentrations.

Phosphorus concentrations rise from D2 to D5 and decreases from D6 to D9. As the stream enters the villages again, it picks phosphorus from the wastes entering the water and causes the P concentrations to rise. The decrease in P from D6-D9 may be as a result of dilution and sedimentations.

## **Motoine River**

From Fig 5-1c, the phosphorus concentration in Motoine river at the point where it enters the villages (M1) is low (0.1 mg/l) but rises sharply once it enters Gatwekeira village (M2). The concentration becomes almost constant downstream from M3 to M5 ranging from 2.1 to 2.3 mg/l. At sampling point M6, the P-concentration rises to 4.7 mg/l and then remains almost constant (ranging from 4.7 to 5.0 mg/l ) until the river joins the upper end of the dam (M9).

The Motoine River passes through Ngong forest where it undergoes self-purification resulting in low P concentration as it enters the villages, M1. This river also marks a boundary between Kibera and the middle class estate of Langata. There are a lot of plants growing along the river and farming activities taking place. The resulting effect due to absorption and sedimentation apparently stabilises the P-input and P-output

### **5.1.2 Nairobi dam**

The average concentration of Phosphorus (as $\text{PO}_4\text{-P}$ ) (see Fig 4-2 above) was found to be  $5.8 \pm 0.3$  mg P /l at 95 % CI (n=6 sd=0.3) (Appendix H). The high concentration may be attributed to high P-loading from the wastes originating from Kibera settlements. At the outlet of the dam, the spillways, the concentration was found to be 2.4 mg/l. This is probably as a result of P retention in the dam and the uptake by the water hyacinths plants. It is an indication that about 60 % of P is retained in the dam.

The following hydrological information was estimated for the dam (Appendix E):

- The water discharge- Inlet was estimated at  $6.7 * 10^6$  m<sup>3</sup>/y  
- Outlet was  $6.3 * 10^6$  m<sup>3</sup>/y
- The evapotranspiration in the dam was estimated at  $7.0 * 10^5$  m<sup>3</sup>/y
- The residence time of the dam was estimated at 6 days
- The P- loading in the dam was estimated at  $6 * 10^4$  kg P/y

The dam is already invaded by water hyacinth and islands have formed where people cultivate fodder (Napier grass).

The concentration was lower at the outlet due to P adsorption by the water plants and also due to sedimentations at the Nairobi Dam.

### **5.1.3 Open drains**

The average concentration of Phosphorus (as  $\text{PO}_4\text{-P}$ ) was  $2.2 \pm 0.1$  mg/l at 95 % CI (n=7, sd =0.1) (Appendix H). The main source of P in the water from the drains is from water arising from bathrooms and wash rooms. Some of the drains contain a mixture of wastes from the toilets such as urine which contains high P concentrations.

## 5.2 Analysis of Phosphorus in spring water

The concentration of P (as  $PO_4$ -P) in spring water was found to be  $0.01 \pm 0.007$  mg/l at 95 % CI ( $n=5$ ,  $sd=0.005$ ) (Appendix H). The spring is located in Karanja road estate which is not highly congested. The estate is served with a sewer system and therefore there is no or less waste likely to contaminate the spring water. The low P concentration can be attributed to low level of pollution from both point and non point sources

## 5.3 Soil Analysis

The bio available P- content of the soils analysed, shows that the P level was dependent on the kind of vegetation growing in the farms

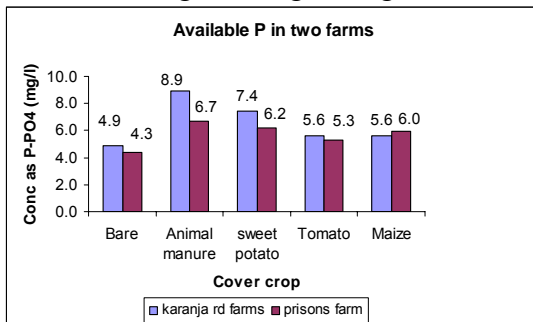


Figure 5-2: P content (as  $PO_4$ -P) of the two farms (Karanja Rd, Prisons farm) (see Fig 3-2 above)

From Fig 5-2 above, Karanja Rd farm was generally found to be having 6-35 % higher P than the Prisons farm in all the samples taken except where maize was grown. In both farms, where animal manure had been applied, the P-concentration was higher than in others.

Prisons farms use prisoners to tend the farms and the management is good enabling efficient utilisation of P by plants. This may explain the lower residual P in the farms. Addition of animal manure increases the amount of residual P, which may not be utilised by the plants. The harvested area represented the bare section of the farms in the study. Plants had already used the P needed and what remains was low.

## 5.4 Respondents results

The aim of the research was to estimate the actual materials flow from the household systems in the whole of Kibera. This research interviewed 200 people and five families with similar questions within the same period (Appendix B).

The first approach gives general information of the people of Kibera without giving the actual quantities of the materials flow. The response from a wider group of people helps to bring out the general perception. The interviews carried out on the five families gives the actual quantities of the materials flow.

The five families selected were assumed to be representative of the whole community, and the results derived may be taken to represent the people in Kibera. An extrapolation can be made based on the results of the five families since in this research it is assumed that their characteristics represent the whole population

This section (sec 5-4) brings out the views of the 200 people, which can be compared with the details of the five families below (sec 5-5)

### 5.4.1 Food consumption

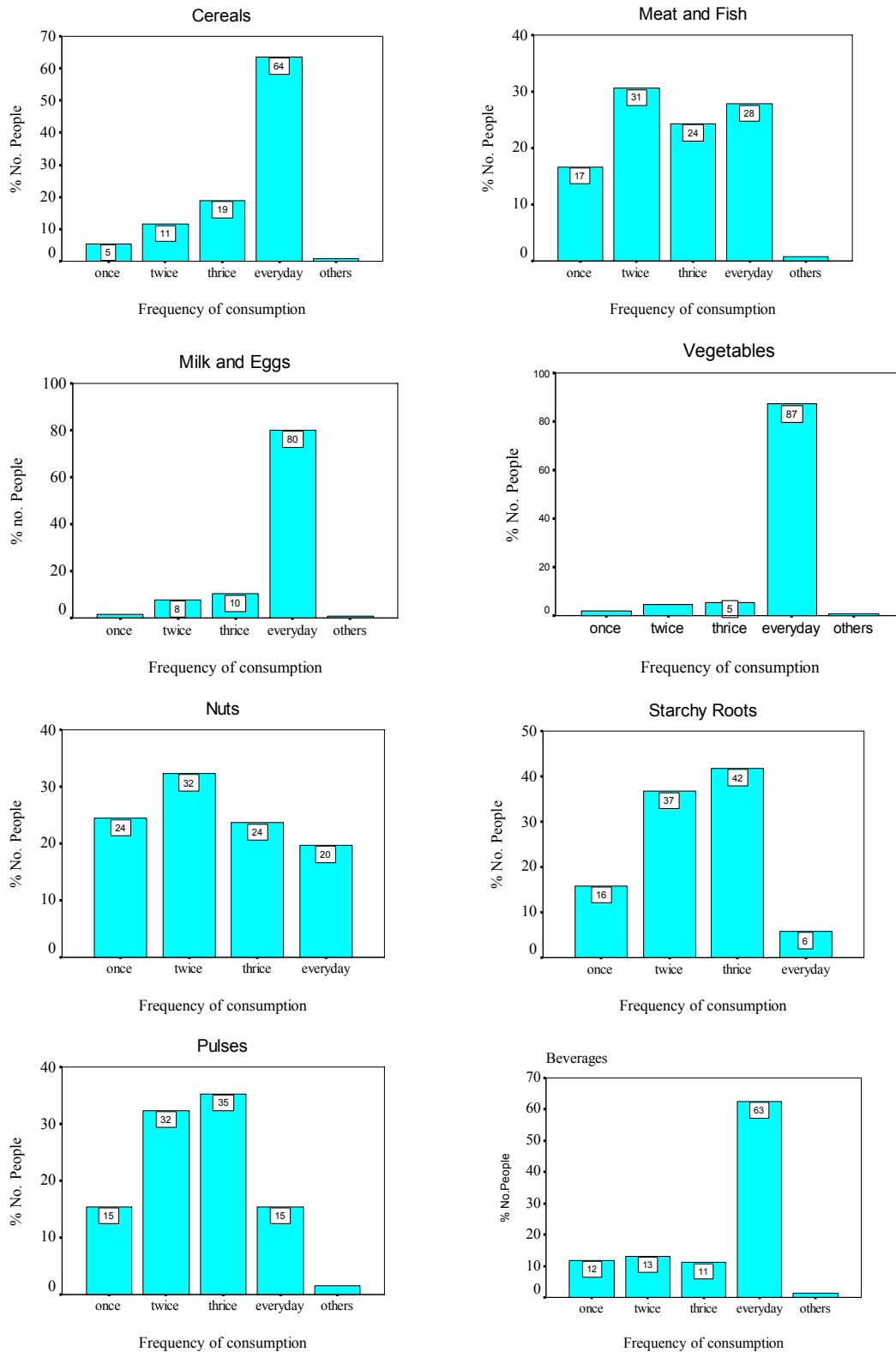


Figure 5-3: Frequency of food consumption per week in Kibera

From Fig 5-3 above it was found that, over 60 % of the people interviewed consume: cereals, milk, vegetables, starch roots and beverages at least on a daily basis this is because the above are readily available from the local market at a cheaper cost.

The most commonly consumed cereal is maize meal commonly known as “ugali”. Beverages are mainly composed of cereal-based liquor and soft drinks, which are affordable.

The second most commonly consumed food components are starchy roots and pulses, which are consumed at least thrice a week by over 30 % of the people interviewed. The starchy roots include arrowroots and sweet potatoes planted in the small gardens along the riverbanks and homestead backyards.

Meat and fish, nuts, starchy roots and pulses are least consumed as represented by 28 % of the people interviewed. This is because meat, fish, and nuts are expensive and are not readily available in the surrounding market.

### 5.4.2 Income

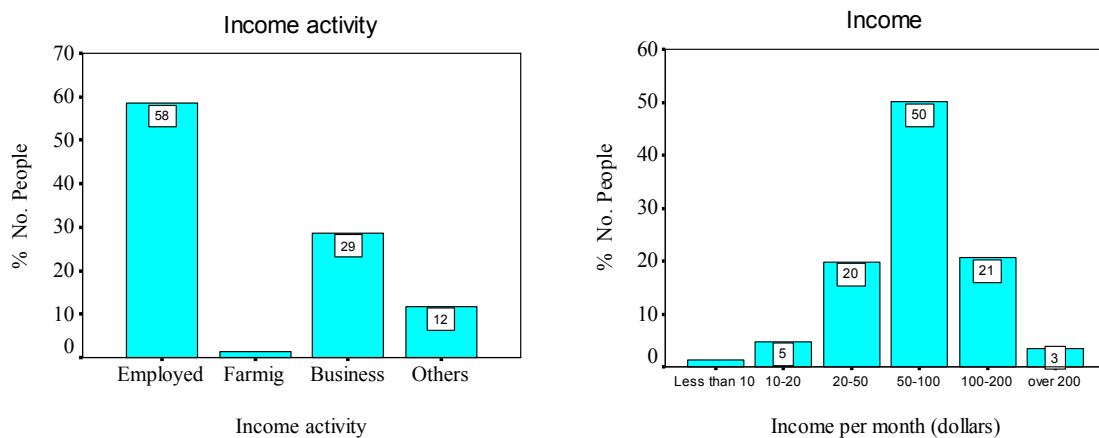


Figure 5-4: Shows the income generating activity and how much income per month

From Fig 5-3 above, it turned out that about 58 % of those interviewed are employed and 29 % depends on business income. The research also established that a low percentage of the people interviewed (1%) practice farming. About 12 % of people are involved in various activities, which could not be categorized into the three clusters of activities.

The gross income per month was found to be low with the majority of the people interviewed (66 %) earning less than 100 dollars per month. Most people are employed in industries in Nairobi on temporary basis and the surrounding estates on very low-income jobs.

### 5.4.3 Water requirements

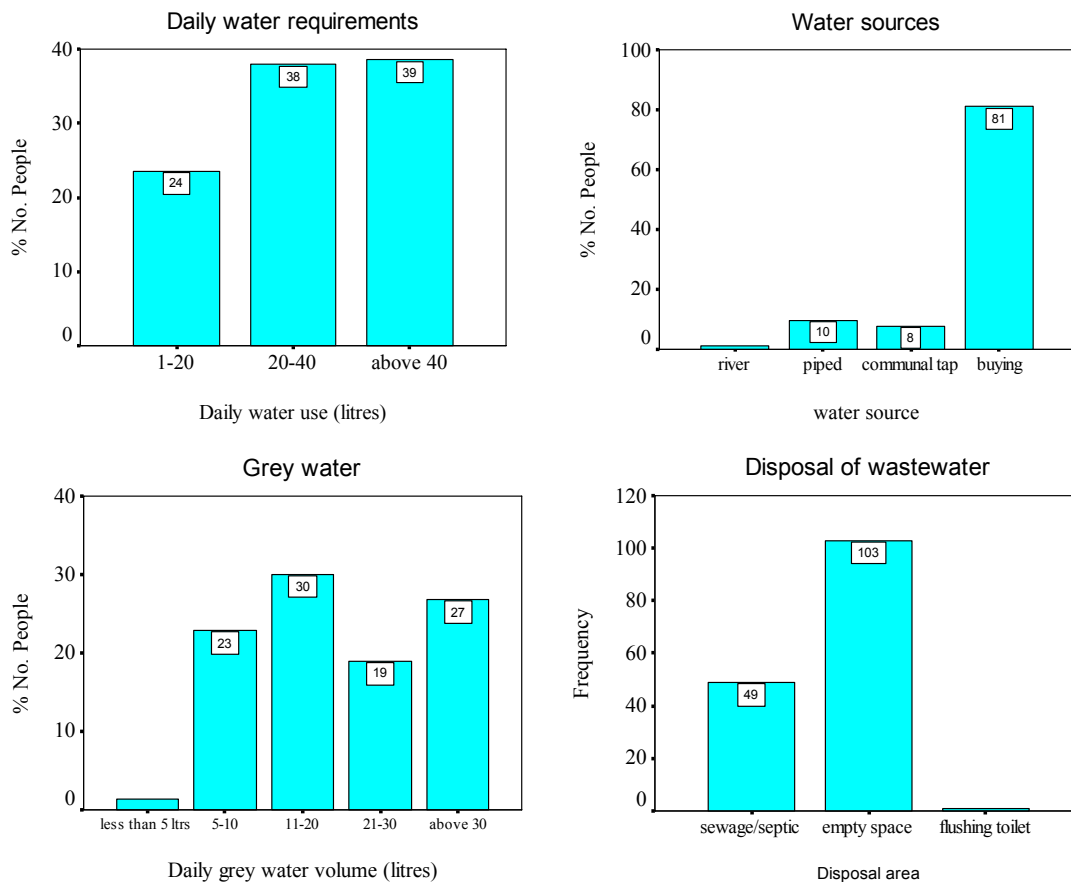


Figure 5-5: Water consumption and disposal in Kibera (litres/day)

From Fig 5-5 above, about 60 % of the people interviewed use less than 40 litres water per day. The main sources of water are community taps, piped water, water vendors and surface water.

About 81 % of the people interviewed buy water from the vendors whereas 10 % get water for use from the community taps. Most of those with piped water are the landlords or the vendors themselves. Those who can't afford supplement by getting some water from the rivers and spring (especially near Karanja Rd farm) but they use this water mainly for washing.

From the interviews and observations, people buy water at a cost of about 3 dollars/m<sup>3</sup>. This is quite high considering that the level of income is low with 76 % of the people earning between 2- 4 dollars per day.

Water generated as waste after washing and cleaning is quite high. 75 % of the people dispose of over 10 litres of water per day as grey water. 37 % of the people interviewed indicated that they dispose over 30 litres of water per day. Disposal of grey water is a problem due the absence of a sewer system. Majority of the people (67 %) dispose the grey water on any empty space while about 32 % pour into the pit latrines.

Most latrines are not functioning well and the wastewater eventually spills and leaks to the environment.

## 5.4.4 Soaps and detergents

### 5.4.4.1 Usage of soaps and detergents

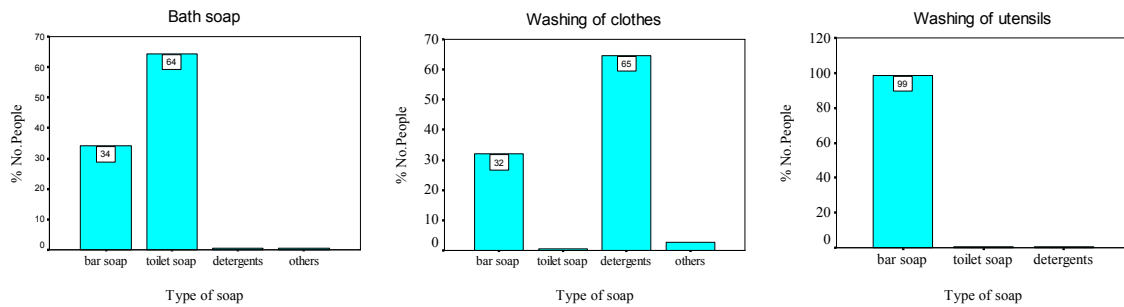


Figure 5-6: Types of soaps used for washing in Kibera

From Fig 5-6 above, 64 % of the people interviewed use toilet soaps for bathing whereas 34 % use bar soaps. Detergents are still the most preferred (64 %) choice in washing clothes sold in powdered form with the trade name “OMO” whose label indicates, “Phosphate- based detergents” compared to 32% using bar soaps due to its effectiveness. However, Majority of the people interviewed (99%) wash utensils using bar soaps because they are sold in small units and at affordable cost.

### 5.4.4.2 Quantities of soaps and detergents

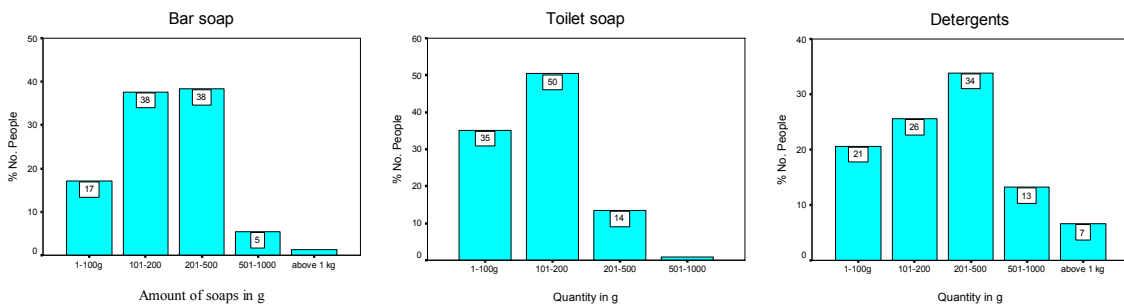


Figure 5-7: Quantities of soaps used per week in Kibera (g)

From Fig 5-7 the majority of people (80%) interviewed estimated that they use less than 500 g of bar soap per week. Only a smaller percentage (20%) estimated above 500g of bar soaps per week. This was due them to lacking a way of measuring the amount of soap used.

Detergents are used in large quantities with 64 % using more than 200 g per week. The use of detergents implies that a lot of P will be found in the grey water.

### 5.4.5 Solid wastes

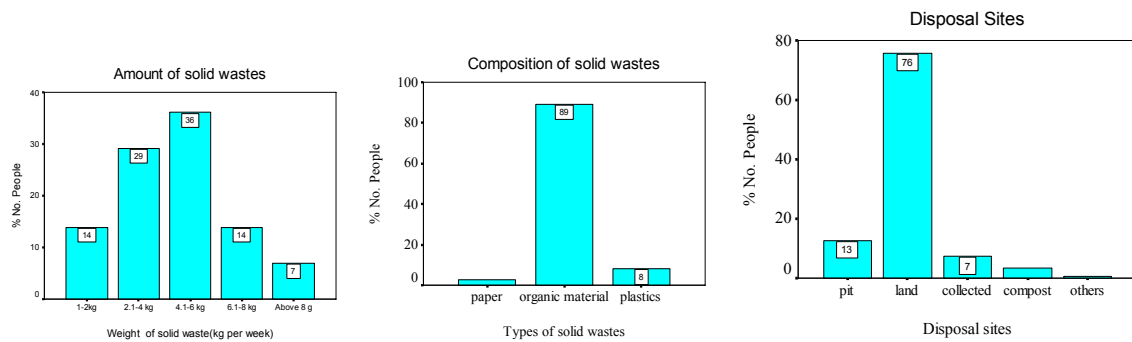


Figure 5-8: Amount of solid wastes and the dumping sites in Kibera

From Fig 5-8 above, it turns out that the majority of the people (over 50 %) believe that the amount of waste they generate per week is above 4 kg. About 30 % of them estimated their wastes to be between 2- 4 kg per week. Only a small percentage (14 %) of the people could estimate their waste to be less than 2 kg per week.

Organic materials formed the largest percentage of the solid wastes. About 90 % of the people interviewed indicated that organic waste formed the most part of their solid wastes. Due to the absence of solid waste system, most people (76 %) dump their waste anywhere on the open land. However, 13 % of the respondents have dug a dumping pit for their wastes.

It is worth to note that some people (7 %) have engaged private services for their solid waste to be collected and disposed, while some people (4 %) compost their waste in their small gardens.

### 5.4.6 Farming Activities

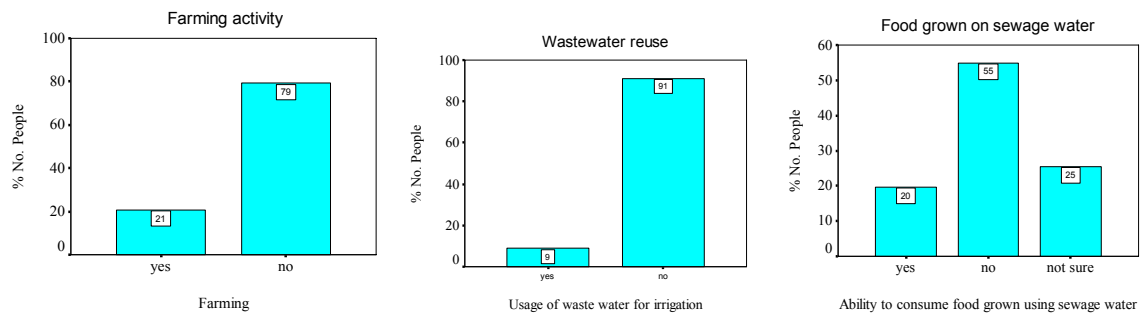


Figure 5-9: Perception of people on food grown using sewage water

From fig 5-9, small-scale farming is practised by a small percentage of people (21%) interviewed. They grow sugarcane, arrowroots and vegetables in their backyards, along Motoine River and next to Nairobi dam. Most of the farmers (91 %) use wastewater for irrigation of their farms.

People have diverse views towards consuming food products grown using sewage water. 55 % of the respondents indicated that they would not consume while 20 % have no problem in this respect. However 29% of the respondents were not sure whether they would consume products from the small farms, which use wastewater for irrigation since the practice of wastewater reuse in agriculture is not a familiar concept.

The following section (5.4.7) gives the views of the respondents in relation to wastewater reuse in agriculture.

### 5.4.7 Perception on waste water reuse

Some of the reasons given by the respondents regarding the re-use of wastes in agriculture are given below:

#### i. I will not consume any product grown on treated wastes (urine or faeces)

Reasons

- No assurance on the treatment and handling of wastes before re-use
- I doubt if the smell will be completely eliminated.
- Cultural believes; the body has rejected urine and faeces and so it is immoral to use it again. It is like taking back the wastes into our bodies.
- Religious believe- the holy book refers to urine and faeces as dirty wastes. So I don't want anything associated with dirt.
- There is no treatment, which will ensure that 100 % of the pathogens are removed.
- I will always have a feeling of seeing the dirty wastes (urine or faeces) in the product. This will definitely make me lose appetite.

#### ii. I will consume the food products grown on treated waste

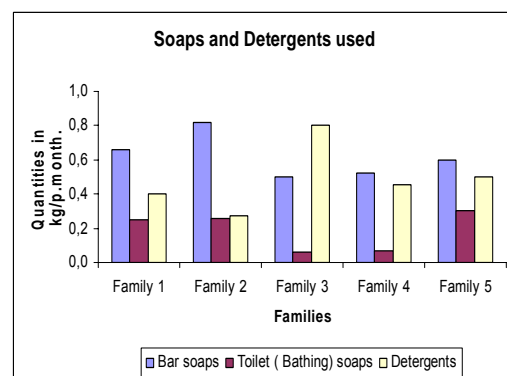
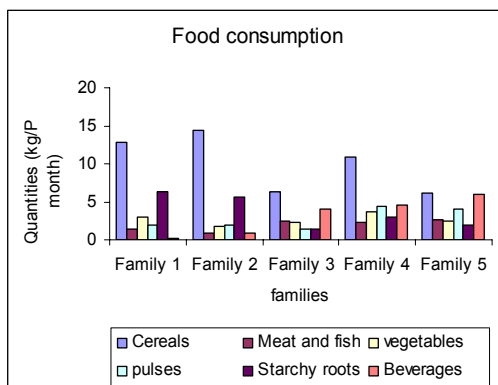
Reasons

- So long as it is treated and it has no smell, I will have no problem
- Plants will only pick the nutrients for their growth. So it is like any fertilizer
- No problem so long as people are trained on treatment and handling or use of skilled personnel to assure no contamination to the crops
- Crops such as vegetables once thoroughly washed are safe for human consumption
- No problem because even what we buy we are not sure of how they were grown.

## 5.5 Monitoring of the five Families

In section 5.4, the views of the people in relation to the material flow in the household systems were presented. The following section (sec 5.5) gives the specific quantities of the material flow based on monitoring of five families (details of each family is given in Appendix D). The results will be used to extrapolate for the whole of Kibera area.

### 5.5.1 Materials flow in five families



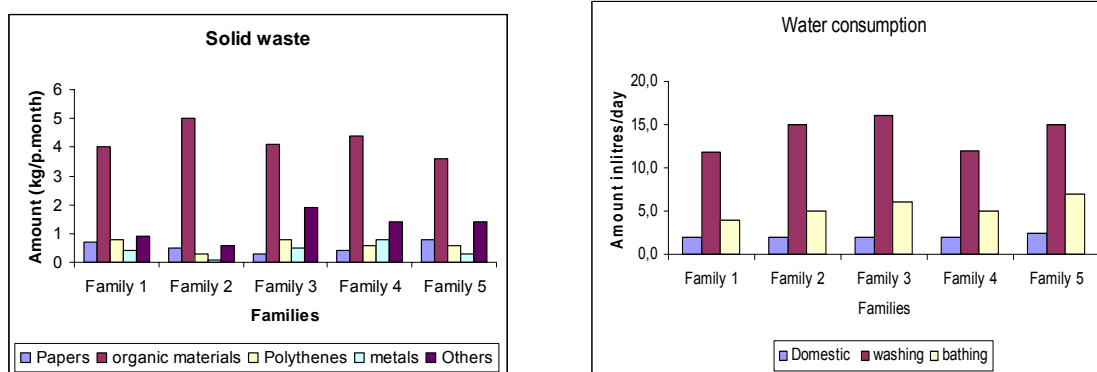


Figure 5-10: Food consumption by different families

From Fig 5-10, the most consumed food component was found to be cereals among all the five families because Cereals were like rice and maize meal are the stable food for most people in Kibera. The consumption of the other food components varied from one family to the other.

Meat and beverages were found to be consumed more by families 3, 4 and 5 than the other families this is because they have a constant source of income. Family 4 however has a relatively low income but can afford meat and beverages because of the small family size. Family 1 has a single person with low income hence the low consumption. Family 2 has a large family size with unpredictable income (business). This family however, uses starchy roots like arrowroots and Irish potatoes from their small garden.

From Fig.5-10 It was found that, bar soap is commonly used by all the families. The bar soap is used in washing clothes, washing utensils and in some cases for bathing. Family 2 had the highest use because of the large family size with a high number of children under the age of 14 who require frequent washing of clothes.

Detergents on the other hand were also found to be commonly used by all the families in washing clothes. Family 3 had more adult female and this would justify the frequent use of detergents in washing clothes. Family 3 and 4 had the lowest toilet soap use but instead used bar soaps both in washing and bathing.

Family 5 had an average use of all the categories of soaps and detergents for the specific purposes. This is because all the members of the family were mature adults of average level of education. Three members of this family were in formal employment and this would explain the rationale in using more toilet soaps for bathing before leaving for work.

.Organic materials formed the major component in the solid waste generated by all the five families (Fig 5-10 c). This is in form of food residues such as cereals, vegetable products etc. Papers and polythene bags were found to be the second most common materials for all the families this is from packaging materials for goods purchased.

From Fig 5-10 (d), all the families consume less than 25 litres of water per day. Water is mainly used for washing and bathing. Since water is bought from vendors, the cost is inhibitive and this could explain the low usage of water among the families.

## 5.6 Quantities and P- concentration of the material flow

The total amount of food consumed and soaps used by the families is summarised in Table 5-3 below. The P- concentration of each item also gives a summary of the amount of food components in the diet of the residents of Kibera. The corresponding P- content of each food type is also given.

Table 5-1: Summary of average food and soaps consumed and wastes generated in Kibera

The details of the calculations are given in Appendix E

Table 5-2: Summary of average food and soaps consumed and wastes generated in Kibera

### (A) Food and Beverages

Food group	Amount Kg /p.month	P (g/kg)	P g P /p.month	P in Kibera (* 10 <sup>3</sup> kg P/month)
Cereals	10.9	1.86	20,3	3,3
Meat and fish	1.9	1.55	3,0	0,5
Milk and eggs	3.2	0.93	3,0	0,5
Vegetables	3.0	0.85	2,5	0,4
Nuts	0.6	4.05	2,3	0,4
Starchy roots	1.9	0.46	0,9	0,2
pulses	2.1	4.62	9,7	1,6
Beverages	3.4	0.13	0,4	0,1
<b>Total</b>	<b>27.0</b>		<b>42.2</b>	<b>6.8</b>

### (B) Soaps and detergents

Soaps & detergents	Amount (kg/p.month)	Phosphorus, (gP/kg)	gP/p month	P in Kibera (* 10 <sup>3</sup> kg P/month)
Bar soaps	0.6	1.1	0,67	0,13
Toilet (Bathing) soap	0.3	1.1	0,28	0,06
Detergent	0.5	2.5	1,27	0,25
<b>Total</b>	<b>1.4</b>		<b>2.22</b>	<b>0.44</b>

### (C) Waste fractions

Type of waste	P-loading (kg P/ca.yr)	P loading in Kibera *10 <sup>3</sup> kg P/month
Urine	0.3	<b>5</b>
Faeces	0.1	<b>1.4</b>
Grey water	Equivalent to P in soaps and detergents	<b>.44</b>

### (D) Solid waste

Solid Waste	Waste generated	Average P for

	(Kg/p month)	dry organic material	P in Kibera * 10 <sup>3</sup> kg P/month
Paper	0.4	0.0016kg/kg	<b>0.5</b>
Organic material	4.3		
Polythene bags and plastics	0.7		
Glass	0.3		
Metals	0.4		
Wood, leather and rubber	0.3		
Textiles	0.3		
Miscellaneous	0.3		
<b>Total</b>	<b>7.0</b>		

(E) Water consumption

Water use	Amount (l/ca.d)	Amount of water used in Kibera * 10 <sup>3</sup> m <sup>3</sup> /d
Water for domestic	2,0	0.4
Water for washing	13,0	2.6
Water for bathing	6,0	1.2
<b>Total</b>	<b>22,0</b>	<b>4.2</b>

From Table 5-1, the total amount of food and beverages consumed per person was estimated at 7 kg/p.month. The phosphorus contained by these foods was estimated at 42.2 g P/p.month. In the entire study area (population of 200,000), the total Phosphorus would amount to  $6.8 * 10^3$  kg P/month (Table 5-1, a) after adjustment of the age factor of the population (Appendix A). Cereal was found to contribute the highest P loading ( $3.3 * 10^3$  kg P/month) followed by the pulses ( $1.6 * 10^3$  kg P/month). Beverages contributed the least amount of P in the food components in Kibera.

The total amount of soaps and detergents was estimated at 1.4 kg/p.month, with bar soaps being highly used and the toilet soap the least. Detergents were the largest contributor of P with an average amount of  $0.25 * 10^3$  kg P/month for the whole of Kibera. This amount is twice the P contribution from bar soaps

Wastes from the households were characterised into urine, faeces, grey water and solids. The Phosphorus loading from urine amounted to  $5 * 10^3$  kg P/month followed by faeces ( $1.4 * 10^3$  kgP/month). Therefore urine contributes the highest amount of P in the wastes. Solid wastes when dumped on land the biodegradable organic materials decompose and nutrients such as Phosphorus are released. In this study, it was estimated that the solid wastes composed of 60 % of organic materials. The P- content of the dry organic matter was estimated at 0.0016kg P/kg (Appendix E).

Water consumption was estimated at an average of 22 litres per day. 85 % of water was used for washing and other domestic activities such as cooking. The entire area consumes about  $4.2 * 10^3$  m<sup>3</sup>/d of water.

## 5.7 P-budget for the entire study area

Table 5-3: Total phosphorus budget in Kibera, Nairobi, Kenya (\* 10<sup>3</sup> kg P/month)

ITEM	IN	OUT
Food and beverages	6.8	
Soaps and detergents	0.44	
Urine		4.1
Faeces		1.4
Grey water		0.44
Solid waste		0.5
<b>Total</b>	<b>7.2</b>	<b>6.4</b>

From the Table 5-2 the major inflows of P in household systems are food and beverages, soaps and detergents; the outflows are through urine, faeces, grey water and solid wastes. The total P taken in by the people in Kibera amounts to 7.2 \* 10<sup>3</sup> kg P/month, of which about 95 % was from food and beverages.

The total loading of Phosphorus from household wastes in Kibera was estimated at 6.4 \* 10<sup>3</sup> kg P/month. The main P loading from the wastes was from urine and faeces, which accounted for 88% of the total P.

This research shows the P-Inflow was higher than the P-out flow by about 13 %. This could be attributed to the estimation error since the P contents of the materials was based on estimates.

## 5.8 P-Calculator results

The following results are the summaries of water and P budgets in four systems namely: rainfall, municipal, households and agriculture  
For detailed simulation results see Appendix H.

### Rainfall water balance (mm/month)

$$\text{Average rainfall, } R, \quad = \quad I + Tr + Qs + Qg$$

Table 5-4: Rainfall water balance in mm/month

ITEM	IN	OUT
Rainfall, <i>R</i> ,	74	
Interception, <i>I</i> ,		24.2
Transpiration, <i>Tr</i>		11.8
Surface Run-off, <i>Qs</i> ,		3.8
Ground water seepage, <i>Qg</i>		33.7
<b>Total</b>	<b>74</b>	<b>73.5</b>

From table 5-3, the model simulation shows that most of the water from rainfall goes into ground water recharge and interception. The high evaporation through interception could be attributed to climatic conditions of this area ( Appendix A)

### Municipal water balance (mm/month)

$$\text{Municipal water supply } (W) = W_c + W_i + W_s \text{ (} W_g + W_b + W_y \text{)}$$

Table 5-5: Municipal water balance in mm/month

ITEM	IN	OUT
Water supply, $W$ ,	23.8	
Water consumed directly or contained in food products, $W_c$		0.8
Water used for irrigation, $W_i$		2.5
Water released as sewage, $W_s$		19.7
<b>Total</b>	<b>23.8</b>	<b>23</b>

From Table 5-4, water from municipal supply is mainly used to transport waste in sewage. Only a small fraction is used for drinking.

### Household P budget (kg P/month)

$$P_{fb} + P_{sd} = P_y + P_b + P_g + P_{sw}$$

Equation 5-1

Table 5-6: Total phosphorus flows, in Kibera, Nairobi, Kenya (\*  $10^3$  kg P/month)

ITEM	IN	OUT
Food and beverages, $P_{fb}$	6.8	
Soaps and detergents, $P_{sd}$	0.44	
Urine, $P_y$		4.2
Faeces, $P_b$		1.4
Grey water, $P_g$		0.44
Solid waste, $P_{sw}$		0.45
<b>Total</b>	<b>7.2</b>	<b>6.4</b>

From Table 5-5, the P budget in a household is similar to the results obtained from the five families (sec 5-7 above)

### Agricultural system (kg P/month)

$$P_{ss} + P_{ma} + P_{mf} + eP_g = P_{sr} + P_{sl} + P_{le} + P_{bu}$$

Equation 5-2

In Eq. 4-4 above, commercial fertilisers are not applied in the farms but only organic manures.

$$P_{mf} = 0$$

P in organic manure,  $P_{ma}$ , = P in urine ( $P_y$ ) + P in faeces ( $P_{bl}$ ) + P in solid wastes ( $P_{sw}$ ) (kg P/month)

$P_{ss}$	$P_y$	$P_{sw}$	$P_{bu}$	$P_{sr}$ flow	$P_{sl}$	$P_{le}$	$P_b$	$eP_g$	New Ac
6103.7	4212.00	450	18	0.13	0.19	0.11	1.3	88	1695

## 6 DISCUSSIONS

### 6.1 Phosphorus trend in the surface waters of Kibera

#### 6.1.1 Rivers and streams

Phosphorus in streams and rivers may come from both point source such as domestic wastes and nonpoint sources (e.g agricultural activities). High phosphorus loading causes eutrophication in surface waters. Research has shown that Phosphorus is the limiting nutrient in most lakes and reservoirs (Moosmann et al 2005).

The high concentration of Phosphorus in the River Motoine and the streams 1 and 2 has been contributed largely by the human settlement in Kibera. It has been indicated that the variability in P concentrations depends on a number of factors; among them, hydrological pathways and their influence on retention, temporal variability in flow conditions and anthropogenic activities (Stalnacke et al 2003). Retention process may reduce the concentration of the nutrients.

Without any human interferences, rivers undergo self purification through sedimentation, desorption and dilution effect to reduce the nutrient load and thus reduce the concentration of nutrients (Krhoda 2002, Stalnacke et al 2003). Another factor, which plays a role, is the dilution effect due to increase in discharge from tributaries downstream.

Along the Motoine River and the streams, there are aquatic plants growing, which require bioavailable P for growth. This will reduce the concentration of P downstream. Other studies have shown that macrophytes may retain up to 25 % of the available P while the benthic and pelagic algae can retain up to 60 % of Phosphorus (Stalnacke et al 2003). On the other hand, the particulate P will not be available to plants and will settle near the inlets of the lake or reservoir without participating in the internal P cycling in the lake and reservoir (Moosmann et al 2005).

#### 6.1.2 Nairobi dam

The dam is currently invaded by water hyacinth and other plants. This has been caused by high nutrient loads. Phosphorus loading to the dam is high ( $59 \times 10^3$  kg/yr) (see Appendix E) and the average concentration of 5.81 mg P/l (or 5810 mg P/m<sup>3</sup>) indicates that it is highly eutrophic as compared to a desirable oligotrophic status (Fig 6-1) with P contents of around 10 mg P/ m<sup>3</sup>. The eutrophication of the dam is a big challenge in water quality management of reservoirs as it encourages growth of algae and causes the oxygen depletion in the water (Porcella 1975, Klapper 2003, Kelderman 2005). It has been shown that a lot of the problem of eutrophication is being faced in many lakes in the world such as lakes in China (Xiancan 2003).

The phosphorus loading into the Nairobi dam (166 g P/ m<sup>2</sup> /yr ) requires a reduction to about 2.8 g P/ m<sup>2</sup> /yr to reach a desired oligotrophic state. This represents a 98 % reduction in Phosphorus loading.

The residence time has been reduced to 6 days (Appendix E) as opposed to its design time of 10-20 days (Krhoda 2002). This is caused by high solid dumping in the dam (see plate 6-3a and b). The dam is heavily silted (Ndede 2002).

From the study, the P outflow from the settlement was found to be  $6.4 \cdot 10^3$  kg/month and the P loading in the dam was estimated at  $59 \cdot 10^3$  kg/yr. This indicates that the source of P loading in the dam is mainly coming from the household activities of Kibera settlements.

The reduction of residence time on the Nairobi dam has been caused mainly by reduction of volume due to solid dumping. Furthermore, Research has shown the residence time is highly dependent on internal physical processes of the water mass which influences its hydrodynamics such as wind force which generates turbulence and current, climatic conditions, calorific value of the water body and the water flows in and out of the dam (Ambrosetti et al 2003).

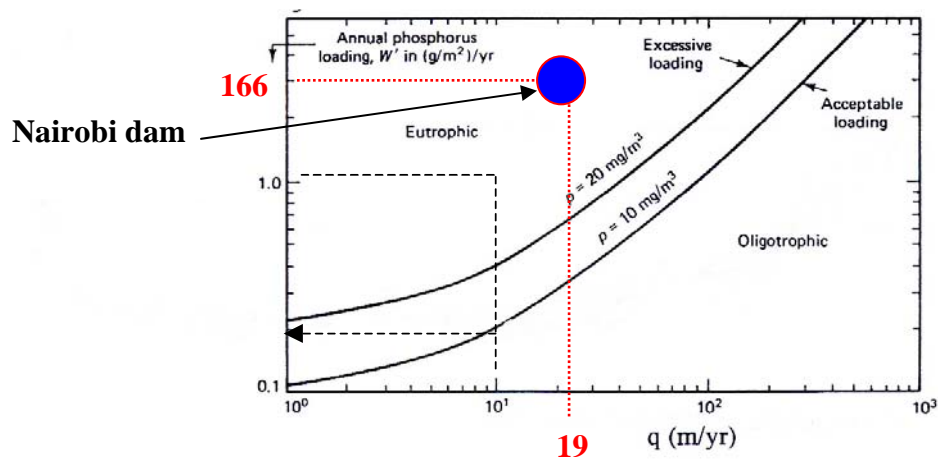


Figure 6-1: Vollenweider model showing the trophic status of lakes; A desirable state is oligotrophic



(a) Napier grass growing in the dam



(b) Solid wastes dumped in the dam



(d) *Water Hyacinth in the dam*

(e) *A section of the dam becoming an island*

*Plate 6-1: Showing the condition of the Nairobi dam in 2005*

## **6.2 P sources, sinks and reuse in Kibera**

### **6.2.1 P sources**

The daily food intake per capita for the people in Kibera (27 kg/pd or 900 g/p d) compares well with the dietary suggestions for daily food intake in Nairobi (935 g/pd) as suggested by FAO (1997). It is also similar to the daily intake of Mufakose and Marimba Park Surburbs (880 g /pd) in Zimbabwe (Gumbo 2005).

The total amount of Phosphorus from food and beverages (42.2 g/pmonth) compared well to studies in Zimbabwe (41.6) (Gumbo 2005). Cereals and Pulses are the major contributors of P.

The high consumption of cereals and vegetables is largely due to their availability and cost. Milk is sold in kiosks or by hawkers in quantities that are affordable to majority of the people.

Detergents, which have not been added phosphorus, have been found to contain phosphorus though at low levels. Studies done on wastewater from detergents without phosphorus contain less than 0.3 mg P/l. However, others will produce wastewater with P as high as 50 mg P/l (Patterson 2001). The detergents most used in Kibera are phosphate based type referred to in its' trade name as "Omo" which is having package clearly labelled phosphate in the composition. According to (Patterson 2001, a similar detergent with the same brand name ("Omo"), in Australia, produced wastewater containing 30 mg P/l. The use of phosphates in making detergents has not been banned in Kenya. This makes soaps and detergents the highest contributor of Phosphorus in grey water.

Even though the survey shows a higher percentage of people use bar soaps, the phosphorus content in detergents used by minority of people is very significant. Most people use bar soaps for washing, bathing and cleaning with a few who use toilet soaps and omo. It is common site to see grey water flowing freely from toilet cum bathrooms makeshifts.

Soaps and detergents contribute about 6 % of total P from the household wastes; a percentage higher than in Mufakose and Marimba Park Surburbs (4%) in Zimbabwe (Gumbo 2005).

Water from washing and cleaning of kitchen wastes also contain phosphorus ions from food waste such as organic remains.

The average per capita of the solid waste generated in Kibera ( 7.0 kg/pd or 0.2 kg/pd) was lower than the figure for Nairobi ( 0.5kg/pd) in 1998 ( JICA 1998). The present study also shows that the amount generated compared well with other cities in the world; Sweden (0.22 kg/pd) (Vineras et al 2002), Zimbabwe (0.2 kg/pd) (Gumbo 2005). It is however lower than China 1.0 kg/pd ( Vineras 2002).

This indicates that the solid waste collection system for Nairobi in general (Kibera included) had improved since 1998. By 2003, it is reported that the solid waste collection increased from 20 % in 1998 (JICA 1998) to 40 % in 2003 (ITDG-EA 2003)

The other source of Phosphorus in a household is solid waste with a total amount of P estimated at  $5 * 10^2$  kg P/ month (or 2.5g P/p.month) which was slightly higher than in studies in Zimbabwe (2.16 g/p.month) (Gumbo 2005).

The percentage of organic material (83 %) in the solid waste was higher than the 1998 figures for both low and high-income areas of Nairobi (ranging from 57-50 % respectively) (JICA 1998). The amount of paper and plastic was lower (7%) than the previous ones (16%).

The high amount of solid wastes being generated in Kibera ( $1.4 * 10^6$ kg per month) composed mainly of organic materials, papers and polythene bags (95 %). Many people (76 %) dump these wastes on any available space due to lack of an effective waste collection system.

The solid waste generated may be composted and reused in agriculture. There are already organized groups in Kibera involved in composting of wastes such as Silanga ya Ngombe group. Many of these composting businesses have been profitable and even sustainable (Kim 1998, Njenga et al 2004<sup>k</sup>). Green wastes such as from vegetables may be used as fodder; food wastes may be fed on pigs and goats (Furedy 2002).



Plate 6-2: Solid wastes dumping site



Plate 6-3: grey water flowing into the stream

### 6.2.2 Sinks and reuse of P

The amount of grey water generated ( $78000 \text{ m}^3$  or  $2600 \text{ m}^3/\text{d}$ ) in Kibera is slightly higher than some areas without sewer of Harare, which was found to generate about  $2400 \text{ m}^3/\text{d}$ . However the per capita daily generation (13 l/d) is far much lower than the Harare case (32 l/d) (Nhabi 2002).

The composition of grey water depends on the sources and installations from where the water is drawn, e.g kitchen, bathroom, or laundry (Eriksson et al 2001). The chemical compounds originate from household chemicals, cooking, washing and the piping. The Phosphorus is mainly coming from the detergents, though it may also come from food remnants from kitchen wash. The phosphorus load from grey water (2.2g/p.month or 0.03 kg/ca. yr) was found to be higher than in studies done in Harare (1.48 g/p. month or 0.02 kg/p.yr) (Gumbo 2005). This can be attributed to the use of phosphate detergents (Patterson 2001) in Kenya.

<sup>k</sup> [http://www.ruaf.org/ruafpublications/genderworkshop/gender\\_njenga\\_nairobi.pdf](http://www.ruaf.org/ruafpublications/genderworkshop/gender_njenga_nairobi.pdf) (Accessed on 2006, January 26)

The total P from grey water in Kibera was estimated at  $4.4 \times 10^2$  kg P/month which can be applied in agriculture as a source of nutrients. Grey water can be recycled and re-used for various purposes such as, irrigation of gardens, car –wash or watering of flowers. It is easy to collect since it originates from laundry, bathrooms and kitchen wash. Grey water is widely reused in countries like Japan, Germany and Australia (Maeda et al 1996, Law 1996 Jefferson et al 2000, Nolde 2000). Recycling of grey water may be having the potential but people needs to be assured on the quality of the water before they use (Jefferson et al 2004). Food crops irrigated with wastewater are not allowed to be eaten raw in many countries such as (Bountoux et al 1996).

Wastewater should be treated before reuse to avoid contamination. According to Jefferson et al 2004, the most suitable treatment technology for grey water is the biological processes such as use of membrane bioreactor or biologically aerated filter.

The phosphorus concentration in urine (0.3 kg/ca.yr) was based on literature data (Jonsson and Vinerras 2004, Gumbo 2005). From this study, urine contributes 65 % of total P in domestic waste. Other studies estimated at 50-90 %P contribution from urine (Maure et al 2002, Vinneras 2002, Gumbo 2005, Tanski et al 2004, Wilsenach et al 2006). This may vary on the ground as this is influenced largely by the diet consumed.

Urine is the major contributor of P in Kibera with a total P of  $4.1 \times 10^3$  kg P/month (or 25gP/p.month) followed by faeces at  $1.4 \times 10^3$  kg P/month (or 8.3gP/p.month). The diet and age influences the amount of P released in Urine. Young children (below 14 yrs) and adults (above 65 yrs) release 50 % of what an adult produce (Gumbo et al 2005).

The high phosphorus in urine ( $4.1 \times 10^3$  kg/month) can be a source of mineral fertiliser for agriculture. Apart from Phosphorus, urine contains other minerals, which are essential for plant growth such as cations; N (>90 %), Ca, Na, K,  $\text{NH}_4$ , and the anions, Cl,  $\text{SO}_4$ ,  $\text{PO}_4$  and  $\text{HCO}_3$  (Kirchmann 1994).

Urine can be separated from the source to avoid contaminations. Source separated urine contains less contaminants and can be applied in agriculture without the danger of polluting the soil with unwanted pollutants. If urine is separated from the source, the nutrients will be recovered in forms that are applicable directly as fertilisers (Maure et al 2002, Vinneras 2002, Degaard 2003).

Use of urine as fertilisers has a number of advantages over commercial fertilizers. It has less heavy metal contaminants and containing readily available Phosphates. It contains fewer enteric micro-organisms but some human micro-organisms or helminth eggs. (Kirchmann 1994, Tanski et al 2004).

The P content in faeces was estimated at 8.3 g/p.month (or 0.3 gP/d) and this value was found to be far much lower than in South Africa (2.5 g P/p.d) according to UNEP report (2000). The kind of diet and the age structure plays a role in determining the amount of P in the human wastes (Gumbo 2005). The faecal P is mainly found as calcium Phosphates, but some as organic compounds (Vinneras et al 2002) In Kibera people are poor and the low P indicates a kind of diet low in P contents.

The total amount of Phosphorus from faeces in the entire study area amounting to 1.4 tonnes/month can provide the necessary nutrients in agriculture. Separating urine and faeces at the source is cheap and requires little or less water (Nhapi 2004). Faeces from

the toilets can be composted and re-used. There are a number of composting toilets in many parts of the world such as barrel composting, vermicomposting and brick built composting bins, which have been implemented in Kumasi, Ghana (Bradford et al 2003).

Wastes may be regarded as a resource rather than the unwanted wastes. Faeces and urine may provide the perfect choice for replenishing of our soil nutrients; one of the quick wins of MDG goals.

The recycling of these wastes poses a threat to our soils in that they may be a source of pollutants such as heavy metals, pesticides, medicines and hormones which may arise from the domestic uses (Nhapi 2004).

### **6.3 Total Phosphorus from household wastes**

From this study the total load from the entire household wastes in Kibera (urine, faeces, grey water and solid wastes)( $6.4 \times 10^3$  kg/p.yr or 1.3 gP/p.day) compares well with studies in Harare, Zimbabwe (1.3 gP/p.day) (Gumbo 2005) but slightly varies with studies done in Austria which ranged from 1.6-2.0 g P/p.day) (Zessner, 2005). This points to the difference in the composition of the diet of the inhabitants.

All this Phosphorus being generated from the study area is lost into the environment causing adverse effects such as eutrophication of the surface water. The way to curb this menace is to stop the nutrient sources and accelerate restoration of the reservoir using various available technologies (Klapper 2003). The challenge is that the available technologies for P removal are expensive to be applied in household systems without sewer systems (Mcgrath et al 2000). It might be cheaper to recycle these nutrients in agriculture to boost production.

#### **6.3.1 Waste Re-use option in Agriculture**

Generally Phosphorus in the soil is present in relatively low concentrations; 100-3000mg/kg (Valsami 2004). The results of the soil analysis of the two farms (Karanja Rd and Prisons farm) shows that the bio available P ranged from 9 mg P/kg (as PO<sub>4</sub>-P) or 9-20mgP/kg (as P<sub>2</sub>O<sub>5</sub>). It was found to fall within the range of some of the farms in Harare, Zimbabwe (Gumbo 2005). Samples were taken at the top 20 cm layer. At the top layer especially at the organic layer most of P is organically bound (Nwoke et al 2004) it has been shown that phosphorus decreases as the depth increases (Gumbo 2005) Increase in depth of the soil layer Research has shown that P decreases with depth and The variability of bio available P in the soils was influenced by the land use (Smalling 1993, Zoysa 1998, Ouyang et al 1999). This amount of P will not be enough for the crops to give maximum yields.

Different plants require different quantities of Phosphorus for their growth. Maize, for instance, requires an application of 40 kg P<sub>2</sub>O<sub>5</sub>/ha for optimum yields (Kogbe et al 1993). Commercial fertilizers are usually applied to agriculture to replenish the soil nutrients which have been depleted due to poor soil management.

It has been shown that the Phosphorus is being depleted in Kenyan soils at a rate of 2-3 kg/ha.y (Smalling 1993,FAO 2004) necessitating the Kenyan government to continuously imports fertilisers costing million of shillings (FAO 1999). However the high cost of the fertilisers has forced people to look for alternatives to fertiliser their

crops. People in the Peri-urban areas of Nairobi city practise small-scale farming in their backyards and they hardly use chemical fertilisers (Mwangi 1998). In these small farms, people grow variety of crops some using sewage water (Dennry 1995).

It is high time that other ways of replenishing of the soil nutrients, such as use waste recycling, should be explored. It has been shown that plants such as spinach, cabbages, maize and wheat produces maximum yield when the wastes such as urine are applied (Mnkeni et al 2005).

Countries like Sweden, Ghana, Japan, Germany and Australia are already promoting waste reuse (Maeda et al 1996, Law 1996 Jefferson et al 2000, Nolde 2000, Kvarnstrom et al 2002, Bradford et al 2003 Degaard 2003). Recycling is one of the way of closing the Phosphorus loop and prevents environmental degradation (Gumbo 2005). There is a general concern that recycling of waste could pose a threat to human health. It has been shown that direct exposure of untreated wastewater could pose a risk of *Ascaris lumbricoides* infection and diarrhoel diseases (Blumental et al 2001). Different treatment technologies are available and have been applied in many parts of the world (Bradford et al 2003, Jefferson et al 2004). It is also possible to separate urine from the source and minimise any contamination (Maure et al 2002, Vinneras 2002, Degaard 2003).

Kibera produce P ( $6.4 * 10^3$  kg/month) which can be used to fertilise a big area agricultural land with expected high food production to feed many people (Box6-1)

Using the P calculator model (Gumbo 2005), reuse of the waste fractions on agricultural land was simulated. This tool helps the agriculturalists to plan for the amount of wastes to be diverted depending on the availability of land.

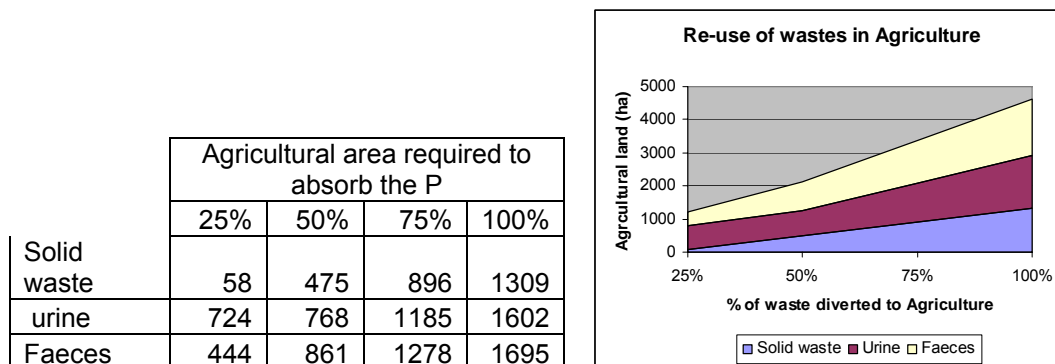


Figure 6-2: shows the results of P-calculator model simulation (Gumbo 2005).

Fig 6-2 above shows different scenarios for P application in agriculture.

#### Different scenarios for waste water reuse in agriculture

- If grey water is applied on the farms at a rate of 2 % per month, without any fertiliser application, the total P- added will be 88 kg P/month
- The excess P- in the soil (Pss) which is not required by the plants and remain in the soil was estimated at 96 kg P/month (calculated as  $[88+27-(18+0.35+0.28)]$ )
- By adjusting the area (Ac) in the model, the total area required to absorb all Phosphorus was found to be about 267000 m<sup>2</sup> (26.7 ha)
- If solid wastes were composted and transported to agriculture as fertilisers, a total of 1309 ha of land would be required.

- Diverting of 100 % urine for use in agriculture would require a total of 1602 ha.
- If all the wastes (urine, faeces, and solid wastes) and 2 % grey water from Kibera were to be used as fertilisers, a total of 1700 ha would be required

*Box 6-1: waste reuse potentials*

If all the wastes produced in one month are diverted to land, a total of about 1700 ha would be required for agricultural productivity. Assuming that it is applied to maize plantations with an estimated maximum yield of 0.2 kg/m<sup>2</sup> (FAO 1996 Gumbo 2005), the total yield will amount to 3400 tonnes/yr of maize. According to FAO (2004) estimates, a person requires 100 kg/yr of maize for food. This implies that 34000 people will be fed with only waste generated in one month from Kibera. If all the wastes generated in one year are reused, a total of 400,000 people will have adequate food supply for the whole year.

*A report by Kenya Food security group of 8/2/06 shows that currently 3.5 million people face starvation and the affected groups are the poor farmers and pastoralists.*

The study has found that majority of people (55%) indicated that they would not eat any food grown using wastewater. However, it was noted that due to lack of awareness, 91 % of the respondents could not appreciate wastewater reuse. In other countries such as Ghana, people have positive perception on the wastewater reuse concept (Danso et al 2003).

## **6.4 Limitations of the study**

This study was carried out within a period of three months. The following were the limitations:

- Sampling of water for analysis was done during a dry spell and owing to the short time it was not possible to establish the P flow during both low and high rainfall seasons and the change with time.
- The limited research period led to a small sample size of 200 people out of a population of 200,000 people in Kibera. A bigger sample size might have provided more comparative results.
- The cost of sampling and analysis was found to be higher than anticipated and this limited the number of samples taken.
- The amount of materials used by the families varied with time. During the day, most people were away from their homes and return late in the night. The period of absence gives a gap in the materials used as well as the waste generated.
- The residents in the area of study were not willing to divulge the information viewing the whole process as a waste of time and with no monetary gain.

## 7 CONCLUSIONS AND RECOMMENDATIONS

### 7.1 Conclusions

From this study, the following conclusions were drawn:

- People in Kibera consume food and beverages at a rate of 27kg/p.month and the soaps and detergents amounts to 2.4 kg/p.month.
- The biggest contributors of P in the household systems are cereals, pulses (e.g. beans) and detergents.
- Urine contributes about 60 % of P in all the wastes from the household whereas grey water and solid wastes contributes the least (8 %). The total amount of Phosphorus lost as waste (through urine, faeces, grey water and solid waste) in Kibera amounts to  $6.4 \times 10^3$  kg/month.
- The results have shown that the P-concentration in the surface water is up to 50 times higher than the Kenyan guidelines for surface water.
- With less farming in Kibera, it can be concluded that the Phosphorus loading in the surface water is mainly from the household wastes from Kibera settlements.
- The P loading to the Nairobi dam is 166 g P/m<sup>2</sup>.yr (or  $6.4 \times 10^3$  kg/month) against the desired loading of 2.2g/m<sup>2</sup>.yr. The dam requires a 98% reduction in P-loading to reach the desired oligotrophic state. It is highly eutrophic and heavily silted. The residence time has reduced to 6 days from the original design of 10-20 days.
- The research also found that the residual P in the soils within Kibera varied with the vegetation cover and the plant species on the ground. Some plants have a high P uptake than others. This has an effect on the residual P in the soil.
- There is a possibility of using the wastes (urine, faeces, grey water and solid wastes) in agricultural land as fertilisers. The area required to absorb all the P from the wastes in Kibera was estimated at 1700 ha.

### 7.2 Recommendations

The research was conducted within a three-month period. This was a limitation on the time needed to evaluate deeply on the anthropogenic activities in the study area. It is recommended that:

- Trend analysis on surface water should be done over a long period of time taking into account spatial and temporal variability.
- To get more comparative results a longer period of time and financial support to cover a wider sample can be used. Future research should be adequately funded so that a comprehensive study is done.
- This study recommends establishment of monitoring stations along surface waters within Kibera to monitor the P-loading from both non point and point sources.

- Further research should be carried out to determine P concentrations in the sediments and its mobility in water.
- Further research, with the support of the Government of Kenya, is needed to establish the best options to treat these domestic wastes taking into account among other factors the technical and financial viability so as to get a comprehensive long term solution.
- The Government of Kenya through the Ministry of Agriculture needs to carry out an in-depth study on the suitability of phosphorus recycling in agriculture and the availability of farms to absorb all the phosphorus “waste” from households.
- Sensitization and education should be done on Kenyan farmers on the possible recycling and re-use of waste as a source of fertilizer in farming.

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## **9 APPENDICES**



**Appendix (A) Demographic information and climatic conditions of Kibera.**

**A) Population of Kibera from 1999 census report**

Place	Male	Female	Total	Proj. pop	Households	Area (km <sup>2</sup> )	Density Person/km <sup>2</sup>
Kibera	9328	6762	16090	16476.16	5226	0.3	53633
Makina	17821	15103	32924	33714.176	10589	0.9	36582
Silanga	10360	6158	16518	16914.432	6281	0.2	82590
Lindi	10983	7172	18155	18590.72	6603	0.3	60517
Laini saba	16412	10800	27212	27865.088	10150	0.4	68030
Gatwikira	13974	10486	24460	25047.04	8036	0.3	81533
Olympic	12119	10978	23097	23651.328	6542	0.7	32996
Mashimoni	12839	12628	25467	26078.208	6131	3.1	8215
<b>Total</b>	103836	80087	183923	200,000	59558	6.2	424096
Nairobi	1,153,828	989,426	2,143,254		649,426	696.1	3079

**B) Age structure of people in Nairobi (1999)**

Age structure	% distribution in Nairobi
0-14 years	36
15-64 years	62
Over 65 years	2

**C) Age adjustment factor, K, for the population of Kibera (200,000 people)**

*Assumption : 0-14yrs and above 65 years excrete waste equivalent to 50 % of adults between 15-64 yrs*

$$\begin{aligned}
 K &= 0-14 \text{ years}(0.36) * 0.5 + (0.02) * 0.5 + 0.62 \\
 &= (0.36 + 0.02) * 0.5 + 0.62 \\
 &= 0.81
 \end{aligned}$$

**D): Nairobi Wilson Airport Meteorological Station** {Location: Latitude 1<sup>0</sup>19' S; Longitude 36<sup>0</sup>49' E, Altitude 1683, Period of Record: 1961-1980}

Month	Temperature		Relative Humidity		Monthly mean Rainfall (mm)	No. of Rain days
	Daily Maximum (°C)	Daily Minimum (°C)	Daily maximum (%)	Daily Minimum %		
January	26.2	12.9	73	40	66.1	3
February	27.1	13.3	72	39	44.9	5
March	27.1	14.4	79	41	83.3	10
April	25.4	15.0	86	53	190.3	15
May	23.8	14.0	86	58	160.6	13
June	22.8	12.0	85	56	34.5	3
July	22.0	11.3	84	54	16.5	3
August	22.7	11.3	84	51	18.8	4
September	25.2	11.8	80	41	22.2	3
October	26.2	13.6	77	40	48.4	5
November	24.5	14.3	83	53	134.6	14
December	24.8	13.8	78	46	83.5	7
<b>Total</b>	<b>297.8</b>	<b>157.7</b>	<b>967</b>	<b>572</b>	<b>904</b>	<b>85</b>
<b>Max</b>	<b>27.1</b>	<b>15</b>	<b>86</b>	<b>58</b>	<b>190</b>	<b>15</b>
<b>Min</b>	<b>22</b>	<b>11.3</b>	<b>72</b>	<b>39</b>	<b>17</b>	<b>3</b>
<b>Average</b>	<b>24.8</b>	<b>13.1</b>	<b>81</b>	<b>48</b>	<b>75</b>	<b>7.1</b>

**E) Nairobi Dagoretti K. Meteorological Station**

{Location: Latitude 1<sup>0</sup>18' S; Longitude 36<sup>0</sup>49' E, Altitude 1798, Period of Record: 1955-1980}

Month	Temperature				Relative Humidity		Monthly mean Rainfall mm	Nos. of Rain Days
	Daily Max (°C)	Daily Min (°C)	Extreme High (°C)	Extreme Low (°C)	Daily Max (%)	Daily Min (%)		
January	24.5	11.5	29.7	3.3	76	46	72	5
February	25.6	11.6	29.7	4.7	74	42	55	5
March	25.6	13.1	30.6	6.7	80	44	95	9
April	24.1	14	28.8	7.8	86	36	220	16
May	22.6	13.2	27.1	7.2	88	61	179	14
June	21.5	11	26.8	4.4	86	59	35	5
July	20.6	10.1	25.8	2.5	87	59	17	3
August	21.4	10.2	27.9	2.9	85	56	22	4
September	23.7	10.5	29.1	3.9	84	47	28	4
October	24.7	12.5	28.3	5	80	44	58	6
November	23.1	13.1	27.8	6.7	86	56	155	15
December	23.4	12.6	27.4	5.3	80	53	100	7
<b>Total</b>	<b>280.8</b>	<b>143.4</b>	<b>339</b>	<b>60.4</b>	<b>992</b>	<b>603</b>	<b>1037</b>	<b>93</b>
<b>Max</b>	<b>25.6</b>	<b>14</b>	<b>30.6</b>	<b>7.8</b>	<b>88</b>	<b>61</b>	<b>220</b>	<b>16</b>
<b>Min</b>	<b>20.6</b>	<b>10.1</b>	<b>25.8</b>	<b>2.5</b>	<b>74</b>	<b>36</b>	<b>17</b>	<b>3</b>
<b>Average</b>	<b>23.4</b>	<b>12.0</b>	<b>28.3</b>	<b>5.0</b>	<b>83</b>	<b>50</b>	<b>86</b>	<b>7.8</b>

## Appendix B: Questionnaire used during the survey

### A. Family information

Let me start by asking you a question, which touches on your family. You may not answer everything, but I would appreciate if you were to answer all.

A 1. How many members of your family do you have? .....

A2. What is the age structure of your family members?

Gender	Teenage (1- 14 years)	Adult (15-65 years)	Old (Above 65 years)	Total
Male				
Female				

A3. What is your source of income?

- Employed 1
- Farming 2
- Business 3
- Others ( specify)..... 4

A4 what is your approximate Household income Per Month (in Ksh)?

1. (< 1000) 2.(1000- 1499) 3.(1500 – 5000) 4. (5000 –10000) 5. (10 000-20000). 6.Over 20000

### B. Food and Beverage

B1. How many times do you (household) consume the following food groups per week?

	1(once)	2(twice)	3(thrice)	4 (everyday)	5 (Other)
Amount of cereals such as bread					
Meat and fish					
Milk and eggs					
Vegetables					
Nuts					
Starchy roots					
Pulses					
Beverages					

### C. Water use

C1. How much water do you use per day?

- 1- 20 litres 1
- 20-40 litres 2
- Above 40 litres 3

C2. Where do you get your water?

- From the river or stream 1
- Piped into respondent's yard or plot 2
- Communal tap (municipal supply) 3
- Buy (delivered Y/ N) KSH.....per 20Litres) 4
- Other (Specify.....) 5

C3. How do you dispose of water that has been used for washing dishes, doing laundry and bathing?

- Pour into sewage/septic tank/pit latrine 1
- Throw into road surface or empty space 2
- Flushing toilet in my house/yard 3
- Irrigating plants in my yard 4
- Other (please explain.....) 5

C4. How much water do you generate, as wastewater, per day?

- Less than 5 litres 1
- 5- 10 litres 2
- 10-20 litres 3
- 21-30 litres 4
- Above 30 litres 5

### D. Soaps and Detergents

D1. Which common soaps and detergents do you use?

	1. Bar soap	2. Toilet soap	3. Detergents	4. Others
For bathing				
For washing of clothes				
Washing of utensils				

D2. Mention one common detergent you use for washing. 1. Omo 2. Jik 3. None 4. Other (specify).....

D3. What size of these soaps and detergents do you use per week?

		1 (1-100g)	2 (101-200g)	3 (201-500g)	4 (501-1000g)	5 (Above 1 kg)
1	Bar soap					
2	Toilet soap					
3	Detergents					
4	Other (specify).....					

### E. Solid waste

E1. How much solid waste do you dispose in a week?

1. 1-2 kg 2. 2.1-4 kg 3. 4.1-6 kg 4. 6.1-8kg 5. Above 8 kg

E2. Which is the most common type of solid waste materials in your disposal?

- Paper and cardboard 1
- Organic material 2
- Plastics 3
- Other (specify)..... 4

E3. Where do you dispose of your solid waste?

- Dumping pit 1
- On land anywhere 2
- Collected 3
- Composting 4
- Other (specify)..... 5

### F. Reuse

F1. Do you grow any crops where you live? (If No go to F8) 1. Yes 2. No

F2. If yes which ones?.....

F 3. What is the yield of your crops?

- Low 1
- Medium 2
- High 3

F4. Do you use any fertilizer for your crops? 1. Yes 2. No

F5. If yes, which type of fertilizer do you use for your crops? 1. DAP 2. Animal Manure 3. compost 4. Others (specify).

F6. How much do you spend per year on this fertilizer? – Ksh 100 - 500 1  
 - ksh 501 - 1000 2  
 - ksh 1001 - 2000 3  
 - ksh over 2000 4

F7. Do you sell any of your crops? 1. Yes 2. No

F8. Do you keep any animals or poultry? (If No go to F10) 1. Yes 2. No

F9. If yes which ones? .....

F10. Do you know of anybody who uses urine/faecal matter/ untreated sewage water in their crops?  
 1. Yes 2. No

F11. What is your opinion about use of treated urine & faeces and sewage water in crops? (treated = free from smell and pathogens )  
 .....

F12. Would you consume products grown in this way? 1. Yes 2. No. 3. Not sure

### **Appendix C: Biodata of survey assistants and selected families**

Detailed information of the selected families and the research assistants

#### **A) List of the Survey assistants**

Name	Education	Field survey experience
Elkana Yegon	-KCSE certificate - Currently doing a computer Course.	Done 2 previous surveys
Charles koech	- KCSE - Diploma in marketing	Done household survey and water sampling
*Kipkemoi	-KCSE certificate	Done household survey on the impacts of Aids in Kibera

\* This assistant was born and brought up in Kibera. So he understood the place very well.

#### **B) Criteria for selection of the families**

- One family with at least one member employed with regular income per month (Regular income is likely to dictate the type and amount of materials used)
- One family with a large family unit ;more than five members (So as to compare with one having a small family unit)
- One family with a garden where they grow crops for consumption ( This will give an indication of the kind of fertilisers used and their perception on the wastewater reuse option)
- One family who depends on business as a source of income ( aim is to compare their material flow with those who are employed)
- One family with no dependant

#### **B) The profiles of the selected families**

Family 1	“My name is John Njuguna, working for a security firm in Nairobi Town. Iam married but my family is at home. So I’m all alone here. I’m 32yrs old with no dependant here. I rent this house and depend on salary alone. I have no garden and I buy water (20 litres per day) from the water vendors. My income is small; Ksh 6200 (approx. 60 euro)”
Family 2	“My name is Mohammed Juma. I have lived here for the last 20 years. My family depends on small business since we have no job. I plant some vegetables and bananas. I sell second hand clothes. In total we get about Ksh 2500 (250 euro) but that is for food, school fees, rent. I have a big family”
Family 3	“Im Abdalla Abba. I work with a private company in Industrial area as a driver. My wife sells roasted maize and smoked fish in the market. Our total income is about ksh15000 (150 euro).this is not enough to feed my big family. In addition we buy water from far. Life is tough”
Family 4	“My name is Alice Khamala. Iam a single parent with two kids. I work in a NGO in Kibera. I also own a shop. I buy water and my income is about Ksh 10,000 (120 euro)”
Family 5	“My name is Omolo. I have a family of 6 and I work in industrial area. My wife also works. Our combined income is about Ksh 20000 (200 euro). I own no land. Everything including rent depends on our salaries”



**Appendix D: Materials flow from the households of the selected families**

**A) Inventories used during the monitoring programme**

**(i) Food and beverages**

Food type (g)	Sat	Sun	Mon	Tue	Wed	Thur	Fri
Cereals							
Meat and Fish							
Milk and Eggs							
Vegetables							
Nuts							
Starchy roots							
Pulses(e.g. Beans)							
Beverages							
Others							

**(ii) Solid waste types**

Solid type (g)	Sat	Sun	Mon	Tue	Wed	Thur	Fri
Paper and cardboard							
Organic material							
Plastics							
Glass							
Metals							
Wood, Leather and Rubber							
Textiles							
Miscellaneous							

**(iii) Water consumption**

Water use	Sat	Sun	Mon	Tue	Wed	Thur	Fri
Domestic use							
Washing							
Bathing							

**(B) Food classes (FAO 1999)**

Cereals	comprising of foods like rice, bread, wheat flour, maize, millet but excluding beer
Meat and fish	Beef, pork, goat meat, poultry meat and all types of fish such as tilapia, Nile perch
Milk and eggs	fresh, sour, yoghurt excluding butter whereas eggs comprised cooked or boiled
Vegetables	All the leafy vegetables comprising of spinach, kales and cabbages
Nuts	Peanuts, groundnuts and macadamia nuts
Pulses	beans , peas ,Soya beans
Starchy roots	included potatoes, carrots, sweet potatoes, arrow roots, cassava, yams
Beverages	Alcoholic, fermented beer, wine

*E) Age adjustment factor for the families*

	Family 1	Family 2	Family 3	Family 4	Family 5
Family size, h	1	7	6	3	6
Age 0-14yrs (x)		3	2	1	
Structure 15-64yrs (y)	1	4	4	2	6
> 64 yrs (z)					
Adjustment factor, K	1	5.5	5	2.5	6

*F) Actual materials flow for the five families*

<b>Food and beverages</b>	Family 1	Family 2	Family 3	Family 4	Family 5	
Food group	<b>{Amount of material used in kg/person/month}</b>					<b>Average</b>
Cereals	12.8	14.4	6.4	10.9	6.1	10.9
Meat and Fish	1.4	0.8	2.5	2.2	2.7	1.9
Milk and eggs	3.7	2.5	5.6	5.6	2.5	3.2
Vegetables	3.0	1.7	2.3	3.6	2.0	3.0
Nuts	0.0	0.0	1.9	0.3	0.6	0.6
Starchy roots	6.4	5.7	1.4	2.9	1.9	2.1
Pulses	2.0	1.9	1.4	4.4	4.1	2.1
Beverages	0.1	0.9	4.0	4.5	6.8	3.4
<b>Total</b>	<b>26.4</b>	<b>28.0</b>	<b>25.4</b>	<b>28.8</b>	<b>26.7</b>	<b>27.2</b>
<b>Solid waste</b>						
Paper	0.7	0.5	0.3	0.4	0.8	0.4
organic materials	4.0	5.0	4.1	4.4	3.6	4.3
Polythene bags & plastics	0.8	0.3	0.8	0.6	0.6	0.7
Glass	0.1	0.1	0.6	0.3	0.2	0.3
metals	0.4	0.1	0.5	0.8	0.3	0.4
wood, leather and rubber	0.2	0.1	0.6	0.4	0.6	0.3
Textiles	0.3	0.2	0.5	0.4	0.3	0.3
miscellaneous	0.3	0.2	0.2	0.3	0.3	0.3
<b>Total</b>	<b>6.8</b>	<b>6.5</b>	<b>7.5</b>	<b>7.6</b>	<b>6.6</b>	<b>7.0</b>
<b>Soaps and detergents</b>						
Washing soap	0.7	0.8	0.5	0.5	0.6	0.6
Bathing soap	0.3	0.3	0.1	0.1	0.3	0.2
Detergent	0.4	0.3	0.8	0.5	0.5	0.5
<b>Total</b>	<b>1.4</b>	<b>1.4</b>	<b>1.4</b>	<b>1.1</b>	<b>1.4</b>	<b>1.4</b>
<b>Water consumption</b>						
	<b>Amount of water used in Litres per person per day (L/p.d)</b>					
water for domestic	2.0	2.0	2.0	2.0	2.5	2.0
water for washing	11.8	15.0	16.0	12.0	15.0	13.0
water for bathing	3.9	5.0	6.0	5.0	7.0	6.0
<b>Total</b>	<b>17.7</b>	<b>22.0</b>	<b>24.0</b>	<b>19.0</b>	<b>24.5</b>	22.0

**G) Calculated P average for the food components**

Food group	kg/p.mon th	P- content in g/kg	gP/p. month	Cal. weighted P (g /kg)
Cereals	10.8	1.86	20.3	0.75
Meat and fish	1.9	1.55	3.0	0.11
Milk & eggs	3.2	0.93	3.0	0.11
Vegetables	3.0	0.85	2.5	0.09
Nuts	0.6	4.05	2.3	0.08
Starchy roots	1.9	0.46	0.9	0.03
pulses	2.1	4.62	9.6	0.35
Beverages	3.4	0.13	0.4	0.02
<b>Total</b>	<b>27.0</b>		<b>42.2</b>	<b>1.55</b>
				<b>0.0016</b>

**H) P value for different soaps (g P/kg)**

No ( n)	Soap type	Quantity ( $M_{sd}$ ) in kg/month	P value ( $\sigma_{sd}$ ) g/kg
1	Bar soap ( example found Kwanga )		1.1
2	Toilet soap ( Common ones were Imperial leather, Geisha , Lifebuoy)		0.5
3	Detergent ( powder) (common ones were Omo, Sunlight powder )		2.5



**Appendix E: Calculations**

**A) Water balance**



The accumulation of water in the dam, change in storage, can be expressed as follows:

$$\text{Accumulation} = \text{inflow} - \text{outflow}$$

Assuming that the change in storage is negligible, then, inflow = outflow

Area of the dam	$= 3.6 * 10^5$
Average Rainfall (P)	$= 970 \text{ mm/yr (sec 6.4)}$ $= 349200 \text{ m}^3/\text{y}$
Volume of the dam	$= 9.8 * 10^4$
Evaporation in $\text{m}^3/\text{y}$	$= 1.75 * \text{Area}$ $= 1.75 * 3.6 * 10^5$ $= 623000$
Evapotranspiration (ET)	$= E * 1.13 \text{ (sec 6.91)}$ $= 704000 \text{ m}^3/\text{y}$
Discharge spillway ( $Q_s$ )	$= 0.2 \text{ m}^3/\text{s}$ $= 6307200 \text{ m}^3/\text{y}$

Assuming that there is no change in storage and the seepage in the dam is negligible, the discharge by the river into the dam at capacity can be estimated as below:

Water flowing into the dam is from precipitation, P and rivers, R. The outflow of water, out of the dam is through evapotranspiration, ET and discharge,  $Q_s$ .

Thus the water balance equation may be written as:

$$P + R = ET + Q_s$$

The discharge flowing from the dam through the spillage was measured at  $0.2 \text{ m}^3/\text{s}$  ( $6,307,200 \text{ m}^3/\text{y}$ )

$$\begin{aligned} \text{Out flow (ET} + Q_s) &= (6,307,200 + 704,000) \\ &= 7,011,200 \text{ m}^3/\text{y} \end{aligned}$$

Rearranging the above equation,

$$\begin{aligned} R \text{ (river)} &= (ET + Q_s) - P \\ &= 7,011,544 - 345636 \\ &= 6,665,908 \text{ m}^3/\text{y} \\ &= 6.7 * 10^6 \text{ m}^3/\text{y} \end{aligned}$$

The river is flowing into the dam at a rate of  $0.2 \text{ m}^3/\text{s}$  (when it is full). This implies that the dam can no longer hold water due the reduction of its volume.

**B) Phosphorus loading to the Dam**

The phosphorus loading in the dam was calculated using the Vollenweider model equation below:

$$[P] = \frac{w^1}{q + 10}$$

Where

P is the phosphorus concentration (g /m<sup>3</sup>)

w<sup>1</sup> is annual phosphorus loading per unit area(g/ m<sup>2</sup> /yr)

q is the water discharge per unit area ( m/yr)

From the above results[ P] = 5.81mg/l  
 = 5.81 g /m<sup>3</sup>

Water discharge, q, ( m/yr) = Discharge (m<sup>3</sup>/y)/ Area of the dam (m<sup>2</sup>)  
 = 6.7 \* 10<sup>6</sup> m<sup>3</sup>/y /3.6 \* 10<sup>5</sup> m<sup>2</sup>  
 = 18.6

Annual P-loading, W<sup>1</sup>(g/ m<sup>2</sup> /yr) = [ P] \* (q+ 10)  
 = 5.81 \* 27.5  
 =166 g/ m<sup>2</sup> /yr

Total loading based on the area of the dam = Loading W<sup>1</sup>\* Area of the dam  
 = 166(g/ m<sup>2</sup> /yr) \*3.6 \* 10<sup>5</sup>m<sup>2</sup>  
 = 6 \* 10<sup>7</sup> g/y  
 = 6 \* 10<sup>4</sup> kg/y  
 =5\* 10<sup>3</sup> kg/month  
 = 160 kg/day

Desirable state of the dam; oligotrophic (10mg/m<sup>3</sup>)  
 Annual P-loading, W<sup>1</sup>(g/ m<sup>2</sup> /yr) = 0.01 \*27.5  
 = 2.8 g/ m<sup>2</sup> /yr

Total P-loading = 2.8 g/ m<sup>2</sup> /yr \*3.6 \* 10<sup>5</sup>m<sup>2</sup>  
 = 99 kg/yr  
 = 8.3 kg P/month

**C) Residence time, T**

This was calculated using the formulae, T, = Volume of the dam (m<sup>3</sup>)/ discharge (m<sup>3</sup>/s)  
 = (9.8 \* 10<sup>4</sup> m<sup>3</sup>/y /6,307,200 m<sup>3</sup>/y)  
 = 0.16 years  
 =5.7 days  
 Approx. = 6 days

**D) Calculation of P in the wastes**

P(tot) from Urine = P-value (urine) (kg/p.yr) \* Age corr. Factor \* Population  
 = 0.3 kg/ca.yr \* 0.81 \* 200,000  
 = 48600kg/yr  
 = 4050 kg/month  
 = 4.1 \* 10<sup>3</sup> kg/month

P(tot) from Faeces = P-value (Faeces) (kg/p.yr) \* Age corr. Factor \* Population  
 = 0.1 kg/ca.yr.\* 0.81 \* 200,000  
 = 16200kg/yr  
 = 1350 kg/month  
 = 1.4 \*10<sup>3</sup> kg/month

P ( tot) from grey water = P-value grey water (soaps and detergents) \* Population  
 = 2.2 g P/p.month \* 200000

$$= 440 \text{ kg/month}$$

$$= .44 * 10^3 \text{ kg/month}$$

P (biodegradable solid wastes = see below

The moisture content was assumed to be 64 % (JICA 1998)

$$\text{Dry organic matter (36 \%), } \lambda, \quad = 36\% * \text{ Total organic in solid waste (kg)}$$

$$= 0.36 * 4.3 \text{ kg/p.month}$$

$$= 1.6 \text{ kg/p.month}$$

Calculated average P content of the main components of food flux in the waste was estimated at 0.0016 kg/kg (Appendix D)

$$\text{The P value of the soild waste} = \lambda * \text{ P average}$$

$$= 1.6 * 0.0016\text{kg}$$

$$= 2.56 * 10^{-3} \text{ kg P/p.month}$$

$$\text{Total P from solid waste in Kibera} = \text{Pvalue of solid waste} * \text{ population}$$

$$= 2.56 * 10^{-3} \text{ kg p/p.month} * 200,000$$

$$= 512\text{kg P/month}$$

$$= 5 * 10^2 \text{ kg/month}$$



**Appendix F: Trend analysis of Phosphorus in streams and River Motoine**

Samples were taken on 18/11/2005 from all the sampling sites (Fig 3-2)

(A) Water sample from drains

(B) Water sample from spring

No (n)	Conc. (mg P/l)
1	(2.02.2)¥ 2.1
2	2.3
3	2.1
4	2.2
5	2
6	2.4
7	2.3
Mean, $X_{av}$	2.20
Stdev, $s_x$	0.1414
t value	2.50
$\sqrt{n}$	2.65
$t * s_x/\sqrt{n}$	0.1336

At 95 % limit  
 $X_{av} \pm t s_x \sqrt{n}$  2.2±0.1  
 Qc\* 3

No (n)	Conc. (mg P/l)
1	0.02
2	0.01
3	(0.01,0.01)¥ 0.01
4	0.012
5	0.02
Mean, $X_{av}$	0.01
Stdev, $s_x$	0.0052
t value	2.80
$\sqrt{n}$	2.24
$t * s_x/\sqrt{n}$	0.0065

At 95 % limit  
 $X_{av} \pm t s_x \sqrt{n}$  0.01± 0.007

Qc tools

Qc sample \* 2.8

© Water from the Dam

No (n)	Conc (mg P/l)
1	5.8
2	6.2
3	5.6
4	5.4
5	5.7
6	6.1
Mean, $X_{av}$	5.80

Stdev,  $s_x$  0.3033  
 value 2.57  
 $\sqrt{n}$  2.45  
 $t * s_x/\sqrt{n}$  0.3182

At 95 % limit  
 $X_{av} \pm t s_x \sqrt{n}$  5.8 ± 0.3  
 QC\* 3.2

(D) Analysis of P trends in Motoine river and the two streams in Kibera

Motoine River		Stream 1		Stream 2	
Site	Conc. Mg P/l	Site	Conc. Mg P/l	Site	Conc. Mg P/l
M1	0.12	S1	0.13	D1	2.59
M2	1.25	S2	2.00	D2	1.52
m3	2.26	S3	7.80	D3	3.10
M4	2.09	S4	9.60	D4	6.00
M5	2.31	S5	7.30	D5	7.58
M6	4.68	S6	7.40	D6	6.30
M7	4.78	S7	6.30	D7	5.10
M8	5.00	S8	5.10	D8	3.70
M9	4.38	S9	3.70	D9	3.67
Qc*	3.2		3.1		3.1

(E) Bio available P in Prison and Karanja Rd farms

Vegetation cover	Conc. P (as PO <sub>4</sub> -P) in mg P/l		
	Prison	Karanja Rd	% difference
Bare	4.3	4.9	12.2
Animal manure	6.7	8.9	33.5
sweet potato	6.2	7.4	19.3
Tomato	5.3	5.6	6.1
Maize	6.0	5.6	-6.2
Qc*	3.3		

\*Acceptance criteria for the Qc = 3 ±0.3 mg P/l  
 ¥ (Duplicates)



**Appendix G: Kenya guidelines for discharge into natural water courses**

Parameter	Natural Water Courses		Public Sewers	
	NCC Standards	G.O.K. Standards	NCC Standards	G.O.K. Standards
pH	6 to 9	6.0-9.0	6-9	6.0-9.0
Temperature	<25 °C	±/-2°C of ambient temp. of the water body	<35	27°C =/-2°C
Oxygen absorbed, 4hr, @27°C,mg/l	<15 mg/l		100 mg/l	
COD, mg/l	<10 mg/l	50 mg/l		1000mgO <sub>2</sub> /l
BOD, 5 days @20°C, mg/l	<20 mg/l	20 mg/l	<450	500mgO <sub>2</sub> /l
Suspended solids	<30	30 mg/l	<300	500mg/l
Total dissolved solids, mg/l	<1500	1200 mg/l		2000 mg/l
n-Hexane extract		30 mg/l		
Total Nitrogen excluding NO <sub>3</sub> , mg/l	1			
Total Nitrogen excluding NH <sub>3</sub> , mg/l	1.5			
Nitrates as NO <sub>3</sub> , mg/l	<45			
Detergents, mg/l				15 mg/l
Phenols, mg/l				10 mg/l
Oils/grease, mg/l		Nil (no trace)		10 mg/l
Oils (Mineral Animal & Vegetable)		5.0 mg/l		
Soaping Oils and Fats mg/l				50 mg/l
Hydrocarbons mg/l				20 mg/l
Hydrocarbons (cyclic)				5 mg/l
Silver (cyclic Ag.)				2 mg/l
Asenic (As)		0.002mg/l		0.2 mg/l
Barium (Ba)		2.0 mg/l		10 mg/l
Cadmium (Cd)		0.05 mg/l		0.5 mg/l
Chloride				2 mg/l
Cyanide (CN)				0.5mg/l
Total Cyanide		0.1 mg/l		2.0mg/l
Cobalt (Co)				1.0 mg/l
Chromium six (Cr)		0.1 mg/l		0.05 mg/l
Chromium (six)(Cr <sup>6+</sup> )		0.005 mg/l		
Total chromium (Cr)				1.0 mg/l
Copper (Cu)				1.0 mg/l
Mercury (Hg)				0.01 mg/l
Ammoniacal Nitrogen (N-N <sub>4</sub> .NH <sub>3</sub> )				10 mg/l
Free Ammonia		0.2 mg/l		
Nickel (Ni)		1.0 mg/l		1.0 mg/l
Nitrates (NO <sub>3</sub> )				20 mg/l
Lead (Pb)		0.1 mg/l		1.0 mg/l
Total Phosphorous		1.0 mg/l		30 mg/l
Sulphur (S)				2.0 mg/l
Sulphide (S <sub>2</sub> )		0.1 mg/l		2.0 mg/l
Selenium (Se)		0.005 mg/l		0.2 mg/l
Tin (Sn)				5.0 mg/l
Sulphite (SO <sub>3</sub> <sup>2-</sup> )				50 mg/l
Sulphate (SO <sub>4</sub> <sup>2-</sup> )		500 mg/l		1000 mg/l
Zinc (Zn)		0.5 mg/l		5.0 mg/l
Total non-Ferrous metals				10 mg/l
Chlorides (Cl <sup>1-</sup> )		1000 mg/l		1000 mg/l
Total Phenol		2.0 mg/l		
Copper (Cu)		0.05 mg/l		
Total mercury (Hg)		0.005 mg/l		
Alkyl Mercury		0.001 mg/l		
PCB (polychlorinated Biphenyl)		0.003 mg/l		
Pesticides residues		0.05 mg/l		
Dissolved manganese (Mn)		1.0 mg/l		
Fluoride		2.0mg/l		
Coliform bacteria		1000/ml100		
Toxic substances		Nil		Nil
Odour	Not objectionable to the nose			
Colour	Not objectionable to the eyes OR not to exceed 5mgPt/l			



## Appendix H: P calculator model calculations

### A) Rainfall water balance (mm/month)

Months	R	I	Tr	Qs	Reff	Beta	Qg	Gamma zero	B
Initial	218.4	47.0	117.1	41.2	171.5	12.4	13.2	0.3	0.7
1	135.2	35.6	68.1	23.9	99.6	9.8	7.6	0.3	0.7
2	105.5	30.5	51.2	18.0	75.0	8.8	5.8	0.3	0.7
3	38.7	15.7	15.7	5.5	23.0	5.8	1.8	0.3	0.7
4	12.4	6.9	3.8	1.3	5.5	3.7	0.4	0.3	0.7
5	0.3	0.3	0.0	0.0	0.0	0.9	0.0	0.3	0.7
6	0.2	0.2	0.0	0.0	0.0	0.7	0.0	0.3	0.7
7	2.9	2.2	0.5	0.2	0.7	2.1	0.1	0.3	0.7
8	4.1	2.9	0.8	0.3	1.2	2.4	0.1	0.3	0.7
9	34.3	14.4	13.6	4.8	19.9	5.5	1.5	0.3	0.7
10	73.5	24.2	33.7	11.8	49.3	7.5	3.8	0.3	0.7
11	162.6	39.7	84.0	29.5	122.9	10.7	9.4	0.3	0.7
12	162.6	39.7	84.0	29.5	122.9	10.7	9.4	0.3	0.7

### B) Municipal water balance

Months	Grey water Wg mm/month	Total water for irrigation Wi mm/month	Black water flux Ws mm/month	Surface Run-off Qs mm/month	Municipal water flux Wms mm/month	Total vol urine Wy mm/month
Initial	12.17	7.61	16.63	11.04	18.38	0.34
1	12.17	7.61	16.63	7.62	17.84	0.34
2	12.26	7.67	16.74	14.8	19.09	0.34
3	12.01	7.51	16.41	38.46	22.5	0.34
4	12.26	7.67	16.74	31.12	21.67	0.34
5	12.17	7.61	16.63	4.74	17.38	0.34
6	12.17	7.61	16.63	1.91	16.93	0.34
7	12.34	7.72	16.85	2.59	17.26	0.34
8	12.17	7.61	16.63	3.28	17.15	0.34
9	12.26	7.67	16.74	8.21	18.04	0.34
10	12.34	7.72	16.85	25.71	20.92	0.34
11	12.34	7.72	16.85	15.23	19.26	0.34
12	12.42	7.77	16.96	15.23	19.37	0.34

### C) Household P-balance

#### P-household balance (kg/month)

Months	Pfb	Pb	Py	Pms	Psd	Psw	Pg
Initial	6,836.40	1,133.72	4,212.00	5,697.72	440	450	440
1	6,836.40	965.53	4,212.00	5,529.53	440	450	440
2	6,836.40	1,352.36	4,212.00	5,916.36	440	450	440
3	6,836.40	2,411.61	4,212.00	6,975.61	440	450	440
4	6,836.40	2153.55	4,212.00	6,717.55	440	450	440
5	6,836.40	824.15	4,212.00	5,388.15	440	450	440

6	6,836.40	685.54	4,212.00	5,249.54	440	450	440
7	6,836.40	786.72	4,212.00	5,350.72	440	450	440
8	6,836.40	752.71	4,212.00	5,316.71	440	450	440
9	6,836.40	1,028.81	4,212.00	5,592.81	440	450	440
10	6,836.40	1,922.06	4,212.00	6,486.06	440	450	440
11	6,836.40	1,407.31	4,212.00	5,971.31	440	450	440
12	6,836.40	1,441.43	4,212.00	6,005.43	440	450	440
<b>Average</b>							
<b>(kg/month)</b>	<b>6,836.40</b>	<b>1,380.95</b>	<b>4,212.00</b>	<b>5,861.35</b>	<b>440.00</b>	<b>450.00</b>	<b>440.00</b>
<b>(Tonnes)</b>	<b>6.84</b>	<b>1.38</b>	<b>4.21</b>	<b>5.86</b>	<b>0.44</b>	<b>0.45</b>	<b>0.44</b>

#### D) Agricultural P budget (kg P/month)

Pss	Py	Psw	Pbu	Psr flow	Psi flow	Ple flow	New Ac	Pb	ePg
27.10				0.35	0.28		75288.89		88.00
6103.70	4212.00	450.00	18.00	0.13	0.19	0.11	16954733.33	1344.60	88.00
12180.30	4212.00	450.00	18.00	0.31	0.37	0.04	33834177.78	1344.60	88.00
18520.10	4212.00	450.00	18.00	0.51	0.96	0.10	51444733.33	1344.60	88.00
24719.55	4212.00	450.00	18.00	0.21	0.78	0.16	68665427.78	1344.60	88.00
30886.56	4212.00	450.00	18.00	0.16	0.12	0.07	85795997.22	1344.60	88.00
36963.16	4212.00	450.00	18.00	0.02	0.05	0.05	102675441.67	1344.60	88.00
43039.76	4212.00	450.00	18.00	0.07	0.06	0.01	119554886.11	1344.60	88.00
49116.36	4212.00	450.00	18.00	0.21	0.08	0.02	136434330.56	1344.60	88.00
55192.96	4212.00	450.00	18.00	0.39	0.21	0.07	153313775.00	1344.60	88.00
61269.56	4212.00	450.00	18.00	0.79	0.64	0.13	170193219.44	1344.60	88.00
67346.16	4212.00	450.00	18.00	0.13	0.38	0.25	187072663.89	1344.60	88.00
73422.76	4212.00	450.00	18.00	0.13	0.38	0.04	203952108.33	1344.60	88.00

#### E) Input data for rainfall

			source
R	Mean rainfall	Yearly data	Appendix
I	Interception	Model	
C	Surface runoff coefficient dependent on land use and amount of rainfall	.24	Gumbo 2005
Qs	Surface run-on or surface runoff		Model
Reff	Monthly effective rainfall	R-I	
Tr	Transpiration from Rainfall	B * Reff	Model
Qg	Ground water flow		Model
Sb	Limiting soil moisture	60	
Tpot	Potential transpiration per day for arable crops	6 mm	

### F) Input data for municipal water balance

A	Area of the study area	690,000 m <sup>2</sup>
Age-factor	Factor to correct the population as adults only	0.81
H	Population of Kibera in 2000	200,000
C fraction	Volume of black water arising from toilet flushing ( toilet cistern size of 10 litres)	0.3
W	Municipal water supply normalised to the catchment area (W) mm/month for year 2000 in Nairobi	$25l/ca.d^1(A=6200000 m^2)$ = 24 mm/month
a	Water use fraction (a), which determines the volume of water used for on-plot garden irrigation.	0.2
b	Determines the grey water volume generated from the kitchen $b_1 = 0.08$ ; bathroom $b_2 = 0.25$ and laundry $b_3 = 0.15$ ( $b = b_1 + b_2 + b_3$ ).	0.47
d	Based on assumption that an average adult person in the study area consumes about 2 litres of water per day either directly or indirectly	0.03
y	The urinary volumetric rate of excretion in l/pd in winter or summer for an adult person in the study area. .	0.4
F fraction	Fraction of greywater which evaporates from laundry fabrics, kitchen utensils and human body after washing and bathing (f)	0.1
Eg	Evaporation due to drying-out of laundry material and kitchen utensils.	$f\_fraction * Wg$
e fraction	The fraction of grey water that is applied an agricultural land	0.15
h	This factor is calculated from the proportion of surface and ground water flow which infiltrates the foul sewer system during wet weather	0.12

<sup>1</sup> Average monthly consumption was established to be 22 L/ca.d. This was not inclusive of flushing water. 3 litres taken ( Gumbo 2005, <http://netwas.org/> )accessed on 2/02/06)

### G) Input data for household P-balance

Total fb	Sum total of P contained in the food and beverages consumed per person per month (kg/month).	0.0422
Total sd	Sum of total P contained in the soaps and detergents consumed per person in the study area (kg/month)	0.0022
Sigma y	The P concentration of urine per an adult in kg/m <sup>3</sup> (An adult excrete 0.012m <sup>3</sup> / p month.	2
Sigma ms	Average concentration of municipal sewage of Nairobi.	0.5
Sigma sw	Taken as the calculated weighted average P-content of the main components of the food flux (kg/kg)	0.0015
Lamda	Is the quantity of dry organic or biodegradable solid waste fraction generated per person per month	1.5

### H) Input data for agriculture P-balance

Ac	Total area of land to be used for agriculture.	5 ha ( 50,000)
Vo factor	Effective volume factor i.e. volume of soil, less the greater than 2 mm soil fraction, which is deemed not to possess P-supply capacity	0.88
Sigma ss	This is the average available or labile P-content of the soil samples taken at the two farms (Prison and Karanja Rd farms) within the study area (kg/kg).	0.0000022
Rho b	The average bulk density of the soil within study area	1400
Pbl rate	This is the P-content in faecal matter for an average adult taken per month	0.3kg/ca.yr (0.0083kg/pm onth)
Yhb	Estimated average maize yield	0.2 kg/m <sup>2</sup>

It was assumed that maize yield is approx. 0.2 kg/m<sup>2</sup> as it was estimated in 1996

Approximate yield of maize and pulses in Kenya in 996

Province	Maize			Pulses		
	Area (ha)	Yield (kg /m <sup>2</sup> )	Production (tons)	Area (ha)	Yield(kg /m <sup>2</sup> )	Production (Tons)
Riftvalley	446000	0.23	1025800	20100	0.04	

Western	150000	0.21	315000	81000	0.05	
Nyanza	132000	0.23		76000	0.09	
Central	83000	0.12		55000	0.05	

Source : FAO 1996

<http://www.fao.org/> (accessed on February 2006)