# INVENTORY OF PHOSPHORUS FLUXES AND STORAGE IN AN URBAN-SHED: OPTIONS FOR LOCAL NUTRIENT RECYCLING

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Global fertiliser use has soared from less than 14 million tonnes in 1950 to about 145 million tonnes today. Consumption is now stable or declining in the industrialised countries but demand is still rising in the developing world. By 2025, it is estimated to reach 250 million nutrient tonnes per year. The major driving force is increasing food production, driven in turn by increasing human population and the growing demand for livestock products, particularly in developing countries. Cereals, rice, wheat, maize etc are the main source of nourishment for the world's population and currently around 50% of the nutrients, including phosphate, used in agriculture, are used in cereal production. Figure 1 shows the breakdown of global fertiliser consumption in terms of the macro-nutrients N (Nitrogenous fertiliser), P (Phosphate based fertiliser) and K (Potash fertiliser) as from 1961.

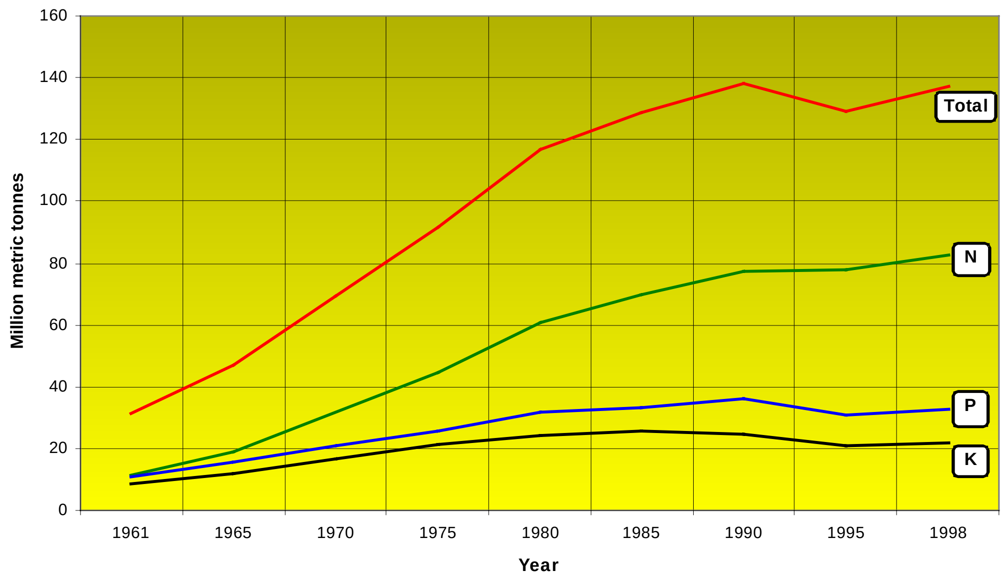


**Figure 1 Global fertiliser consumption**

Phosphorus (P) is a finite resource, with present recoverable reserves calculated to last for less than 200 years. Today, the annual global production of phosphate is around some 40 million tonnes of $P_2O_5$, derived from roughly 140 million tons of rock concentrate. Around 80% of phosphates produced by the world's industry are used in fertilisers, 5% to supplement animal feeds, 12% in synthetic detergent manufacture and about 3% is used in diverse applications such as metal surface treatment, corrosion inhibition, flame retardant, water treatment and ceramic production.

P originates from a mined non-renewable rock, therefore its presence in the urban-shed demonstrates the impact of urbanisation, agricultural intensification and the anthropogenic influences on natural cycles of material flow. In passing through the linear urban system P is mobilised from particulate to soluble forms and transported mostly via the urban water cycle, mostly as untreated or partially treated sewage, into the aquatic environment leading to adverse ecological and health impacts.

“Sustainability” is a way in which society utilises the environment. The environmental load that follows from social activities should be “ecologically suitable”. This means that the functioning of regeneration systems, absorption capacities, and other parts of the ecosystems is guaranteed both quantitatively and qualitatively.

With this in mind recycling of P in urban or peri-urban ecological agriculture (without synthetic fertilisers) is therefore becoming increasingly important. The ecological sanitation concept is a piece in this puzzle of global cycling of nutrients. As such, it may be useful to postulate that its “desirability” particularly in the urbanshed, should be assessed on its capacity to recycle nutrients locally relative to the global nutrient cycles of the pre-industrial era. The wholesome adoption of the concept should not portend future disruptions to ecosystems or human well being. This study seeks to establish a clear pattern of flow of water and P-bearing materials through an urbanshed, identifying options of short-cutting or closing the open-ended P-flows.

An inventory of annual P-fluxes based on charecterisation of input goods, processes, transformation, output fluxes and storage is presented for a high-density suburb in Harare, Zimbabwe where agriculture is already a major activity. Using systems thinking approach and material flow accounting two compartments or subsystems are defined to enable accounting and analysis of P-bearing materials. The “household” (consumption/use and excretion/waste) and “agriculture” (soil-plant interaction).

The micro study catchment falling within the Lake Chivero basin (main water supply source for Harare) consists of Mufakose and Marimba Park suburbs, which lie within a distinct hydrological catchment area of 6.5 $km^2$. The total population is about 100 000 which translates to a population density of about 7000 inhabitants/$km^2$. There are an estimated 9 400 residential stands including flats and about 100 non-residential stands. The average occupancy per stand is estimated to be 10.6 people. The age structure is as follows: 0-14 years, 43%; 15-64, 54% and 65 years and over, 3 %.

P inflows into the “household” subsystem (mainly to do with the activities “to nourish and clean”) amount to about 26 600 kg/a as food/beverages and 1 860 kg/a as detergents. Storage is taken as negligible by assuming that as soon as household P-bearing goods are purchased they are immediately consumed/used. The amount of P in food was established through mapping of weekly diet of the inhabitants based on a national nutrition survey and a local solid waste study.

The consumption patterns of Zimbabweans has been fairly well studied resulting in eighteen items being identified as significant components of the food expenditure. . For, unless the source and composition of local foods and habitual diet is known, nutrient recycling cannot be imagined satisfactorily. In Harare, like many major cities in Africa, some urban dwellers grow their own vegetables and part of their cereal requirements within the confines of the city boundary. In Harare today more than 10 000 hectares of public space is under cultivation annually (36% of open space). The figure is considerably higher if on-plot cultivation is included.

The most common food/beverage items consumed in considerably amounts and at least periodically were inventoried and the total P-content determined in the laboratory. Literature values were used to compliment and confirm laboratory results. The most common food is sadza (thick mealie meal porridge with the consistency of mashed potatoes made from white corn meal) taken with a leafy vegetable called 'rape'. Mealie meal has a P-content of 2 g/kg whilst for the vegetable its 1.19 g/kg and it is estimated that a household (residential stand) consumes about 15 kg of mealie meal and 1.3 kg of vegetables per week.

Similarly the type of soaps and detergents used were studied in a survey by observing weekly usage and chemical analysis of the most popular soaps was carried out. The quantities used per week multiplied by the average P-content of 1.5 g/kg in the soap/detergents produced the P influx as soap/detergents.

Since the transport and transformation of P in a region is dependent on the water cycle, a water flux balance was also established for the study area. The inputs being water supplied from the municipal mains (2.1 $Mm^3$/a) and rainfall (820 mm/a), and main outflux being evapo-transpiration, sewage (1.77 $Mm^3$/a) and storm water (1.54 $Mm^3$/a). Samples of sewage and storm water were collected for analysis and the average concentration of P as Ortho-P was 12.0 mg/l and 0.85 mg/l respectively. The average daily water consumption per stand for the past five years is 720 l/stand.day. The breakdown of water usage per stand was as follows: toilet flushing, 30%; bathing, 25%; laundry, 15%; kitchen, 10%; and garden, 20%.
Tests on fresh and stale urine indicate that the P-content varies between 0.4 to 0.6 g/cap.day whilst P-content of faeces was derived indirectly from wastewater characterisation. About 75% of P outflux is through sewage (combined black and greywater; 21 240 kg/a) and the remainder through the solid waste stream. P composition of sewage varies between 0.7 to 1.1 g/cap.day this includes the contribution by detergents/soaps. The solid waste generation rate and content varies significantly with the time of the year, from 0.2 kg/cap.day to about 0.5 kg/cap.day. Up to 65% of the waste is compostable organic material consisting of food scrap, agricultural residues and garden waste. Using the average P-content of 1.10 g/kg, with suitable adjustment for the moisture content of waste, the solid waste flux accounts for about 5 480 kg/a as P.

Urban agriculture extending over an area of about 3.5 $km^2$ (both on-plot and off-plot) accounts for the importation of about 4 410 kg/a of synthetic fertiliser as P (10.5 kg/ha). A variety of crops are grown, but the major ones being maize, sweet potatoes and vegetables (rape, tomatoes and onions). The maize crop is used for calculations in this subsystem. The main outfluxes are runoff/washout (1 750 kg/a) and the harvested portion of the crop (1 440 kg/a). The washout rates are estimated at about 4.5 kg/ha.a, which is high compared to commercial farming areas where the average rate is about 8 kg/ha.a considering that the latter apply five times as much fertiliser. This discrepancy is mainly due to poor soils with limited humic substances, which act as a soil conditioner for P retention, steep slopes and lack of knowledge on conservation tillage, by the urban farmers. Average maize yield of 2 000 kg/ha.a was estimated, and this is comparably higher than the less than 1 000 kg/ha.a observed in communal areas of Zimbabwe.

A net storage of about 220 kg/a is realised. Soil fertility tests done after the harvesting period however, indicate a deficiency of available P in the plow layer for maize production. An average value of 10 mg/kg was obtained using the resin extraction method. In Zimbabwe a soil is considered P deficient if the concentration is less than 30 mg/kg. This demonstrates that although there is a net accumulation of P in the soil, a large percentage is strongly absorbed in or precipitated by the soil and not immediately available to the crop. In Zimbabwe the recommended mineral fertiliser application rate as P for commercial maize production is about 42 kg/ha. This is commonly administered as compound D fertiliser also called "maizefert" (8:14:7;N:$P_2O_5$:$K_2O$) which at current prices costs about US$0.50 per kg. The majority of the urban agriculturists in the micro-study area apply "maizefert" as basal fertliser once a year or season at application rates of about 20% (90 kg/ha as "maizefert") the recommended commercial farming value. Ammonium nitrate is applied as "top-dressing" usually twice because of its susceptibility to leaching and washout.

A total diversion of P in sewage onto the land under agriculture translates to an application rate of about 95 kg/ha.a. Whilst if urine is diverted and stored properly, an equivalent of 52 kg/ha.a can be achieved. In both cases fertilisation rates attained are way above the recommended commercial farming rates in Zimbabwe. Partial diversion of the waste flux from the "household subsystem" in the form of urine can sustain activities in the "agricultural subsystem" in terms of P thereby enabling the closing of the P-cycle in this human settlement through ecological agriculture. Also the staggering 660 tonnes/a as dry mass of the organic component of solid waste generated can be composted or co-composted with faeces to produce the much needed soil conditioner as humus.

This paper illustrates the advantages of approaching the ecological sanitation concept from a systems analysis and material accounting angle. By creating such mass balances of macro-nutrients, it becomes more convincing especially to urban planners to integrate activities which assimilate out "waste" like urban agriculture within the urbanshed. An inventory of P-fluxes is therefore an important planning tool in assessing technological options of closing or short-cutting nutrient cycles.

*If at first an idea isn't absurd, then, there is no hope for it. (Albert Einstein)*