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Potential Costs and Revenues of Ecological Sanitation in Accra (Ghana)

Is there a chance for urine-based fertilizer to be market competitive?

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1 Introduction

The History of Sanitation

Waterborne sanitation systems as used in most industrialized countries of the world today are still a relatively new development in history. Only 200 years ago human excreta were either just thrown onto the streets or collected in pits and buckets for reuse in agriculture. With beginning urbanization the volumes of human excreta lying about in the cities also increased and caused diseases like cholera and typhus. The solution to the problem was quickly found in the water closet and from then on human excreta were simply washed out of the cities and ended up in nearby water bodies. The dilution of excreta made them unattractive for reuse in agriculture [Prager (2002)]. A few years later it became obvious that the problem was not solved but only shifted from the cities to natural watercourses and diseases now resulted from contaminated waters [Lange and Otterpohl (2000)]. Instead of rethinking the approach of mixing human excreta with freshwater the first simple sewage treatment plants were developed and the was born [Prager (2002)]. The technology was further developed and with todays wastewater treatment plants high rates of nutrient removal can be achieved. But such treatment plants are expensive and the treatment processes are energy intensive [Maurer et al. (2003)]. In Germany, still 20% of total wastewater are treated without nutrient removal, because the upgrade of treatment plants is too costly for municipalities [Prager (2002)]. An additional shortcoming of the "end-of-the-pipe" technology is the high amount of precious freshwater that is wasted to transport excreta, which represents the principal error that the system is based on as some sanitation experts believe [Jönsson et al. (2004)].

The further development of the "end-of-the-pipe" technology in industrialized countries also involved further investments, such as the construction and extension of sewerage networks, house connections and construction of treatment plants. When switching to another sanitation technology, these investments are lost. Therefore, industrialized countries are confronted with high switching costs, if they abandon their current sanitation technology and invest into another system. Many developing countries have not yet invested much into the "end-of-the-pipe" technology and still have the opportunity to develop alternative systems at lower costs relatively to industrialized countries.

Sanitation Problems in Developing Countries

The number of people lacking basic sanitation services in 2004 is stated at 2.6 billion (more than 50% of the world's population) following an upward trend in recent decades. More than

90 % of global wastewater is discharged to the environment untreated WHO (2008). Every year approximately 2 million people die due to sanitation related. Among children under the age of five diarrheal diseases account for 21% of all deaths WHO (2008). The majority of people suffering from inadequate sanitation live in developing countries, often under extreme conditions of poverty.

For many years the supply of safe drinking water to the poor has been in the focus of the member states of the United Nations. But recently the promotion of safe sanitation has come into international focus and it now enjoys the same priority as water supply. Within the Millennium Development Goals it was set the target to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015 [gtz (2008)]. Additionally the year 2008 has been declared the international year of sanitation by the UN General Assembly in order to raise awareness of the sanitation crisis and to accelerate actions to achieve the MDG's.

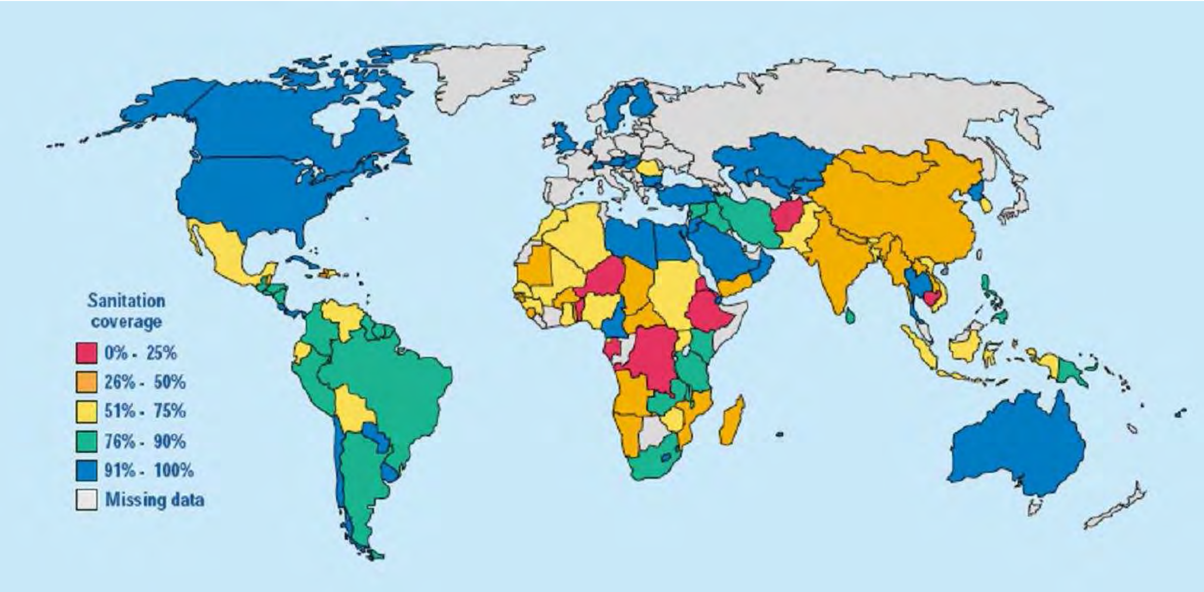

Figure 1.1: Map of Global Sanitation Coverage (Source:WHO/UNICEF (2000))

Experts agree on the fact that the sanitation problems in developing countries cannot be solved with the conventional waterborne systems, because . The German "Gesellschaft für technische Zusammenarbeit (GTZ)" names the major shortcomings of conventional end-of-pipe solutions as:

- Pollution of water bodies by organics, nutrients, pathogens, pharmaceutical residues, etc.
- Severe environmental damage and eutrophication of the water cycle
- Consumption of precious water for transport of waste
- High investment, energy, operating and maintenance costs

- Loss of valuable nutrients and trace elements contained in excrement through their discharge into water bodies

[gtz (2008)]

Particularly the high investment cost and the high water demand disqualify the system for countries where financial resources are as scarce as water resources.

The Soil Fertility Crisis in Sub-Saharan Countries

While the lacking sanitation facilities in developing countries cause the discharge of nutrients into water bodies, the same nutrients are badly needed to maintain the fertility of agricultural soils. They are removed from the fields by harvest year by year and are not sufficiently replaced by fertilizers. Particularly in Africa, where soils are old and contain little organic matter declining soil fertility causes huge problems. In Africa's rural areas 75% of the population live below the poverty, because the decreasing productivity of their lands does not allow higher incomes from farming activities anymore [Camara and Heinemann (2006)]. Hunger in rural areas leads to low productivity in agriculture which in turn contributes to food insecurity. A productive agriculture is needed to reduce hunger and to achieve broad and sustainable economic growth.

In order to reach poverty reduction goals agriculture in Africa must not only keep pace with population growth, but even needs to grow at higher rates. As the extension of arable land is limited the growth can only be realized by productivity increase (intensification). History shows that the productivity increase in agriculture in industrialized countries was ever related to increased fertilizer consumption. With 9 kg/ha in 2002 Sub-Saharan Africa had the lowest fertilizer share in Africa, which is the continent with the lowest fertilizer use in the world (22 kg/ha)

Farmers around the world require 135 Mio tons of mineral fertilizer per year for crop production, while 50 Mio tons of fertilizer equivalents get lost in conventional sanitation systems [gtz (2008)].

It is time to think of more than just one solution to sanitation problems.

2 The Concept of Ecological Sanitation

2.1 The Ecosan Approach

The term "ecological sanitation", in short "ecosan" was created by the Swedish scientist Uno Winblad and first mentioned in his book "Sanitation Without Water" published in the early 70th. The concept behind it stands for efficient and sustainable sanitation systems. It describes a new philosophy in sanitation rather than a certain technology. Ecosan supporter assume that the world sanitation problems cannot be solved with the existing technologies and the widespread opinion people have on human excreta. The underlying idea of conventional sanitation systems is that human excreta are a dangerous waste product. The central point in the ecosan philosophy is not to consider human excreta as waste but as a precious resource, since they contain valuable plant nutrients, that can, or better should be reused in agriculture [gtz (2008)]. In that way the emphasis is put on the hygienization of human waste streams, which shifts the task of sanitation from waste disposal to resource conservation.

Apart from artificial fertilizers human excreta represent an important source of plant nutrients. Thus, in the ecosan mindset sanitation and agriculture cannot be separated from each other, as the one produces an important input factor for the other.

Figure 3.2 illustrates the two different approaches to sanitation. While ecological sanitation closes the nutrient loop and ensures a sustainable and locally limited nutrient flow, conventional sanitation systems break up the cycle and misplace the nutrients.

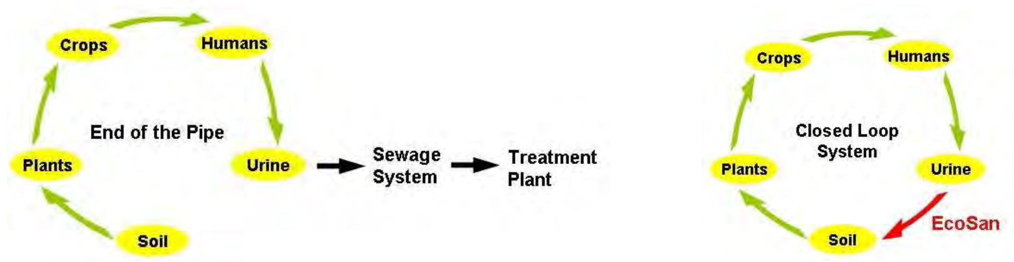

Figure 2.1: Nutrient flows in conventional and ecological sanitation

Ecological sanitation can be realized in many different ways involving different grades of technology. All technologies have in common that the excreta (urine and faeces) are separated from each other and treated individually. The excreta can either be separated from the beginning using so called "no-mix" toilets, or they are discharged together and then separated again (e.g.

by a filter). Technically sophisticated solutions are for example vacuum separation toilets combined with a vacuum sewer system with separate sewers for urine and faeces. Such a system is currently tested within a GTZ project at Lübeck-Flintenbreite, Germany [Werner et al. (2005a)]. Among the low-tech applications simple gravity based diversion toilets are used where the excreta are collected in separate tanks underneath the toilet. Faeces are usually dried and sanitized on-site, while urine is transported to a farming site where it can be used as a fertilizer after a certain storage time (see subsection 2.3.1).

As no general definition of the term "ecosan" exists in the literature, for this thesis sanitation systems are defined as ecosan, when within the system nutrients are either recovered and made plant available again or when the human excreta are collected and sanitized so that they are safe for reuse in agriculture.

2.1.1 Ecosan Principles and Aims

The three long term goals of ecological sanitation are to supply the majority of the world population with safe sanitation, to avoid negative impacts from sanitation on the environment and to keep soil fertility at a high and constant level by recycling the nutrients from the excreta. But as the ecosan thought is only a few decades old and is just about to be adopted by NGO's and other institutions in the development aid sector, the principal objective for the moment is to raise awareness for the sanitation problems in the world. In a first step ecosan shall inspire people to rethink their opinion on human wastes by showing them alternative solutions for the handling and potentials for the reuse of human excreta.

Winblad and Simpson-Hébert (2004) define three fundamental principles ecological sanitation is based on:

- preventing pollution rather than attempting to control it ex post
- sanitizing the urine and the faeces
- using the safe products for agricultural purposes

The GTZ gives a more general interpretation of the approach by naming the following principles:

- to minimize the consumption and pollution of water resources
- to provide low-cost sanitation systems and thus make sanitation affordable for everybody, even the poorest
- not to recognize human excreta and water from households as waste but as valuable resources of nutrients that can be recovered and used again

- to secure soil fertility and safeguard long-term food security by promoting sustainable agriculture [gtz (2008)]

These principles already reflect that ecosan represents a sustainable approach to sanitation, whose overall goals refer to ecological as well as to economic and social benefits.

2.1.1.1 Ecological Benefits

From the ecological perspective the advantages of ecosan over conventional sanitation systems are evident. Conventional systems dispose wastewater into natural water bodies. If the wastewater is not treated adequately before disposing, which is the case for approx. 90% of the sewage in cities in developing countries [Esrey et al. (1998)], the consequences are pollution and eutrophication of rivers, lakes and coastal areas. This is particularly dramatic, if fishing is an important source of nutrition and income for the people. Figure 2.2 shows the completely contaminated Odaw River in Accra (Ghana) which permanently receives untreated wastewater from the city. In ecosan systems water bodies and human excreta are strictly separated, so that rivers and lakes are spared from pollution.

Figure 2.2: Polluted Odaw River in Accra, Ghana

Furthermore ecosan helps to regulate the nutrient balances in the soils. Nutrients are removed from the fields when crops are harvested and enter the human body (see section 2.2). As humans cannot make use of them they are discharged via the excreta. Using a conventional end-of-pipe system the nutrients are transported to a sink (e.g. the ocean) or they are burnt with the sewage sludge. Consequently, the soil nutrients must be replaced by artificial fertilizers. The problem is that usually not the same amount of nutrients is replaced as it was removed. Yanggen et al. (1998) states that there is a growing evidence from intensive agricultural production systems that the overuse of fertilizers can cause environmental damage. On the other hand, an underuse of fertilizers, which means that too few nutrients are replaced, can cause severe degradation of soil fertility. The use of a closed loop system like ecosan guarantees that the same amount of nutrients is replaced by the excreta as it is removed from the fields by harvest.

2.1.1.2 Social and Economic Benefits

Today the worst sanitary conditions are found in urban and peri-urban areas in developing countries. In these areas the poor have considerably less opportunities to get safe sanitation than the rich, because hygienic sanitation is expensive and cheap sanitation (like e.g. simple pit latrines) is often unsafe. Conventional waterborne sewerage systems have proved to be too costly to be provided to all, and only upper and middle class people can normally afford them [Winblad and Simpson-Hébert (2004)]. Thus, most of the urban poor live in the worst polluted and disease ridden habitats of the world [Esrey et al. (1998)]. Safe sanitation is a basic condition for health which again is a basic condition for work and income generation. Hence, for the urban poor only affordable and safe sanitation facilitates social advancement. Ecological sanitation is widely promoted as a low-cost solution in the literature. While it is certainly cheaper than a waterborne sewerage system, it must be proved for every single country or application area whether it is also affordable for the majority. The costs of ecological sanitation can be reduced by selling the collected urine as fertilizer (either treated or untreated).

In countries with low agricultural productivity because of low fertilizer inputs the additional amount of fertilizer made available by ecological sanitation is of particular importance. Population growth in developing countries is often faster than agricultural sector growth, which results in a per capita productivity decline. As a result less food becomes available for the individual from year to year and more people are threatened by hunger [N.U. (2002)]. At the same time the production of tropical fruits like pineapple or coconut must be increased as their export is a good possibility to gain foreign exchange. Ecosan can contribute to a productivity increase by supplying additional nutrients and therewith enhance national food security and strengthen the agricultural export market.

2.1.2 State of the Ecosan Technology

During recent decades ecosan systems of various types have been installed all over the world[1]. Generally four different ecosan technologies can be distinguished:

- Composting toilets
- Urine-diversion dehydrating toilets (UDD)
- Urine-diversion small flush
- Vacuum toilets [Winblad and Simpson-Hébert (2004)]

In a composting toilet urine and faeces are generally composted together by the addition of dry matter like soil, ashes or sand. The compost is then used for fertilizing purposes. The UDD is a low-tech solution usually consisting of a container for urine collection and two vaults for the faeces, so that they can be dried in one vault while the other one is in use. While the first two systems can operate without water, small flush and vacuum systems are designed to use as little water as possible to flush down the faeces. The last three options are suitable for the installation in multistory housing. Concerning the UDD system, in that case the toilets on each floor are connected to a chute where the faeces fall down into a storage tank at street level. Urine is piped into another tank as normal.

Though principally there are suitable technologies to apply ecosan in industrialized countries as an alternative to the conventional waterborne system, the ecosan thought spreads easier in areas where appropriate technologies are currently lacking, like in developing countries. Additionally areas with low and medium population density have proved to be more feasible for the installation of ecosan toilets than densely populated areas. Projects with multistory housing exist, but naturally they are linked with a slightly higher technical effort. The currently biggest ecosan project is running in Dongsheng, China, where a whole village including 825 apartment buildings is equipped with ecosan toilets (for more information see Lixia et al. (2007)).

Having a look at the ecosan projects worldwide it becomes clear that the double vault UDD toilet currently is the best technical solution as it is relatively low priced and easily adaptable to diverse cultural needs [ecosanres (2008)]. Furthermore it is noticeable, that the reuse of urine has not yet been commercialized. There are many small scale demonstration sites, for example at universities (Valley View, Ghana), office buildings (GTZ-headquarter, Eschborn Germany) or in small communities (CREPA, Burkina-Faso) where people collect the urine and reuse it on their own fields which are part of the demonstration site. But their is no evidence of a project,

[1] a map of running ecosan projects is available at: http://www.ecosanres.org

where the produced urine, either pure or processed, is sold as a fertilizer on the open market. Thus, there is no knowledge and experiences with the commercial value of urine or urine-based fertilizers yet.

This thesis highlights the financial aspect of ecological sanitation. The basic question is, whether enough money can be gained from sales of ecosan products to cover the costs for ecological sanitation. Since its ecological benefits are evident, the next question should be whether ecosan can also operate economically sustainable. Therefore some background information about the role of fertilizer in agriculture are needed.

2.2 Fertilizer Use in Agriculture

Fertilizers are products that increase the availability of plant nutrients and therewith enhance plant growth, yields and crop qualities by improving either the physical or the chemical soil quality [Müller (1999)].
During the growing period plants need nutrients to build up organic matter. The soil provides the plants with nutrient and serves as a "nutrient pool" from which the plants can take up the amount of nutrients they need, as long as there are enough available in a form that plants can use them. Plant growth is a function of light, temperature, soil structure, water and nutrients [Jönsson et al. (2004)]. In case one of these factors is missing, the plant will not achieve its optimal height, size and weight of the crops will also be limited. In agriculture a certain amount of nutrients is removed from the fields by harvest every year or cropping season. If the nutrients are not returned to the fields they must be replaced by mineral fertilizers, so that the availability of nutrients is assured for the following cropping period and optimal crop yields can be realized. Plants can only take up nutrients from the soil in ionic form, which is an important detail for the fertilizer production.

In general nutrients needed in large quantities are called macronutrients. In agriculture the six macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg) as their uptake by plants is about 100 times higher than that of micronutrients. Consequently the lack of macronutrients in the soil is more likely. Scarcity of micronutrients only limits plant growth under special circumstances [Jönsson et al. (2004)].

The effect of fertilization is strongest when nutrients are supplied that were badly missing before. In that case the yield increase is linear to the addition of lacking nutrients. After a certain amount (amount A in Figure 2.3) is supplied, yields still increase, but at a decreasing rate. When the maximum amount B is reached, additional fertilization does not lead to anymore yield increase, because another factor becomes limiting (e.g. other nutrients, water, temperature).

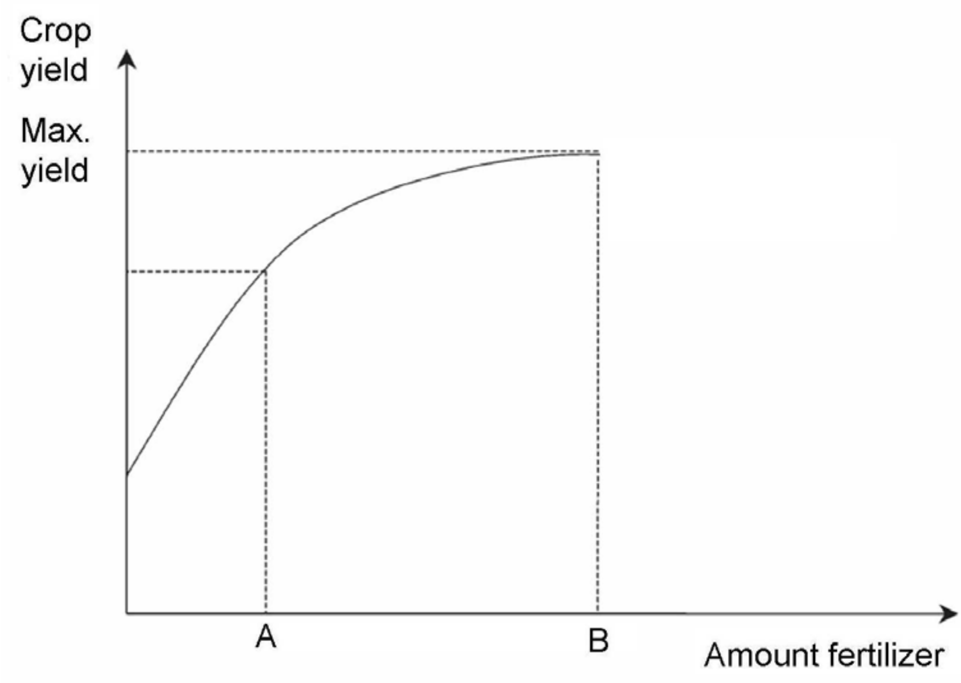

Figure 2.3: Effect on crop yield when different dosages of limiting nutrient are supplied (source:modified from Jönsson et al. (2004))

2.2.1 Mineral Fertilizers

Mineral fertilizers are available in different compositions and aggregates. Straight fertilizers contain a declarable content of only one of the major plant nutrients nitrogen (N), phosphorus (P) or potassium (K) while compound fertilizers contain at least two of these nutrients and possibly a small amount of secondary nutrients such as magnesium and calcium [Isherwood (2000)]. Most fertilizers are sold as grains, but liquid alternatives do also exist.
The worldwide use of mineral fertilizers has increased dramatically within the 20th century. The increase mainly took place in (nowadays) industrialized countries. In Germany, for example, N-P-K fertilizer use increased from 5 kg/ha in 1880 to 200 kg/ha in 1974. In 1997 1,372 million tonnes of nutrients were applied to agricultural areas in the world corresponding to about 91 kg/ha [Niederste-Hollenberg (2003)]. But the distribution of fertilizers in the world is unbalanced. In many developing countries, primarily in African countries, fertilizer use is still lower than 10 kg/ha while in some industrialized countries 200 to 400 kg/ha are common. Nitrogen makes up about 60% of the total nutrients, followed by phosphorus (24%) and potassium (16%) [Niederste-Hollenberg (2003)].

N-fertilizer

Regarding fertilization nitrogen plays a particular role, because it is often the most limiting nutrient for plant growth. The N demand is usually higher than the total demand of all other nutrients together [Jönsson et al. (2004)]. As mentioned before, plants can only take up nutrients in ionic form, which in regard to nitrogen means either as ammonium (NH_4^+) or as nitrate (NO_3^-). Nitrate is absorbed by plants easier and quicker than ammonia, because it is negatively charged and solute in the soil water. When taking up NH_4^+ plants need to exchange a H^+-ion which is a relatively slow process. N-fertilizers may either contain ammonium (e.g. ammonium sulfate) or nitrate (e.g. calcium nitrate) or both (ammonium nitrate). The characteristics of nitrate fertilizers are:

- **advantage:** Nitrogen is directly available to plants which is particularly important during the main growing period and for plants with high nitrogen demand (e.g. C4 plants)
- **disadvantage:** Nitrate does not stay in the soil for long but is washed out easily as it is solute in water

The characteristics of ammonium fer fertilizers are:

- **advantage:** The positively charged ammonia attaches to the negatively charged soil so that nitrogen is not washed out, it provides a constant supply of nitrogen over the time, which can make a second fertilization unnecessary
- **disadvantage:** Gaseous losses may appear during application, acidification of the soil because H^+-ions are released when ammonium is absorbed by plants

Nitrogen is the major element of the atmosphere, where it is present as N_2. To make it plant available it is synthesized to ammonia in the Haber-Bosch process ($N_2 + 3\,H_2 \longleftrightarrow 2\,NH_3$). It is the only component of mineral fertilizers that can be produced industrially, but the production is very energy intensive and fossil fuels are needed for the provision of hydrogen. Today, more than 100 million tonnes of NH_3 are produced by the Haber-Bosch process every year [Niederste-Hollenberg (2003)] for fertilizer production and experts attribute the world population growth of the recent century to this process. The negative effect of industrial ammonia production and the related oversupply of nitrogen is that only 4 to 14% of nitrogen from mineral fertilizers reach the consumer's mouth. The rest is lost to the environment, leading to an unbalance in the global nitrogen cycle [Udert (2002)].

The prices for industrially produced N-fertilizers usually rise with rising oil and gas prices. In January 2006 the price for one metric tonne of urea ranged between $240 to $260 [IFDC (2008)].

P-fertilizer

P-fertilizer is produced from naturally occurring rock phosphate. The most important producers are China, Morocco and the United States who currently produce almost two thirds of global phosphate. China's reserves are estimated to account for 36% of world total reserves and Morocco holds 31%. It is not clear yet how long the global phosphate reserves reserves will last, but estimates range from 60 to 130 years [N.U. (2005)]. But certainly the reserves will decline in quality and the costs for mining will increase. The energy requirements for P-fertilizer production are almost as high as for N-fertilizer, mainly due to the long transport distances [Udert (2002)].

The most common P-fertilizer is diammonium phosphate (DAP) containing 47% phosphorus and 18% ammonium. At the beginning of 2006 the price for one metric tonne of DAP ranged from $240 to $260 [IFDC (2008)].

K-fertilizer

About 90% of all K-fertilizers are applied in form of potassium chloride (K^+Cl^-) also called muriate of potash (MOP). Potassium mining for fertilizer production is less worrying, since potassium ressources are great enough to last for the next centuries and losses of potassium from agriculture do not seem to have any negative impacts on the environment. Additionally the energy consumption for K-fertilizer production is significantly lower than for the other two fertilizers [Udert (2002)].

2006 prices for one metric tonne of MOP containing 60% potassium oxide ranged around $170 [IFDC (2008)].

2.2.2 Urine as a Fertilizer

With the daily food humans consume a certain amount of organic materials, containing nutrients, that are (among others) nitrogen, phosphorus and potassium. During adolescence a small percentage (approx. 2%) of these nutrients are accumulated in the body, but grown-ups usually excrete the same amount of nutrients via faeces and urine as they consume [Höglund et al. (2001)]. As mentioned above nitrogen, phosphorus and potassium are also the three major plant nutrients and consequently the three major components of plant fertilizers. Thus it is self-evident that human excreta can be used as a fertilizer or as a source material for fertilizer production. Indeed, before the introduction of mineral fertilizers the agricultural nutrient demand was covered by recycled animal waste and human excreta. In Europe, the beginning urbanization and the invention of the flush toilet and sewerage systems have brought this tradition to an end [Niederste-Hollenberg (2003)]. In many parts of the world, especially in Asia, it is still a tradition to keep urine and faeces apart in order to make use of the fertilizing qualities of urine [Höglund et al. (2001)]. According to Jönsson et al. (2004) urine contains the higher nutrient fraction relative to faeces, namely 85-90% of the nitrogen, 65-70% of the phosphorus and 70-75% of the potassium that leaves the human body while faeces hold a higher proportion of organic matter. Hence, the fertilizer that is produced from urine is comparable to industrially produced N-P-K fertilizers, while faeces can be used as a soil conditioner.

2.2.2.1 Components of Urine

Apparently the nutrient concentrations in urine are directly linked to the diet of the single individual. Jönsson et al. (2004) observed vast differences in the urine nutrient fractions for people from different continents. They state, that there is a positive correlation between the daily food uptake in calories and the amount of excreted nutrients.
Additionally the composition of human urine varies according to metabolic activities. In the morning urine usually has a higher nutrient concentration than during the rest of the day, and the urine from people who drink a lot is naturally more diluted [Tettenborn et al. (2007)]. Generally it can be said that the average nutrient concentration in the urine of a population reflects the nutrient ratio contained in the consumed crops and thus the ratio in which nutrients should be returned to the soil to maintain the fertility [Jönsson et al. (2004)].

Niederste-Hollenberg (2003) has averaged several literature values (including own experimental results from Germany) of N,P and K concentrations in urine. Table 2.1 compares the results with the nutrient content of a usual N-P-K (15-15-15) fertilizer.

Table 2.1: Nutrient contents in N-P-K fertilizer and urine

	N	P	K
N-P-K (15-15-15) ($\frac{g}{kg}$)	150	66	125
Urine ($\frac{g}{l}$)	9.5	0.8	1.9

As it can be seen, there are large differences in the nutrient concentrations of mineral fertilizer and urine. The differences become even clearer, if the required amounts for the fertilization one ha of agricultural land are compared. It is assumed that the optimal amount of nutrients was 60kg N, 40kg P and 40kg K per ha and year, which corresponds to the recommended fertilizing intensity for maize in Ghana. If mineral fertilizer was used 600kg of N-P-K (15-15-15) would be needed to cover the required amount of phosphorus (nitrogen and potassium demand are exceeded). Using undiluted human urine instead, 6,316 liters were needed to cover the N demand, 50,000 liters for P and 21,053 liters for K. Taking 500 liters of excreted urine per capita and year [Winblad and Simpson-Hébert (2004)] 13 people would be needed for nitrogen production, 100 people for phosphorus and 42 people for the production of potassium.

2.2.2.2 Application in Agriculture

It is possible to use pure urine as a fertilizer in agriculture, but a certain storage time should be kept in order to sanitize the urine (see subsection 2.3.1). Numerous studies, particularly by Swedish scientists and on-farm trials have shown mostly positive results concerning the fertilizing effect, applicability and acceptance. Evidence of the successful use of pure urine as a fertilizer comes from ecosan projects all over the world e.g. from Burkina Faso[2], Ghana[3] and Botswana[4], just to mention a few. The urine can be applied to the fields either pure and in large quantities before planting or several times diluted with water during the growing period. In general the same application intervals as recommended for mineral fertilizers can be adopted [Jönsson et al. (2004)]. In case food crops are consumed raw urine should not be applied four weeks before harvesting. When fertilizing crops whose edible parts grow just above the surface like vegetables, lettuce, spring onions etc. urine should be directly inserted into the ground [Schönning and Stenström (2004)]. Apart from that, the incorporation of urine directly into the ground minimizes gaseous losses of ammonia and avoids possible foliar burning.

In stored urine nitrogen is predominantly present in form of ammonia (NH_3) and ammonium (NH_4^+). Ammonium is directly plant available but a significant portion is nitrified into nitrate (NO_3^-) by soil bacteria which can also be easier taken up by plants.

Phosphorus in stored urine is almost entirely (95-100%) inorganic and present in the form of ions, which makes it directly plant available .

Potassium is also excreted in form of ions, which are directly plant-available [Höglund et al. (2001)].

Altogether the plant availability of all three nutrients is about the same as that of chemical N-P-K fertilizers. This fact suggests that the fertilizing effect of urine is also comparable to that of mineral fertilizers with the same nutrient concentrations. Indeed, Kirchmann and Pettersson (1995) concluded that for urine the nitrogen effect is 85-95% compared to mineral fertilizers. The fertilizing effect of phosphorus was found to be the same for both fertilizers.

Various pot and field experiments have also been carried out at the Humboldt-University of Berlin between 2004 and 2006 in order to evaluate the nitrogen effect of untreated urine compared to mineral fertilizer (Ammonium Nitrate and Calcium Nitrate) [Muskolus and Ellmer (2007)]. The results support the findings above with a nitrogen effect of 90% compared to the mineral fertilizer for most plants. But an interesting exception was found for C4 plants like

[2] Dagerskog (2007)
[3] https://www.uni-hohenheim.de/respta
[4] Werner et al. (2005b)

maize and sorghum. These plants have the ability to photosynthesize faster than C3 plants and therefore they need to take up large amounts of nitrate within a short spell of their growing period. In case the nitrification of NH_4^+ in the soil is too slow, the availability of nitrogen in form of NO_3^- is the limiting factor for plant growth. The field trials at Humboldt-University showed that indeed the yield of urine fertilized maize was significantly lower compared to the corresponding yield of maize fertilized with nitrate.

2.3 Urine Processing Techniques

For basically two reasons treatment options for the collected urine should be taken into consideration:
Firstly urine contains a large portion of water, so that the concentrations of nutrients are relatively low compared to the concentrations of mineral fertilizers. For example, one kilogram of NPK (15-15-15) fertilizer contains 150g N, 66g P and 125g K. One liter of urine contains only about 9.5g nitrogen, 0.8g phosphorus and 1.9g potassium, thus the mass fractions are between 15 to 83 times lower. This results in an unfavorable ratio of fertilizing effect to weight which makes handling and transportation of urine-fertilizer relatively expensive. A volume reduction would reduce the handling costs and improve the market chances for urine-fertilizer.
Secondly pure urine is not a well marketable product, because people consider it as a smelly and worthless waste product and often have hygienic concerns on the reuse. The prices that can be achieved for one m^3 of urine are far below the actual nutrient values (see section 5). A liquid non-odorous substance that does not remind on human urine would be more accepted by the customers and thus higher prices could be realized for such a product. Hygienic concerns and the unpleasant smell of urine can also be eliminated by several treatment methods. In recent years different techniques have been developed with the aim either to concentrate the urine or to recover its main nutrients. Basic research is still ongoing in this field and most of the processes are still in laboratory stage. The next subsection gives a short introduction to the presently most promising methods.

2.3.1 Storage

Storage reduces the pathogen concentration in urine. Urine itself has usually a very low germ concentration but in separation toilets it may be contaminated with faecal pathogens. Höglund et al. (2001) states that probably all pathogens (viruses and protozoa) die when urine is stored for at least 6 months at a temperature of 20°and that urine then can be regarded as hygienized

and ready to be applied to all kinds of crops. As the pathogenic decay strongly depends on the temperature, urine that is stored at a higher temperature needs less storage time.
The storing process also affects the chemical quality of the available nitrogen and phosphorus. Fresh urine leaves the human body with an average pH of 6.2 [Larsen and Gujer (1996)] and nitrogen is predominantly present in form of urea. During storage organic matter is degraded by microbial activity and urea is hydrolyzed into ammonia:

$$2\,CH_2NO_2COOH + 3\,O_2 \longrightarrow 4\,CO_2 + 2\,H_2O + 2\,NH_3$$

The reaction causes a pH increase up to 9 and after 24 hours 90% of total nitrogen is present as ammonia (NH_3) or ammonium (NH_4^+) depending on the temperature and the pH[5] [Udert (2002)]. In order to avoid ammonia evaporation, urine should be stored in airtight-sealed tanks. The pH increase in turn leads to precipitation of phosphorus. If no flush water is added to the urine, phosphorus can only precipitate in form of struvite ($MgNH_4PO_4$), where the availability of magnesium in urine is the limiting factor. Udert (2002) showed that in undiluted urine 30% of the soluble phosphate precipitates.
Hydrolyzes and precipitation can be inhibited by keeping the pH value low, for example by acidification [Maurer et al. (2006)]. But as high quantities of acid (11.3g/l) are required, this method is not taken into consideration in this thesis.

2.3.2 Volume Reduction

2.3.2.1 Reverse Osmosis

If two liquids of different concentrations are separated by a partially-permeable membrane, water diffuses from the solution of low solute concentration to the solution with high solute concentration. Urine can be concentrated by inverting this process (reverse osmosis) so that urine is pressed through a membrane and solids like salts and nutrients remain in the retentate. For the process stabilized urine is more suitable than hydrolyzed urine, since the retention is better for ammonium than than for ammonia and the precipitation of salts in the membrane (scaling) is hindered by the acidification [Maurer et al. (2006)]. For a fivefold concentration of urine Dalhammer (cited in Maurer et al. (2003)) calculates an electricity demand of 5 to 10 kWh/m^3 which corresponds to a specific demand for primary energy of 29 MJ/kgN.

[5] high temperatures and a high pH shift the equilibrium towards ammonium

2.3.2.2 Evaporation

Up to 60 fold concentrations of urine can be reached by evaporation, but again stabilized urine is needed in order to achieve high nitrogen fractions in the concentrate. Besides acidification, n-depleted urine as a substrate is a suitable alternative [Tettenborn et al. (2007)]. Based on experimental results Maurer et al. (2003) calculated an energy requirement of 34 MJ/kgN for a tenfold concentration of urine in a vapor condensation evaporation plant.
In case urine cannot be stabilized (e.g. for monetary or logistical reasons), evaporation is a feasible method to concentrate phosphorus and potassium rich urine after recovering nitrogen in a first step.

2.3.3 Nutrient Recovery

2.3.3.1 Struvit Production

Magnesium ammonium phosphate (MAP or struvite) contains two major plant nutrients plus magnesium and is therefore a very suitable and marketable fertilizer. MAP precipitation allows to recover ammonia and phosphorus from urine at the same time, but since urine contains much more ammonia than phosphorus 98% of phosphorus but only 3% of ammonia can be recovered by precipitation [Maurer et al. (2003)].
By adding magnesium oxide (MgO) or chloride (MgCl) to hydrolyzed urine the precipitation is triggered without pH adjustment, since a pH between 8.5 and 9 is optimal for struvite production [Maurer et al. (2006)]. The process is relatively simple and energy is only required for stirring. Maurer et al. (2003) converted the necessary amount of magnesium oxide into energy equivalents and calculated a total energy demand of 25 MJ/kgN for quantitative P-fixation.

2.3.3.2 Ammonium Adsorption with Zeolite

Zeolite can serve as a cation exchanger and adsorbs the ammonium ions from urine. Bán and Dave (2004) have combined the addition of clinoptilolite, a naturally occurring zeolite, and magnesium oxide and report that recovery rates of 80% could be achieved with dosages of 0.5mg/l MgO and 15g/l zeolite. Like for struvite production the process handling for zeolite adsorption again is very simple and thus it qualifies for regions where technologically sophisticated treatment plants are difficult to realize due to a lack of technological know-how and infrastructure. The major shortcoming of the process is the relatively high amount of zeolite that is needed to adsorb ammonium. In large scale systems, e.g. if the urine from 1,000,000 people is collected, 7,500 kg of zeolite would be needed per year to reach an ammonium recovery rate of 80%. In order to avoid high handling and transportation costs, further research is needed on the optimization of the recovery efficiency or on the applicability of synthetic zeolite. Unfortunately no energy equivalent is available for zeolite, so that an energetic comparison with other processes is not possible.

2.3.3.3 Steam Stripping

Steam stripping is another technique to recover nitrogen from human urine. Heated urine is injected at the top of a stripping tower and travels downwards, while steam that is injected at the bottom of the tower rises upwards. The intimate contact between the two phases causes volatile ammonia to transfer into the vapor phase, so that a condensate enriched with ammonia can be gained at the top of the stripping tower [Tettenborn et al. (2007)]. Within experiments at the TUHH a $120gNH3/l$ ammonia solution could be produced from human urine condensed to 3% of its origanal volume. The pH value of the N-depleted substrate decreased to a value below 6 and the nitrogen concentration could be reduced by 90% to 98%.
The process needs hydrolyzed urine as a feed substance with most of the nitrogen being present in form of volatile (NH_3). A combination of struvite production and steam stripping seems reasonable as very high removal rates of both nutrients (nitrogen and phosphorus) can be achieved that way. If the energy efficiency of a stripping tower is optimized, a specific demand for primary energy ranges between 30 MJ/kgN and 40 MJ/kgN.

2.3.4 Final Products

Table 2.2 summarizes the treatment processes and their final products.

Table 2.2: Energy requirements of different treatment methods

Process	**Specific Energy** (MJ/kgN)	**Energy** (MJ/m^3)	Product
Storage	0	0	hygienized urine
Reverse osmosis	29	27	concentrated nutrient solution
Evaporation	34	180	concentrated nutrient solution
Struvite production	25	50	struvite
Zeolite adsorption	n.a.	n.a.	ammonia laden zeolite
Steam stripping	35	150	(NH_3-solution)

(Source: based on Tettenborn et al. (2007) and Maurer et al. (2006))

It is difficult to give a statement about the quality or fertilizing effect of the single products, because many externalities like the soil quality, the kind of cultivated crop, water availability, climate etc. influence the choice of the right fertilizer. The most appropriate fertilizers for the single crops in Ghana need to be determined by further research.

3 Analyzing the State of Sanitation in Accra

3.1 The Context of Accra

Ghana is a West African English-speaking country that covers an area of about 238,533 km^2 with a population of 18.5 millions in 2000 [Ghana (2002)]. It is surrounded by the three bordering countries Ivory Coast in the West, Burkina Faso in the North and Togo in the East as well as the Gulf of Guinea as a natural border in the South.
The country is divided into ten administrative regions with the Northern Region as the largest and the Greater Accra Region as the smallest (Figure 3.1).

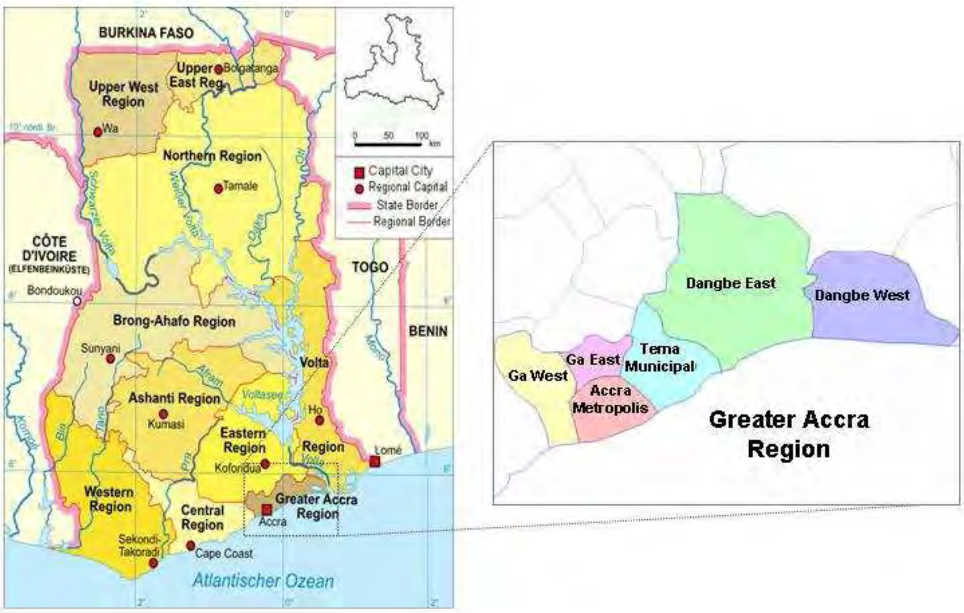

Figure 3.1: Map of Ghana and Greater Accra (Source:http://www.afriqiyah99.de/270.html)

Accra, the capital of Ghana, is situated in the Greater Accra Region, which is one of the coastal regions in the south-east of the country. The Greater Accra Region comprises five sub-districts, from East to West these are: Ga District, Accra Metropolitan Area (AMA), Tema District, Dangbe East and Dangbe West.
As Accra is one of the fastest growing cities in Western Africa , it is quiet difficult to outline the exact border between the urbanized area of the metropolis and its peri-urban surroundings.

But certainly the city limit is somewhere between the old boundary of AMA and the current administrative boundary, which is referred to as the Greater Accra Metropolitan Area (GAMA). GAMA represents the aggregation of Ga District, Accra Metropolitan Area and Dangbe District who all are part of the Greater Accra Region (Figure 3.3). With the objective to determine the actual size and population of the urbanized area of Accra the population development and the physical extension are analyzed in the following.

3.1.1 Population Development

Within the past decades Accra has experienced a dramatic urbanization. This is certainly due to its unique position in the country. Accra represents a typical primate city, which means that it is not only the capital in political and administrative terms, but also the industrial, commercial and cultural center of Ghana. With the only international airport and the busiest port at Accra-Tema, almost any imported or exported goods make their way through the capital [Yankson and Kofie (2004)].
Accra's primacy is crucial for the prediction of its further development and it also explains the city's development in previous decades. In order to get an idea about the future of Accra, it might be useful to have a look at its recent development. Table3.1 shows the population growth of the five districts of Greater Accra Region between 1970 and 2008.

Table 3.1: Greater Accra Population Development 1970-2008

District	**Year**				
	1970	1984	2000	2008 (est.)	Growth
AMA	636 667	969 195	1 658 937	2 167 675	3.4%
Ga	66 336	132 786	550 468	897 425	6.3%
Tema	102 431	190 917	506 400	1 031 466	9.3%
Dangme East	n.a.	n.a.	93112	131 404	4.4%
Dangme West	n.a.	n.a.	96809	136 622	4.4%
Greater Accra	n.a.	n.a.	2 905 726	4 358 937	5.2%

(Source: Ghana Statistical Service 2002)

In the 1970s growth in Accra was still moderate and predominantly induced by immigration from surrounding rural areas to the center (AMA). By 1984 AMA had almost reached the size of one million citizens, while Ga and Tema where still comparable small.

The second period (1984 to 2000) is characterized by movements from downtown to the periphery, namely to the districts Ga and Tema. It was caused by endogenous population growth in AMA coupled with rising rents in the center that the poorest could no longer afford [Yankson and Kofie (2004)]. Column 6 of Table 3.1 illustrates the growth rates of the single districts during that time. As expected, annual growth was moderate in AMA with 3.4% and notably higher in Ga and Tema with 6.3% and 9.3% respectively.

Nowadays, Accra's city center is already densely populated (approx. 100 people/ha [Yankson and Kofie (2004)]) and rents are dramatically high. Buckley and Mathema (2007) assume that the high real estate prices are caused by Ghanaians who live and work abroad (10-20% of the population) and transfer money back to their families in Ghana. Apparently a great portion of this money is used for housing investments and most Ghanaians consider Accra to be the perfect place for such investments. In addition the country more and more attracts foreign investors (like shipping companies, banks, NGO's, etc.) because of its stable (though slow growing) economy and its friendly political environment. Many of those companies, especially NGO's, have moved over from countries with political instabilities like Iverory Coast, Liberia or Sierra Leone in recent times and have established their headquarters for West Africa in Accra. Of course, those foreign companies also compete for real estate in AMA and drive up the prices. In a recent study Accra was ranked 75th of the 150 most expensive cities in terms of real estate, just between Melbourne and Houston [Buckley and Mathema (2007)]. In spite of the price development, there are still some informal settlements of considerable size in the city center today, but in future times it will become harder for the urban poor to maintain their seetlements in the city, as space is needed for the development of new buildings in the center.

Figure 3.2: Construction site and modern office building in Accra Airport Residential Area

Assuming that population has been growing on steadily since 2000, the 2008 population of

Greater Accra and its districts is estimated in column 5 of Table 3.1. The rates for AMA, Ga and Tema are based on the annual population growth of the districts between 1984 and 2000. In order to estimate the population of Dagme East and Dagme West a 4.4% rate given by Ghana Statistical Service in 2002 is used, as no data was available for the two districts for 1984.
In the year 2008 the administrative boundaries of Accra already include the two districts Ga and Tema making it the Greater Accra Metropolitan Area (GAMA). The GAMA region is the home for 4,096,566 dwellers and constitutes about $1577km^2$ [Hofny-Collins (2006)]. According to the 2000 census 92% of that population live in urban settlements, which is the city of Accra in that case. From this it follows that today 3,768,840 people live in the urbanized area of Accra Metropolis. This number is the basis for the calculation of a general sanitation system for the city in this thesis.

3.1.2 Physical Extension

As illustrated in Figure3.3 the numeral population growth is accompanied by a remarkable physical growth of the region. Yankson and Kofie (2004) states that the urban area of Accra grew from a size of $216km^2$ in 1985 to $555km^2$ in 2002, and is now growing at a rate of $25km^2$ per year. As a result the city of Tema was already completely included into the urban surrounding of Accra in 2002. Looking at the extent of area that was under transition in 2002 it is supposable that nowadays the shape of the city limit is similar to the one on the bottom right side of Figure3.3 and that the size of urbanized are in 2008 is about $705km^2$, or 45% of the total are of GAMA.

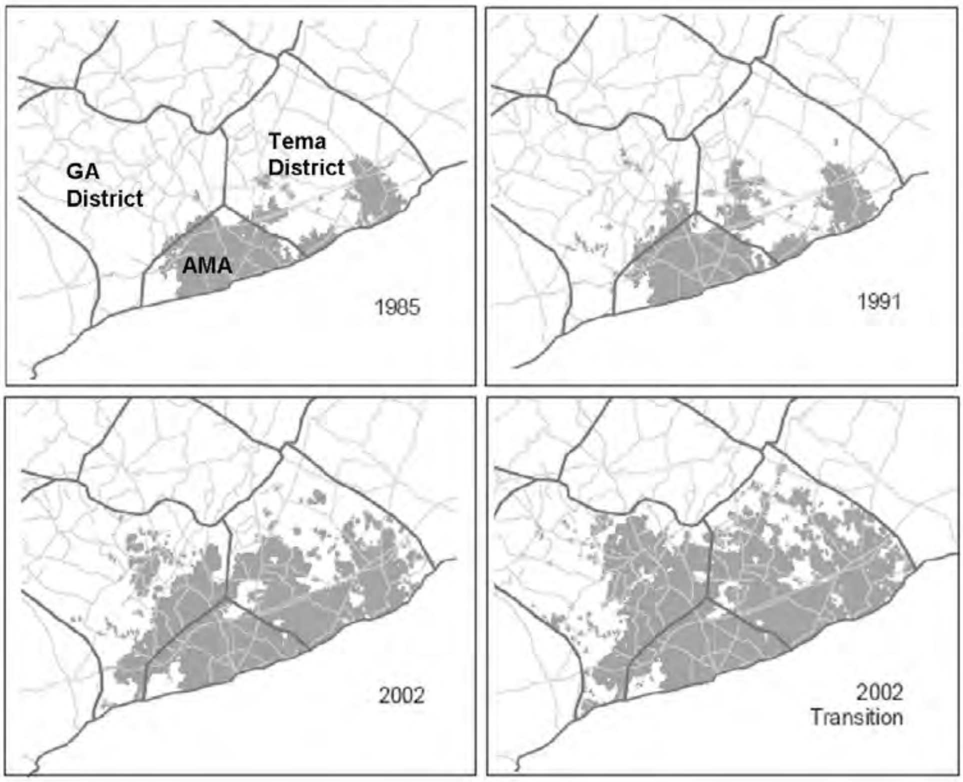

Figure 3.3: Extension of Urbanized Areas of Accra in 1985, 1991 and 2002
Area under Conversion into Urban Use in 2002 (Source:Yankson and Kofie (2004))

3.1.3 Income and Housing

In 2003 the average annual income in Accra was $915 [Cofie et al. (2004)], which was about three times higher than the country average of $320. But there is great evidence that the distribution of income is highly unbalanced, as about 48 percent of Accra's metropolitan population earn less than the World Bank's absolute poverty threshold of $307 per capita per year [Annorbah-Sarpei (1998)].

Table 3.2: State of Urbanization in Accra 2008

Region	**Area** (km^2)	**%**	**Population**	**%**	**Houses**	**Density** ($\frac{people}{ha}$)
Greater Accra	3245	100%	4 358 937	100%	431 578	13.43
GAMA	1577	48.6%	4 096 566	94.0%	405 601	26.0
Accra Metropolis	705	21.7%	3 768 840	86.5%	298 418	53.46

(Source: Calculations based on Ghana (2002))

The labor market in Accra is divided into a formal and an informal sector. Only 25% of the urban population are employed in the formal or "official" sector [Annorbah-Sarpei (1998)]. The number of dwellers who work informally in the so called private sector is more than two times higher (56% [Hofny-Collins (2006)]). In this sector workers usually run their own micro-enterprise and their income is generally at the level of subsistence. Typical jobs in the private sector are farmer, market vendor or street vendor. The annual earnings from farming activities were $160 in 1998, while a street vendor gained about $180 [Ghana (2002)].

The housing conditions show a similar classification. Corresponding to the 56% working in the private sector, 58% of the citizens live in low income areas. These are ususally informal settlements of high density and large household sizes with lack of basic services such as water supply, sanitation, greywater drainage and electricity. In general these areas are not included into official policy and planning initiatives.
32% of Accra's population live in middle income areas, that are characterized by limited infrastructure and planned housing in the city but also unplanned housing on the outskirts.
Only in the high income, low density areas (10%) in the city people are provided with adequate basic infrastructure. On the outskirts even high class houses are developped without any planning and therefore are not connected to water supply, sanitation and electricity networks. Instead water is delivered by tanker-trucks, human waste is collected in septic tanks which are emptied by honey-trucks and generators are used to produce electricity.

Table 3.3: Housing Conditions in Accra

Housing Category	Population	%
Low	2 185 927	58%
Middle	1 206 029	32%
High	376 884	10%

(Source: Hofny-Collins (2006))

Table 3.4: Income Distribution

Profession	Income	%
Unemployed	$107.50	7%
Farmer, Fisher, Petty trader	$150-163	32%
Food vendor, Business, Skilled labor	$172-206	46%
Professionals, Unclassified	$516-602	15%

(Source: Ghana (2002))

3.2 State of Sanitation

In Ghana 63% of the population have access to improved sanitation technologies, compared to an average sanitation coverage of 60% in entire Africa. The situation is worse in Ghanaian cities, where only 62% have sanitation coverage compared to an overall coverage of 84% in African cities [WHO/UNICEF (2000)].
The wastewater generated in Accra is mainly of domestic origin as the city's industrial zone is primarily located along the coastline which allows the discharge of its wastewaters directly into the ocean. Two different types of domestic sanitation systems can be distinguished:

1. On-site disposal: methods that do not make use of any transportation, excreta are stored and/or treated where they are produced
2. Off-site disposal: excreta are transported to where they can be disposed and eventually be treated, transportation may be via a sewer but also by car (e.g. desludging tanker)

The present methods for greywater and blackwater collection and disposal in Accra are itemized below. In terms of blackwater disposal the sorting already reflects the standing each facility enjoys in the Ghanaian society, with a water closet and sewer connection as the best and the public toilet as the worst conceivable solution.

- Drainage System (greywater)
- Sewerage system (blackwater)
- Underground septic tanks

- Improved pit latrines (KVIP) or simple pit latrines
- Bucket latrines
- Public toilets

So far, there are no ecosan toilets available in Accra yet. Only a pilot project with ecosan toilets runs at Valley View University (VVU) in cooperation with the University of Hohenheim, Germany. Within the project, urine diverting toilets were installed in the university building and the collected urine is used for fertilization on the university's own farmland (for more information see: http://www.uni-hohenheim.de/respta/index.php). Apart from that, ecological sanitation has not yet been introduced to the city.

Figure 3.4 shows the percentage distribution of toilet facilities among the population of Greater Accra, as it is reported by the 2000 national population and housing census. The distribution is considered to be representative for Accra Metropolis, as 86.5% of Greater Accra's population live in the Accra Metropolis. It is remarkable that the highest portion of citizens make use of public toilets (27%). 43% are equipped with relatively safe sanitation facilities like water closets or (improved) pit latrines. But still 30% depend on unsafe sanitation like bucket latrines or have no toilet facilities at all, so that they either have to use the neighbour's toilet or relief themselves in open spaces like bushes or on the beach.

The form of sanitation is directly related to the way people receive their fresh water. Waterborne systems like the water closet (W.C.) can only operate properly when fairly reliable inhouse water supply is provided. In a 2004 study where 960 households were surveyed in the Accra Metropolis regarding their connections to the water supply system. It revealed that 39.8% of the houses have indoor water supply [Boadi (2004)]. The rest of the population, mainly the poor and people who live on the outskirts of Accra, are dependend on private or communal standpipes, neighbours and water vendors. And among those who have an indoor water connection, only 25% enjoy a 24-hour water supply. About 30% have an average of 12 hours service every day for five days a week and another 35% have service for two days each week [wateraid (2005)]. The lack of constant and convenient water supply explains why most dwellers choose waterless sanitation for their houses.

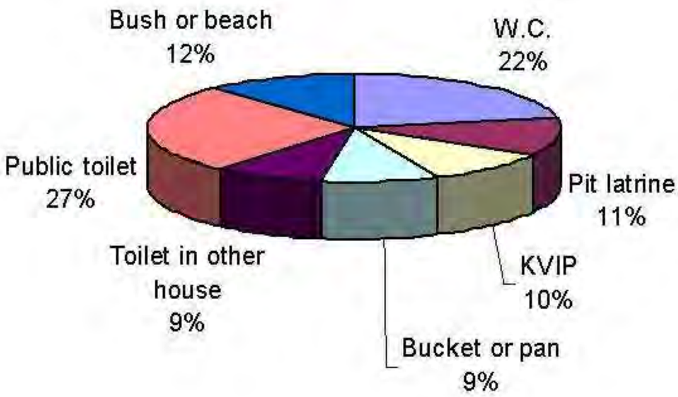

Figure 3.4: Water Supply and Sanitation facilities in Greater Accra (Source:Ghana (2002))

In the following analysis of the different sanitation systems in Accra the focus is put on organisational and cost aspects. The results shall serve as a basis for the ecosan concept and therefore reveal the weaknesses of the current systems, so that demands on a new concept can be developed. The running costs of each sanitation option are of special interest, to make the costs of the ecosan system comparable to those of present solutions.

3.2.1 Drainage System

Paved roads in GAMA are typically flanked by concrete drains to channel the stormwater that runs off the streets. Whenever a road is built, a drain is constructed alongside, so that there is a well-established drainage network, that corresponds to the road network of the city. The channels empty into natural water bodies, mostly rivers that arise from the hinterland and disembogue into the ocean in Accra or nearby. The Odaw River is the most important natural drain as it receives about 60% of Accra's stormwater. It flows through the city from north to south and empties into Korle Lagoon, which has an artificially maintained opening to the ocean.

As the majority of houses is not connected to the central sewer system (see next section), most people make connections from their houses to the drains. In this way they discharge domestic wastewater like washing water, kitchen waste and water from showers and basins directly into the drains. This is a very convenient way to get rid of wastewater and it is tolerated by the municipality.

Most of the urban gutters are uncovered or just partly covered in order to easily absorb high quantities of stormwater in times of heavy rainfalls. But thereby they are often abused for solid waste disposal as seen in Figure 3.5. Walking around in Accra during the dry season, one will notice that almost all open drains are choked with rubbish. Additionally, in areas where adequate sanitation facilities are missing, the open gutters also serve for urinating and defecating. This is particularly problematic, if the downstream water is used for irrigation by urban farmers (see chapter 5). The problem has been addressed by the municipality and newly built drains are now completely covered (Figure3.5).

Figure 3.5: Drains blocked with rubbish and newly constructed covered drains in Accra

3.2.2 Sewerage Network and Treatment-Plants

Officially about 5% of the Accra Metropolitan Area is served by a piped sewage water system [Ghana (2002)]. This number is made up of many smaller private networks that are not interconnected. Hence each sewerage system must have its own seperate treatment plant, of which there are about 22 all over the city. Some of the high class hotels like Golden Tulip Hotel, La Palm Hotel, etc. or military institutions like Burma Camp or the 37 Military Hospital run such decentralized sewerage systems and treatment plants. The largest sewer network is located in the central part of AMA, to the east of Korle Lagoon (Figure 3.6). It is the only public system in the city under municipal authority to which private households can connect. The network was constructed and financend by The World Bank in 1973 with a total length of 28.5 km [Porter et al. (1997)]. Since then, it has seen only litle maintenance and no extension. Though the network covers almost 10 km^2 in an area of high population density (more than 10,000 houses) only 800 houses are currently connected [1], which is equivalent to only 0.27% of total houses in the Accra Metropolis. Porter et al. (1997) gives the following reasons for such a low connection rate:

- most houses did not meet the standard for connection
- the rich did not want to connect, because they already had adequate septic tank systems
- the poor could not afford to connect, because the sewerage tariff was 25-35% surcharge on the water tariff

Additionally the use of the sewerage network requires a waterborne toilet and inhouse water supply, which is unaffordable or unavailable to most dwellers. Originally the network was not connected to a treatment plant, it only accumulated the faecal sludge from the city and emptied into the Korle lagoon. In 2000 the Accra West Plant (AWP) was built with financial aid of the Department for International Development (DFID) in order to treat the effluent of the central sewerage system. It was designed to treat $16,000m^3$ of sludge per day but due to the low connection rate it received only $5,000m^3$ [Obuobie et al. (2006)]. The low connection rate not only had a negative influence on the financial but also on the technical sustainability of the system. The treatment plant, that was originally designed to treat the septage of some thousand households for at least 20 years broke down in 2003, two years after it was handed over to the municipality, mainly because of the insufficient inflow. So today, the effluent of the sewers is discharged directly into Korle Lagoon and from their it goes untreated into the ocean.
At present, those households who make use of the central sewer pay 35% of the freshwater tarrif to the Ghana Waste Department (GWD), which is equivalent to $\$0.22$ per m^3 [Wonder (2007)]. There are three more big municipal treatment plants in Accra, that are not connected to a sewer. They are supposed to treat faecal sludge from the septic tanks, that is dumped there by desludging vehicles (so called honey trucks). The biggest is located at Achimota $(250m^3/day)$ followed by Teshie-Nungua $(80m^3/day)$ and Korle Gonno $(50m^3/day)$ (3.6). But a survey carried out by Ghana's Environmental Protection Agency (EPA) uncovered that only 6 of the 22 treatment plants in Greater Accra were functional in 2001 [Obuobie et al. (2006)]. Suleiman (2007) states that during his visit to Accra in 2007 none of the municipal treatment plants was in operation.

[1] personal information from an interview with AMA officials

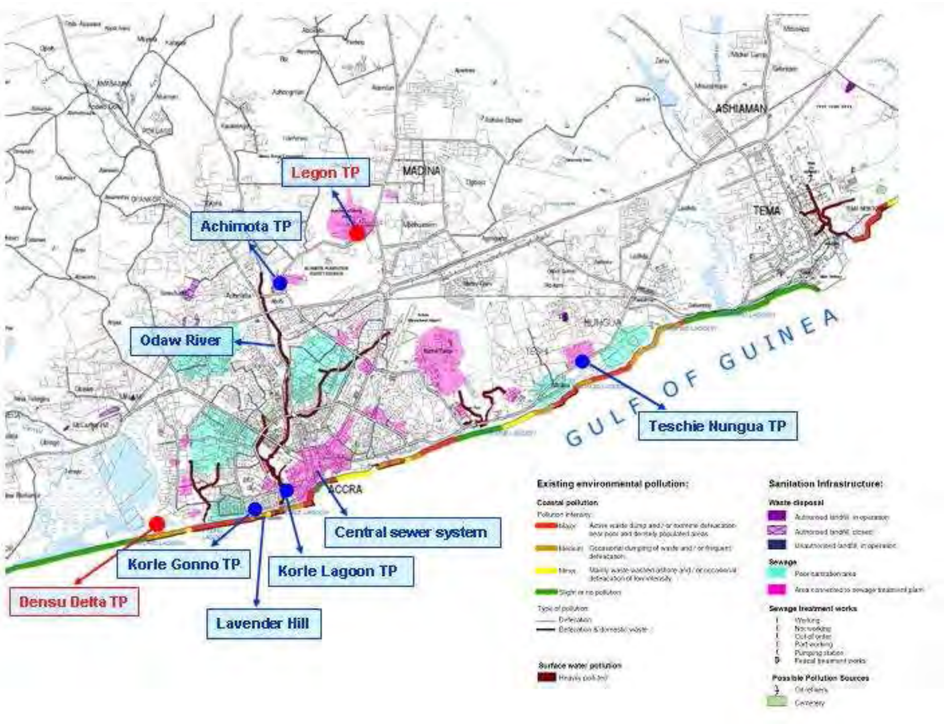

Figure 3.6: Sanitation Infrastructure and Marine Pollution in Greater Accra Metropolitan Area

3.2.3 Private Toilet Facilities

The poor maintenance of sewerage systems and sewage treatment plants as described above has forced house owners to invest into individual on-site sanitation facilities, if they do not want to depend on public toilets. The advantage of on-site solutions is their flexibility, as the urban sprawl does not allow any static centralized systems. In recent years AMA encourages people in installing on-site facilities like septic tanks in combination with flush toilets. The aim is to ban pit latrines, bucket latrines and the use of public toilets instead of own sanitation facilities. In order to achieve this goal, AMA enacted a by-law for all newly constructed dwellings to install either water closets with septic tanks or improved pit latrines.

The following section presents the prevailing domestic toilet options in the GAMA Region.

Septic Tank Systems

This system combines a W.C. and a septic tank for storing the excreta. Thus it also requires a reliable indoor piped water connection. The septic tank is usually made of concrete, it has a volume of approx. 4000 liters and is buried in the yard or under the house. After using the toilet the excreta is flushed into the tank together with urine and flush water. Solids and liquids are then separated in the tank: the sinking particles (faeces) are collected at the bottom in form of sludge while floating particles (water and urine) flow off into the soil via a soak away at the top of the tank. To avoid an overflow of faecal sludge, the septic tank must be emptied periodically dependent on the number of users. The amount of faeces excreted by one person per year is approx. 50 kg [Winblad and Simpson-Hébert (2004)]. If this is present in form of faecal sludge Porter et al. (1997) estimates that one person produces approx. 100 liters per year. Accordingly a septic tank used by ten people needs to be emptied every two years. Among on-site facilities the combination of septic flush toilets and septic tanks is the most convenient but also the most expensive. Thus septic tanks are predominantly found in the high and middle income areas either in the center or in the newly developed villas on the outskirts. They account for 22% of all sanitation facilities.

According to a WMD official the initial costs for setting up a septic tank range between $1500 and $2000, dependent on the size of the tank and the ground conditions. The clearing fee is $60 to $80, clearing of the tanks is provided by some private companies and the municipality. The tanks are cleared by vacuum trucks, that discharge their loads either at one of the sewage treatment plants or into the ocean at a place called lavender hill close to Korle Lagoon. A honey truck can take a maximum of 7000 liters of faecal sludge. For desludging the truck at lavender hill the driver pays $12 per truckload to the municipality. Every day between 80 and 100 trucks discharge at Lavender hill while about 40 trucks discharge at the treatment plants. It is notable that even though none of the treatment plants is presently working and stabilization ponds are entirely filled up, faecal sludge is continuously dumped there (Figure 3.7).

Figure 3.7: Desludging honey trucks at Teschie-Nungua (left) and Lavender Hill (middle and right)

Pit latrines

The pit latrine is a waterless low-cost toilet option that is very common in African countries. It consists of an underground pit (lined or unlined) and a superstructure that may vary in design and quality (e.g. bricks, metal, wood). The solids accumulate at the bottom of the pit while the liquids infiltrate into the soil. When a pit latrine is highly frequented it fills up rapidly and must be cleared by a vacuum tanker.

Traditional pit latrines often smell and serve as a breeding ground for flies and other disease-transmitting insects. Therefore the Kumasi Ventilated Improved Pit latrine (KVIP) was developed as a modern version of the traditional pit latrine. The KVIP is equipped with a ventilation pipe that ensures air circulation in the the latrine through the chimney effect (Figure 3.8). Flies are hindered to enter the pipe by a flyscreen and in case they enter the latrine via the toilet, they are attracted by the light in the vent pipe and stay there until they die [Mara (1996)].

In fact pit latrines are typical solutions for rural areas where population density is low and toilet use is occasional. For urban use they are rather inconvenient, because in high density areas the pollution of soil and groundwater is too strong. Nevertheless (11%) of the population in GAMA use conventional pit latrines and (10%) use KVIP's.

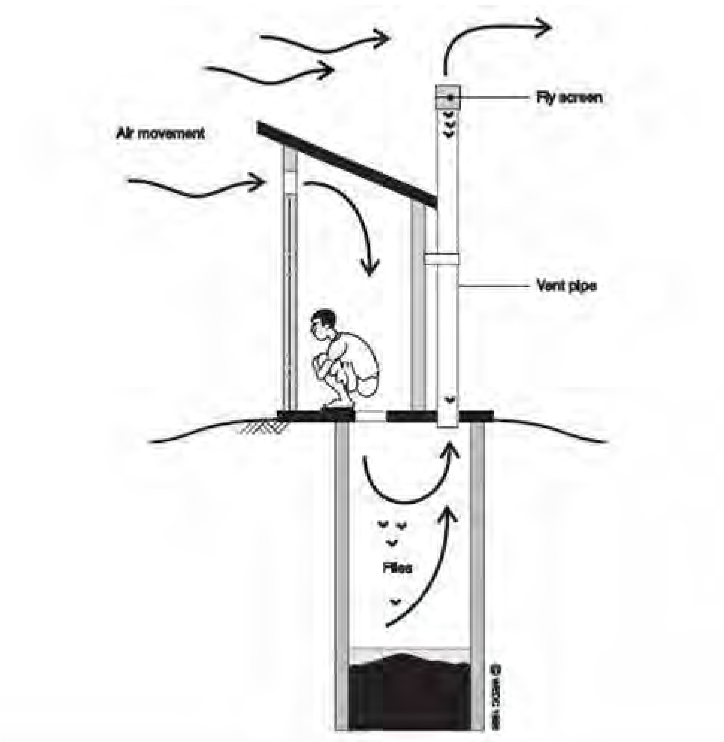

Figure 3.8: Sanitation Infrastructure and Marine Pollution in Greater Accra Metropolitan Area

Bucket latrines

Bucket and pan latrines are the simplest way to collect human waste. The excreta drops from the toilet into a bucket placed in a small vault underneath the toilet. Most of the times the vault has a door towards the street, so that it can be emptied from outside during nighttime. This service is offered by private companies, as the municipality does not provide it anymore in order to encourage the switch to improved facilities. The so-called "conservancy workers" usually carry the septage on their heads to the next collection (cesspool) point from where it is transported by truck to Lavender Hill. As workers get into direct contact with the sludge, they often suffer from diseases and cases of death are also not uncommon. For many years now the municipality has been trying to eliminate these kinds of toilets, particularly by subsidizing the upgrade to KVIP's and by banning the construction of new bucket latrines all over the city. Even so still a relatively high proportion of households in Accra (9%) depend on bucket and pan latrines, but the number is decreasing. Due to its informal character it was hard to get information about the price of the collection service, but according to Porter et al. (1997) it was around $2 per month for cleaning the bucket twice a week in the early 90's and according to Suleiman (2007) it was $5.50 per month for cleaning the bucket three times a week in Kumasi in 2006. For further calculations a cleanig fee of $0.50 per bucket is assumed for Accra in 2008.

3.2.4 Public Toilets

Public toilets are of great importance in the GAMA region and certainly deserve a closer look. They represent the least acceptable way of excreta management on the one hand while they are the most common practice (27%) on the other hand.

The municipality's overall concept is to support people in installing domestic toilet facilities so that public toilets are reserved for travelers and visitors. The reality is that not only street vendors use them, who come from outside of Accra every day, but so do many residents who cannot afford own facilities or who prefer to use public toilets from having their own facilities at home. Most toilets are located in the AMA district, close to busy public places like markets and bus stations. There are about 150 toilet blocks, each block containing 20 seats in average. The toilets are predominantly pit latrines which are regularly cleared by AMA owned honey trucks.

As the public toilet facilities are insufficient regarding the size of the population lacking domestic toilet facilities, long queues are prevalent, especially during the rush hours. Therefore some private individuals have recognized the opportunity to make money in this sector and have set up self-constructed toilet huts. These privately run toilets are usually just urinals without any facility for defecation, due to the lack of a nightsoil reception tank. A hut normally consists of two urinals (one for females and one for males) and the urine is piped into the open drains (Figure 3.9). Though they have no official admission and compete with municipal toilets, the small businesses are tolerated by the officials. Presently they are still small in number, but they might keep spreading in the city as one can make good money with public toilets. In the central part of Accra the common fee for urinals is $0.05 per use and $0.15 for complete toilets.

Figure 3.9: Self-constructed public urinal at Novotel Market, Accra

3.3 Projected Sanitary Improvements

On the 26th of April 2006 the Accra Sewerage Improvement Project (ASIP) has been approved by the directors of the African Development Bank (ADB). This section gives a short description of the project details with focus on the implementation costs and projected running costs and user fees. Most of the information is taken from the ASIP appraisal report [Wassel et al. (2005)]. The ASIP project involves the construction of two new sewage treatment plants, one at Densu Delta and one at Legon with a total capacity of 12400 m^3/day, the rehabilitation of Accra West Plant and the extension of the existing sewerage network up to 63km. The Burma Camp sewerage system and treatment plant shall be revised after 2020. Thus, after the completion of the project in 2010, Accra will be divided into three areas for sewage treatment (see Figure 3.10). Altogether 4184 houses will then be connected to a sewer.

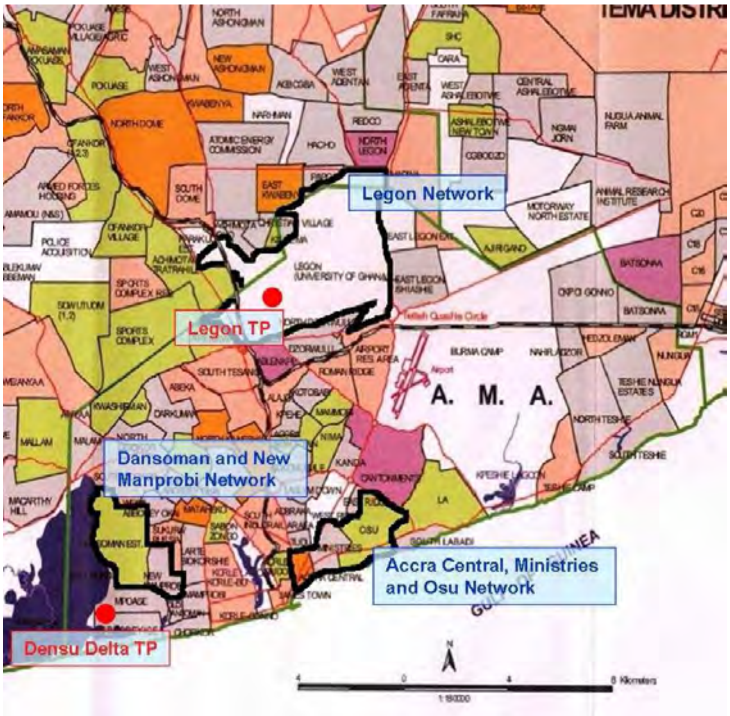

Figure 3.10: Location of projected sewerage networks and treatment plants

In addition 147 new public toilet blocks are planned, with 20 toilet seats in each block making it 2940 toilets. The facilities are of the water closet type and for those that are not in the catchment area of one of the new sewerage systems, septic tanks will be provided. The sewage sludge shall be transported to the treatment plants, therefore 20 additional emptying vehicles are supplied. Unfortunately no information is given about the location of these toilets, but it can be assumed that they will be located in the central part of Accra.

Table 3.5 shows the investment costs for the ASIP project. The project is designed to be cost recovering with a financial rate of return of 2.2% while the interest rate of the ADB loan is 0.75%. The financial sustainability is based on the folowing assumptions:

- subventions of about $9 million
- a yearly fresh water use of 58 million m^3
- a 35% surcharge on the water bill for sewerage use
- yearly revenues of $21.4 million

It is not made clear where the 58 million m^3 of freshwater shall come from, especially considering only 4184 household connections. That would imply a yearly freshwater consumption of 13850 m^3 per household, equivalent to yearly cost of $8700 for freshwater and $2500 for sanitation per household. At the same time the revenues from 58 million m^3 of water at a price of \$0.18 per m^3 only account for \$10.44 million, the source of the missing \$11 million revenues remains unexplained.

Table 3.5: Components and costs of ASIP

Components	Description	Costs in million U.S.$
Densu Delta STP	capacity of 6000m^3/day	18.44
Legon STP	capacity of 6400m^3/day	6.70
Sewerage network	extension to 63km in central AMA	15.55
House connections	4184	3.53
Public Toilets and Septage Tanks	147	9.92
Maintenance Equipment		5.20
Other Costs	Environmental measures, institutional strengthening, etc.	6.32
Contingencies	Physical and price contingencies	11.91
Total		77.57

(Source: Wassel et al. (2005))

Once the system is established in 2010 the yearly operating costs are reported to be \$20.6 million including the depreciation of the assets. Assuming that each household that is connected to the system has one toilet, the running costs can be divided by 7124 toilets making it \$2892 per toilet per year.

3.4 Evaluation

In 2008 the sanitary situation in Accra is alarming. Every day almost $1000m^3$ of faecal sludge accrue in the city, none of it is treated. Instead, about 80% of the are dumped on the beach and about 20% are discharged at the broken treatment plants, that cannot take anymore. The Korle Lagoon and the Odaw River, Accra's main water bodies, are highly polluted with all kinds of wastes they receive from the city. The Odaw River is the principal outlet for all major

drainage channels and thousands of m^3 of faecal sludge are infiltrated into Korle Lagoon every day through the central sewerage system. In times of flood it occurs that wastewater from the lagoon is pushed back into the city which is a big health hazard for the population.
A good indicator for the miserable sanitary conditions are the cases of waterborne diseases. Two of the most frequent and most dangerous diseases are intestinal worms and diarrhoea, since they can lead to death if not treated adequately. In 2004 in the Accra Metropolitan Area (approx. 1.8 mio inhabitants) 26780 cases of diarrhoea and 6727 cases of intestinal worms were reported [Lunani (2007)], and the number of unreported cases is presumably still higher. Proper sanitary infrastructure could significantly reduce these diseases.
But at present, lacking technologies inhibit the installation of a central sanitation system and inadequate policies have driven people to find solutions for their sanitation problems by themselves. As a result, many different means of sanitation are prevalent in the city, but none of them is safe, environmentally acceptable and convenient. 40% of the dwellers use on-site systems (pit latrines)[2] and 60% use off-site systems (sewerage system, septic tanks, bucket latrines). For 27% of the population public toilets are the prefered means of sanitation and 12% relief themselves in bushes or on the beach. The choice of sanitation is strongly influenced by financial means. In general it can be said that the richest use WCs in combination with septic tanks followed by KVIPs, traditional pit latrines and bucket latrines in the middle and low income classes. The poor use public toilets when they can afford to, otherwise they have no other chance than to defecate in open spaces.

None of the existent sanitation systems represents an overall suitable and sustainable solution. The shortcomings of each system are described in the following, in order to determine demands that a new ecosan concept should fulfill.

Sewerage system

The extension of the sewerage system is very arguable, as it is very costly but will not help to improve the overall sanitary situation of the city. It covers only a small area and allows those who already have adequate sanitation facilities to upgrade to a sewer connected WC. Those who have no or inadequate facilities will not benefit from the system. The main shortcomings of sewerage based sanitation in Accra are listed below:

- a connection to the system is too expensive for the majority
- for a significant percentage of households not enough water is available for flush toilets
- the overall benefits of a sewerage system will not be realized, if too few people connect

[2] note that pit latrines are only ranked among on-site facilities if they are abandonned when they are full, latrines that are periodically emptied are off-site facilities

- the technical functionality of the treatment plants is at high risk, if too few people connect
- at the moment, the lack of know-how to maintain the system is still too big in Ghana

Supposing that these problems can be solved in the future, a sewerage system might be a reasonable solution for the central part of Accra, where housing density is high and new building development has come to an end. But it is very unlikely that within the next 30 to 40 years more than 25% of Accra's population will be served by a functioning sewerage network.

Septic tank system

Flushing toilets are regarded as very modern and hygienic in Ghana. A septic tank system offers the comfort of a water closet without the necessity of a sewerage network. It is the only flexible system that can be operated with a flushing toilet and is therefore the preferred sanitation system for those who live in middle and high class houses on the outskirts of Accra and who can afford the relatively high installation costs.

The major shortcoming of the septic tank system is its water dependency. Already today Accra faces severe water shortages, and it is not foreseeable when these problems will be solved. Because of the high costs and logistic difficulties of installing a city wide water supply network in combination with uncontrolled development of houses and high rates of urbanization water supply is likely to stay unreliable in many parts of the city for the next decades. Even if every household had indoor water supply, one must consider that there might never be enough water available to flush all the toilets. [3].

Another critical issue is that septic tanks are installed underground. Possible leakages remain unnoticed and often faecal sludge can make its way into the soil which can cause groundwater contermination. In a safe longterm sanitary system groundwater sources should be protected from pollution by human excreta.

Last but not least the problem of faecal sludge treatment in Accra has not yet been solved. Treatment plants are designed to treat human excreta that are diluted with water. Faecal sludge however is concentrated and the past has shown that no treatment plant was able to cope with the huge amounts of sludge that is produced in Accra every day. Even the three projected treatment plants do not permit the treatment of Accra's daily amounts of faecal sludge.

To sum up, the septic tank system offers high comfort and hygiene for the single user but in the form it is currently exercised in Accra, it has a huge negative impact on the environment and on the public health.

[3] In Sweden, the average demand for freshwater is 130 liters per person per day, 40 liters of that are used as flush water [Winblad and Simpson-Hébert (2004)]. In 2000 in Ghana GWCL was able to withdraw 235 mio m^3 for domestic use [aquastat (2008)], the actual demand was higher. That makes 32.2 liters per capita per day, not even enough to flush the toilet

KVIP's

In Accra's poor areas water is expensive since standpipes are inexistent and people have to buy it from commercial water sellers. Here, the KVIP is the best alternative as it functions without any water. However, poor people often cannot afford a KVIP because of its

- high initial costs
- relatively high costs of maintaining
- high costs for clearing the pit by a vacuum tanker

Additionally a high density of on-site facilities like KVIP's or traditional pit latrines in a city increases the risk of groundwater and surface water pollution, because contaminated liquids infiltrate into the soil from the bottom of the pit.

Public toilets

With the intention to promote domestic facilities Accra's policy makers have neglected public toilets on purpose for a long time. This has lead to a lack of facilities where they are badly needed and unsanitary conditions in and around the existing ones. Additionally, some people cannot afford to pay for a public toilet twice or three times a day. Therefore many dwellers (12%) relieve themselves into the gutters or in other open spaces instead, which leads to the pollution of open drains and an increased risk of pathogenic infections all over the city, especially in poor areas. Hence, as long as the majority of people in Accra live under difficult financial circumstances and do not have the monetary means to build their own facilities, public toilets will remain an essential feature of the city's sanitation management. To make people use the toilets, the service must be offered at reasonable prices, which includes free toilets in the poorest areas. A functioning system of public toilets is an essential pre-condition for a clean and healthy city.

In the next chapter the costs of ecological sanitation in Accra are calculated. In order to make them comparable to those of the existing sanitation systems, the yearly costs that incur for the user are summarized in Table 3.6. The calculations for the per capita use are based on the following assumptions:

1. The water costs are \$0.515 per m^3 as stated in Wassel et al. (2005)
2. If a water closet is used, the daily per capita water consumption is assumed to be 90 liters per day of which 30 liters are used as flush water
3. If a septic tank is or a pit latrine are used, the amount of faecal sludge produced per capita per year is estimated at 100 liters

4. If a bucket latrine is used, the amount of total excreta is estimated at 550 liters per capita per year
5. If the public toilet is used, a W.C. is used once and a urinal is used twice a day

Ecosan shall particularly present an alternative to those systems that currently have negative impacts on peoples health or on the environment, such as bucket or pit latrines. The fact that these sanitation facilities do not require high investment costs implies that there are also no high sunk costs, which facilitates switching to the ecosan system.

Table 3.6: Yearly sanitation expenditures for individuals in Accra

System	Invest. costs	Yearly costs ($\frac{US\$}{ca*day}$)	Lifespan (Years)	Comments
Sewer Connection	$900[4]	$11.70	40	35% surcharge on water bill
Septic tank	$1860[5]	$7.67	25	$75 for clearing of 4 m^3
KVIP	$160[6]	$1.90	10	$75 for clearing of 4 m^3
Bucket latrine	$0	$9.13	irrelevant	$0.50/bucket for clearing
Public toilet	$0	$91.25	irrelevant	$0.05 for urinal, $0.15 for WC

Considering only running costs the KVIP by far is the cheapest form of sanitation since it works without water and compared to the bucket latrine it needs to be cleared less frequently, because the liquid fraction of the excreta infiltrates into the soil. Surprisingly the costs for public toilet use are about ten times higher than the rest. It is probably quiet unrealistic that someone uses the public toilet three times a day, but even if a WC was used every second day, the costs still accrue to $54,75 per annum.
If the investment costs are taken into account by using linear depreciation and supposing that 10 people (average household size in Accra) share one toilet the individual annual costs are lowest for the KVIP ($3.50) followed by the bucket latrine where the investment costs are considered as nonexistent (still $9.13). The annual costs for a sewer connection are $13.95 per capita and the septic tank system costs $15.11. Still using exclusively public toilets causes by far the highest annual costs for the individual ($91.25).

Demands on the new sanitation system:

- It must be flexible (independent from other infrastructure)
- It must work with little or no water
- It must be affordable even for the urban poor
- Sanitation coverage of at least 90%

4 Costs of Ecological Sanitation in Accra

Chapter 3 showed that the sanitary situation in Accra is unsatisfactory at the moment. ecosan could contribute to the solution of the current problems by providing safe on-site sanitation facilities. But ecosan toilets will only be accepted by the public, if they do not cause significantly higher costs for the individuals. This chapter examines the potential costs related to the whole ecosan system. The basic questions are:

- How expensive are ecosan toilets for the individual and are they cost competitive to the existing sanitation options?
- How much does it cost to transport and to treat the urine, so that it can be reused in agriculture?

The costs for transportation and treatment represent the production costs for a urine based fertilizer (respectively reusable urine) that can be sold for agricultural purpose. The investment and running costs of ecosan toilets are compared to the annual costs of the existing sanitation methods to point out, whether it can be advantageous or not for people in Accra to switch to ecosan toilets. Therefore the system is divided into three parts:

1. Costs for toilet facilities
2. Transportation and storage costs
3. Treatment costs

The basic assumption is that the urine collection must be for free. There are two possible alternatives to that assumption: The households must pay for the collection or they get paid for the collected urine. It is considered as impossible to make people pay for the collection, because this would create high incentives to discharge the urine into the soil (e.g. by manipulating the tank), particularly because this is already practiced today with KVIP's and septic tanks. Hence it would be better to set positive incentives for the urine collection by paying a small amount of money for each m^3 of urine. But this could also have negative effects, for example it might lead people to dilute the urine with water in order to get more money. Thus it is assumed that people must be indifferent about the urine collection and therefore it must be provided for free.

4.1 Possible Designs and Costs for Toilet Facilities

The analysis of the current state of sanitation in Accra has revealed two major problems that should be addressed by the ecosan system:

1. Open defecation because of insufficient public toilets and
2. Dumping of untreated faecal sludge because of lacking facilities to treat the excreta

Consequently ecosan in Accra shall comprise two parts: The first part addresses the problem of open defecation by providing ecosan public toilets in the city. The second part includes domestic toilets for those dwellers who currently have insufficient toilet facilities at home.

4.1.1 Public Toilets

Many people who live outside of Accra come to the city during daytime to do their work. But unlike people in more industrialized cities, most of them work in the streets where they sell food, clothes, housewares, jewelry, souvenirs, etc. For these people public toilets are essential, as they have no other sanitation options during the day. The problem of open defecation in the city is the first that should be addressed by a new sanitation system, since almost 30% of the population have no adequate toilet facilities in their houses. This is not only dangerous for those who are directly affected, but the resulting open defecation represents a health hazard for everybody who moves around in the city.

Public Urinals

At present urinals fill a niche in the public sanitation sector in Accra, because they offer a cheaper alternative to water closets for those who only need to urinate. Therefore they are widely accepted by the public and are well frequented. The reason is that many people defecate at home and only need to urinate during the day while they are working. Thus, as long as the urinal service is provided at a relatively low price, a lot of customers per day are guaranteed. A second advantage of urinals is that they do not replace a whole domestic toilet, so that there remains an incentive for citizens to have "complete" toilets at their houses.

A third reason to integrate urinals in the ecosan system is that the collected urine is more or less sterile and needs no storage for hygienization, because it does not get into contact with faeces. Thus it can be used in agriculture immediately, which is a great advantage as it reduces the storage costs (see chapter 6.

Trials with urine collection from public urinals have already been carried out in Accra five years ago. The aim was to stop the discharge of urine from public urinals into the open drains in the city. Special toilet blocks were constructed by the municipality, with a superstructure made of steel, two ceramic urinals and a 200 liters collection tank underneath the toilets. The full tanks were lifted onto a truck and brought to the Accra West treatment plant. But since some urinals were frequented by more than 1000 people a day, the tanks ran full very quickly and some had to be emptied more than once a day. The lifting of the tanks was so expensive ($32 per lift) that running the urinals became uneconomically. So the trials were phased out after a few weeks and the outflows of the urinals are now directed into the drains again. Figure 4.1 shows a five year old trial urinal and a close-up onto the clack for the collection tank. The investment costs for that kind of urinal are quoted by AMA officials at $1000, cost for maintenance including repairs (mainly welding and repainting) amount at $200 per year. As urine collection is assumed to be free of charge, operation costs only accrue in form of chemicals for the cleaning ($\$100/year$). There is a caretaker responsible for each toilet block who collects the money from each customer and cleans the toilets from time to time. His monthly salary is set at $ 200.

One thing the trials have shown is that a collection tank of 250 liters is too small for a toilet block with two urinals in the city. From the fact that at one of the busiest toilet blocks (800-1000 customers/day) about 300 liters of urine were collected it can be derived that one person leaves about 0.3 liters at the toilet. The maximum number of customers can be assumed at 1000 per day while an average of 400 customers per day is realistic. Urinals are usually closed on Sundays, so that 312 operating day per year can be assumed. Taking the average of 400 customers per day 37.5 m^3 urine can be produced from one block. Hence a 500 liters tank guarantees, that none of the toilet blocks needs emptying more than once a day and that they need to be cleared every 4th day in average. A tank of that size can still be stored easily under the toilets[1] and the additional costs are moderate. The steel construction is not as durable as a concrete construction but it offers the possibility to relocate the toilet block, and with regular maintenance a life span of ten years can be achieved. The additional costs for the bigger storage tank are estimated at $50, so that the total investment costs add up to $1050 (Table 4.1).

[1]one possible size would be 0.5*1*1 meters

Figure 4.1: Superstructure of public urinal (left) and clack for access to storage tank (right)

Public Urine Diverting Toilets

In addition to the public urinals also urine diverting toilets (UDD) are needed to give people the possibility to defecate. But in this context, the effect of offering UDD's to the public should be carefully observed. In case people tend to use the public toilets instead of caring for their own domestic facilities, the number of toilets should be limited, because the prime target of the ecosan approach is still to enable individual and safe on-site sanitation.

Public toilet blocks with UDD's have been constructed in many African countries within various ecosan projects so far. Unfortunately there have been no projects with locally built toilets in Ghana yet, and therefore no precise data on the costs of such toilets is available for Ghana. Costs for complete UDD toilet blocks are stated by De Silva (2007) for Uganda between $296 to $464 and for Burkina Faso at $135. These toilets are equipped with self-constructed concrete toilet sockets at low prices. Concrete toilet sockets are not feasible for public toilets in Accra, because they are not durable enough for user frequencies of approx. 400 people per day.

Instead, the cost calculation for a toilet block is based on the costs for public urinals as stated by AMA. The required modifications are:

- a toilet bowl with urine diverting mechanism
- a 500 liters urine collection tank
- additional basket for the faeces collection underneath the toilets

The price of a toilet block without urinals is $550[2].

[2]The two urinals make up almost 50% of the total costs for a toilet block, because they must be imported from India or China as they are not manufactured locally

Ecosan toilet sockets for dry toilets with urine diversion made of hard plastic are available for $11 and $17 from manufacturers in South Africa[3] (excluding shipping costs). But as there is no information about the durability of hard plastic toilets, ceramic toilets are considered to be the best choice. Apparently no ceramic urine diversion toilets are manufactured in Africa at present. For the calculation the European price of a porcelain dry-toilet with urine diversion ($450 [Winblad and Simpson-Hébert (2004)]) is used, though they can probably be purchased at lower prices from India or China. For the urine collection tank again $50 are calculated.
The costs for additional baskets for faeces collection are regarded as marginal, the costs for operation and maintenance are assumed to be the same as for the urinals. The total investment and operation costs are listed in Table 4.1

Table 4.1: Costs for ecological sanitation in Accra

Description	Invest.	Maintenance	Operation	Salary	Lifespan	Using Fee	Income
ASIP toilet (2 seats)	$ 6,748	$ 202	$ 850	$ 200	30 years	$ 0.15	$ 18,720
2 Udd's	$ 1,500	$ 200	100	$ 200	10 years	$ 0.10	$ 12,480
2 urinals	$ 1,050	$ 200	100	$ 200	10 years	$ 0.05	$ 6,240

The costs for one ASIP toilet block are derived from Wassel et al. (2005). For the investment and maintenance costs those given for the construction of a 20 seat toilet block were divided by ten to make them comparable to the 2 seater ecosan toilet blocks. The operation costs include costs for flush water and for septic tank clearing. Theoretically costs also accrue for the faecal sludge treatment, but these are not included into this calculation, since their amount is unknown. Assuming 400 customers per day, 312 opening days per year and linear depreciation on the investment costs the ASIP toilet block generates a surplus of $ 15,043 per year. With a Udd toilet block a surplus of $ 9,630 per year can be achieved. A toilet block containing two urinals generates annual revenues of $ 3,435. The revenues are generally very high and the differences between the three systems are significant. This is mainly due to the big differences in the using fees and a high number of customers per day. For the ecosan toilets the comparison to the ASIP toilets in terms of profitability is of minor importance. The fact that ecosan public toilets can work cost covering is more important. By variating the number of customers how many customers per day are needed to keep the investment profitable. The Udd toilet block needs a yearly average of 91 customers (46 per toilet) to operate cost covering and the urinal toilet block breaks even at 180 users per day (90 per $urinal/day$).

[3]Cemforce, 8 Cabinet Street, Kimberley 8301

4.1.2 Domestic Urine Diversion Toilets

Despite the fact that many people do not have access to domestic toilet facilities in Accra, the second big problem is that large amounts of faecal sludge accumulate in the city every day. This is because faecal sludge is produced by each of the different forms of sanitation, no matter if it is a bucket latrine, a pit latrine or a septic tank system, but no facilities for faecal sludge treatment exist. The problem can be solved if people are convinced to install ecosan toilets in their houses. This can only be achieved, if the toilets offer the same or higher comfort and hygiene at a lower or at least at an equal price. Dwellers who currently use septic tanks or the sewerage system are already used to flush toilets and consider them as higher standard and it will certainly be very difficult to convince them to switch to dry toilets. Concerning the other forms of sanitation ecosan toilets are considered as (at least) equal in terms of hygiene and comfort.
The fact that there is already a broad network of greywater drains, supports the implementation of ecosan toilets in the city, as no extra sewer must be constructed for the greywater. People who use latrines or public toilets already do separate greywater and blackwater and even those who use septic tanks usually discharge the greywater into the open drains. If the greywater drains are cleaned and then properly covered they complement the ecosan system with only little effort. For the greywater cleaning reed and grass could be planted in the natural drains like the Odaw River.
The next chapter analyzes deals with the costs of building respectively rebuilding the single toilets, as this will be the biggest cost driver in the ecosan system.

Costs of domestic Urine diversion toilets

The costs for installing ecosan toilets in the single houses are hard to assess, as they depend on the particular circumstances in each house (e.g. location of the toilet) and the designated features of the toilet (e.g. porcelain or concrete toilet socket, design of the superstructure) But after reviewing some research that has already been done on the investment costs of urine diversion toilets (see Mayumbelo (2006), De Silva (2007)) it can be said that in general UDD's equipped with a simple squatting pan and a 100 liters urine collection tank are about 10% more expensive than VIP's. Taking the costs of a VIP toilet from Burkina Faso ($160) a price of $176 is calculated. A decent toilet socket as shown in Figure 4.2 costs approx. $35[4]. If the UDD is also upgraded with a 1000 liters collection tank, additional costs of $75[5] accrue. The total investment costs of an ecosan system with a concrete urine diversion toilet and 1000 liters storage tank as shown in Figure 4.2 then accrue to $ 286. For the collection tank a lifespan of 20

[4]personal communication with Stefan Deegener, construction engineer, TU Hamburg-Harburg
[5]http://dodave.com/price.htm

years is assumed, for the toilet construction 10 years are taken (like for the KVIP). Assuming again that 10 people share one toilet and that no costs accrue for the emptying service the annual per capita costs accrue to $ 2.49. Compared to the individual sanitation costs from chapter 3 the different sanitation facilities are ranked according to their annual per capita costs as follows:

- Ecosan UDD: $ 2.49
- Pit latrine/KVIP: $ 3.50
- Bucket latrine: $ 9.13
- Sewerage Connection: $ 13.95
- Septic tank: $ 15.11
- Public toilet: $ 91.25

Despite its slightly higher investment costs compared to the KVIP the ecosan toilet is cheaper regarding the annual costs when urine collection is provided for free. It must be noted that costs for faeces collection are not considered in the calculation for the ecosan toilet. Either the collection is also financed through the sales of dried faecal matter as a soil conditioner to agriculturists or it is used on-site (e.g. in the garden) or additional costs for the collection must be added to the ecosan costs. The volume of faeces ($50kg/person/year$) is relatively small compared to urine, so that the transportation can be realized at lower costs.

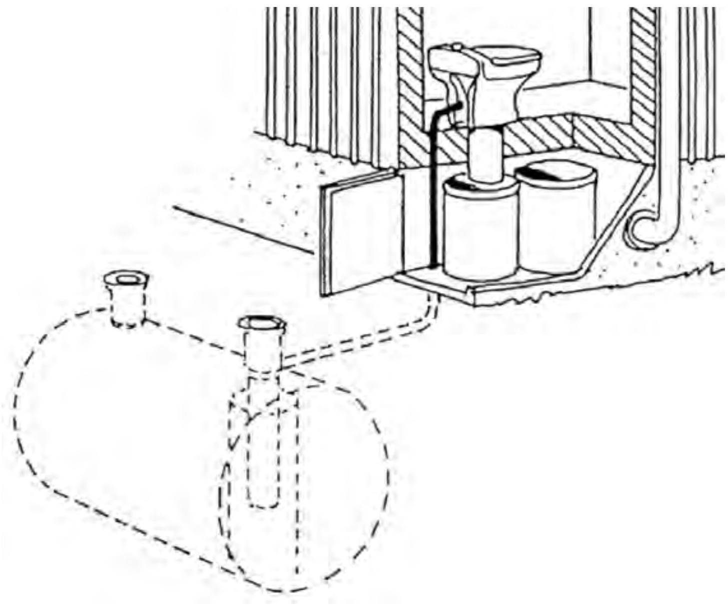


Figure 4.2: Possible arrangement of toilet, faeces collection buckets and underground urine storage tank (left) and low cost concrete diversion toilet from Burkina Faso (right) (Source:Winblad and Simpson-Hébert (2004) and Dagerskog (2007))

4.2 Urine Transportation and Storage

Transportation

As mentioned in section 4.1.1 trials with urine collection in public urinals have shown that the lifting of the full tanks is too much of an effort and too expensive. Instead the urine could be pumped into a barrel which is transported by a normal pick-up truck. Slob (1995) proved for an Indian community of 50,000 people that using a generator pump is the cheapest way of collecting urine from household storage tanks.

But so far, no experiences have been made with large scale urine collection and transportation in Ghana. From the septic tank and pit cleaning in Accra it is known that pumping out and transporting 4000 liters of sludge within the city boundaries costs $58[6]. But pit emptying requires a sophisticated and expensive vacuum truck. Since for urine collection a usual generator pump is suitable, it can be offered at a lower price. De Silva (2007) assumes that within the boundaries of Accra emptying and transportation of $1m^3$ of urine can be realized for $\$5$. For further transportation a price of $0.5 per m^3 per km is applied.

Storage

As mentioned in chapter 2 certain storage times for the collected urine must be kept in order to reach complete hygienization. For Ghana a relatively short storage time of 4 weeks seems to be sufficient, because the warm climate supports the hygienization process. But even when storage times are short the storing costs still tend to make up a relatively high fraction of the total costs in the ecosan system. As possible storage options polyethylene tanks are often mentioned in the ecosan literature, but particularly if large volumes of urine are stored centralized, the storing costs of such tanks exceed presumably the value of the urine. Therefore low-cost storage options must be found to keep the reuse of urine economical. One possibility is to dig a hole of the desired size and cover the ground with a tarpaulin. The basin is then filled with urine and covered with a second tarpaulin to protect it from rain and evaporation. Unfortunately no information about the prices of such tarpaulin sheets in Ghana are available, so the price is estimated at $1 per m^2, which is half the British price[7].

If the urine is stored decentralized (e.g. at the farming sites) polyethylene tanks are considered as the best option. The average price for a polyethylene tank in Ghana is $100 per m^3 for tank sizes between 1 and 10 m^3. In Ghana people usually use the poly tanks to store water on the rooftops of their houses. They are very durable and sunlight resistant, thus a lifespan of 20 years can be assumed. Using linear depreciation the annual storing costs amount to $5 per m^3.

[6]average emptying tariff of $70 minus discharge fee at Lavender Hill

[7]www.tarpsexpress.co.uk/prices.htm

4.3 Urine Treatment

Of the six treatment methods described in section 2.3 reverse osmosis and evaporation do not qualify for Ghana, because the methods need stabilized urine as feed substrate. That would mean, that each household regularly had to add acids in the right amount to the storage tank, which is considered to be too difficult and too dangerous. The resting available methods are classified below according to their energy demands respectively process costs:

1. **Low cost**
   Storage: Urine is stored without any treatment either at a central storage site in Accra or decentralized at the single farming sites where it is used, after at least 4 weeks the urine is hygienized and safe for reuse on the fields, as no additional energy or chemicals are needed the costs can be calculated from the transportation and storage costs
2. **Medium cost**
   Struvite production combined with ammonia adsorption by zeolite: Urine is brought to a central treatment plant where 98% of the phosphorus are recovered by addition of magnesium oxide. By adding zeolite to the P-depleted urine about 80% of the ammonia are recovered. The remaining liquid still contains about 20% of its origanal nitrogen load and needs further treatment before it can be discharged. The costs for energy and magnesium oxide based on the current price for natural gas are \$0.53 per m^3 of treated urine[8]. Prices for zeolite in Ghana could not be determined.
3. **High cost**
   Struvite production combined with steam stripping: In a central treatment plant phosphorus is recovered by struvite production (like above) and in a second step about 95% of the nitrogen are concentrated in a NH_3-solution by steam stripping. The total energy costs of the two processes are \$2.10 per m^3.

As no information about the investment and operating costs of potential treatment plants in Ghana are currently available, the overall production costs can only be determined for the storage option. A cost estimation for the other two options is not practicable at the moment as too many variables are missing, such as costs for materials, land requirements, labor, maintenance and repairs, etc. Normally the product costs are needed to carry out a market analysis for a certain product as the demand always depends on the product price. For the remaining two treatment options the market analysis shall identify a target price for the products, so that the highest possible production costs can be derived.

[8]price for one British thermal unit(BTU): \$11.07 (http://www.oilnergy.com/1gnymex.htm, accessed on April,27 2008) 1BTU=1055MJ

4.4 Conclusion

The cost analysis carried out in this chapter showed that domestic ecosan toilets in Accra generally have investment costs that are slightly higher than those for KVIP's, that are comparable in comfort and quality. Compared to septic tank systems and sewer connections the installation of an ecosan toilet causes lower costs per capita. Including the yearly costs for the individual user, ecosan toilets are even cheaper than KVIP's provided that no costs for urine and faeces collection accrue.

In regard to public toilets, the yearly net revenues of ecosan toilet blocks are lower than those achieved with water closets, because it is assumed that customers are willing to pay only $\frac{2}{3}$ of the user fee of a W.C. But still ecosan toilet blocks operate cost covering as long as an average frequency of 91 customers per day for a Udd toilet block and 180 customers per day for a toilet block with urinals is obtained (each block contains 2 toilets). Here again it is assumed that urine collection is provided for free.

Chapter 6 will show whether the urine collection, transportation, storage and eventually treatment can be financed by the sales of urine respectively a urine based fertilizer to agriculturists in Accra. Prior to that, the general market for fertilizers in Ghana is reviewed in the next chapter.

5 The Fertilizer Market in Ghana

Ghana has no facilities for domestic fertilizer production. The national fertilizer demand is completely covered by imports. Common fertilizer blends used in the country are NPK 15-15-15, which contains 15% N, 15% P_2O_5 and 15% K_2O and ammonium sulfate (AS) containing 20% nitrogen.

The largest fertilizer producer is China accounting for 20.4 % of the world's production in 2002. Other countries with a significant share of total world fertilizer production are the United States (15.9%), India (12.1%), Canada (10%) and Russia (10.1%). The shares of the remaining 15 of the world's 20 leading producing countries ranged between 0.9% and 3.6% [FAO (2003)].

The leading exporters of nitrogenous fertilizers are Russia, the United States and Canada having exported 4.1, 2.8 and 1.5 million tonnes respectively in 2002. The total exports of these three countries reached 24.3 million tonnes in 2002 and represented 41% of the total fertilizer trade.

The United States are also the largest phosphate fertilizer exporter (5.1 million tonnes in 2002), while China is the major importer. There is also an international trade in phosphoric acid. Total exports amounted 2.9 million tonnes in 2002, of which Morocco had the largest share (36%). Phosphoric acid is also produced in Africa, e.g. in Senegal (13%) and South Africa (8%). Holding 56% of all imports of phosphoric acids India is the prime destination country followed by Western Europe (20%) [FAO (2003)].

Canada is the largest potash exporter with a share of 38% of the total world potash trade. The other three big potash exporting countries are Belarus, Russia and Germany. The major importers are China, India and Brazil.

5.1 External Factors Influencing the Fertilizer Market in Ghana

In a well functioning unrestricted market demand and supply are the two forces that determine the market volume. The demand for fertilizers is positively linked to the demand for agricultural products, since fertilizers are a productivity enhancing input factor in agriculture. The population in Ghana increased from 6.7 millions in 1960 to 18.5 millions in 2000 at an average rate of 2.6%. Consequently the demand for agricultural products rose steadily in the examined period. But despite of the constantly growing demand in agriculture, the fertilizer market in Ghana experienced dramatic fluctuations and showed some unexpected developments between 1960 and 2000 (Figure 5.1). This leads to the assumption, that the market for fertilizers in Ghana is influenced by some external factors, like the country's overall economic performance, policy adjustments and possible restrictions on the supply side. In order to understand the factors that influence the fertilizer market, the reasons for the recent fluctuations in fertilizer consumption are analyzed in this section.

Furthermore it is interesting to see that the crop yields in Ghana did not experience any significant constant increases within the past decades (Figure 5.2). But a productivity increase in the agricultural sector is badly needed, since the population growth leads to a reduction of open spaces for agriculture and to a higher demand for agricultural products at the same time. Ghana can no longer afford stagnating crop yields but needs to increase food production in order to keep pace with population growth. Increased fertilizer use can have a positive impact on yields, but it must go along with overall improvements in the agricultural sector. If such improvements do not take place, fertilizer use may also be irrational, since it would not lead to additional revenues for the farmer. Possible constraints for fertilizer use on farm level are considered in the demand analysis in subsection 5.2.1.

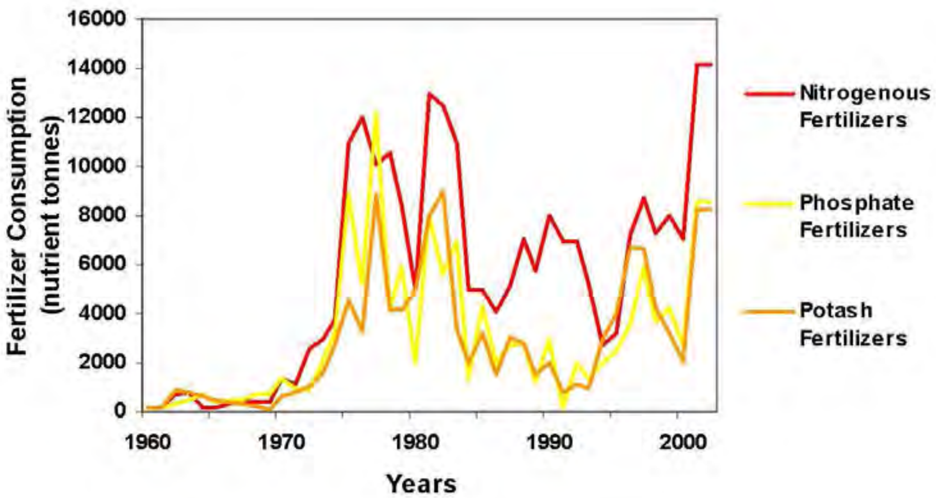

Figure 5.1: Ghana Fertilizer Consumption 1960-2002 (data derived from: FAOSTAT)

In the 1960s fertilizer use was still moderate in Ghana with none of the compounds exceeding 1000 tonnes per year. It followed a sharp increase in the 1970s reaching its peak in 1977 when about 10,000 tonnes of each nutrient were consumed. This is represents a tenfold increase in fertilizer consumption in ten years. The following years were characterized by massive fluctuations until in 1984 phosphate and potash fertilizers reached a longtime low of about 2,000 tonnes while N-fertilizers stayed at a relatively higher level of 5,000 tonnes. The total fertilizer

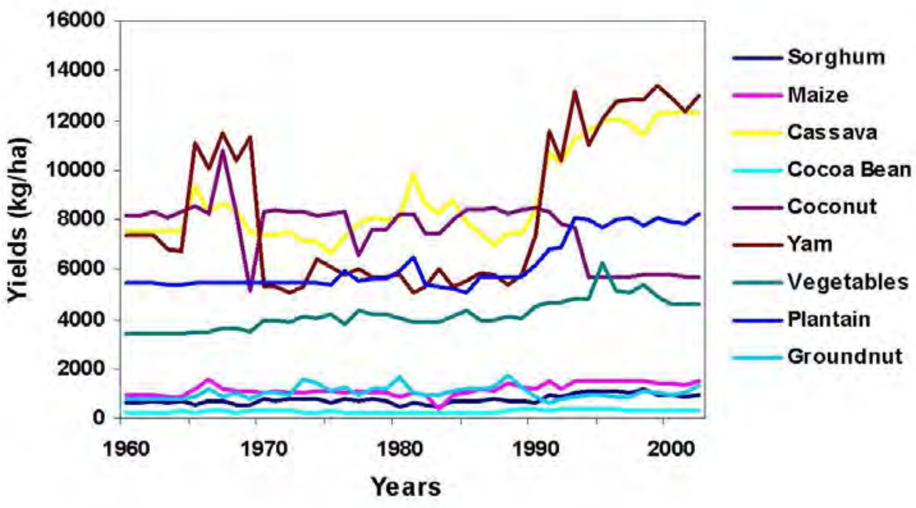

Figure 5.2: Ghana Crop Yields 1960-2002 (data derived from: FAOSTAT)

consumption stagnated until 1994 and then began to rise again accompanied by wide fluctuations. In 2002 only nitrogen had exceeded its 1977 level with 14,000 tonnes, while 8,000 tonnes of phosphorus and potassium were consumed, which was even less than 25 years before. As mentioned above the reasons for such profound instabilities of the fertilizer market probably can be credited to externalities rather than to the agricultural market development. Bumb and Baanante (1996) state that among others policies dealing with devaluation, subsidy removal and privatization seem to have the strongest impact on the fertilizer market.

5.1.1 Agricultural Reform Programmes

Policy changes in Ghana always had a great influence on the agricultural sector. In the 1960s and early 1970s the government supported crop production with low taxes on agriculture in order to strengthen the export market and the market for domestic food crops. Farmers earned well and were able to invest in fertilizers to increase their production. But in the late 1970s the government went on an industrialization strategy and put heavy taxes on the agricultural sector to finance industrial and infrastructural investments. In average farmers in 1983 received only 21% of the producer price they received in 1970 [Bumb (1994)]. The result was a declining agricultural production between 1977 and 1983, the output of staple food crops for instance almost halved from 7.9 million tonnes to 4.1 million tonnes during that period. Thus, the bad performance of the agricultural sector explains the sharp decrease in fertilizer consumption in the late 1970s. There have been many reform programmes that affected the agricultural sector, the most important were the Economic Recovery Programme in 1983, the Ghana Agricultural

Action Plan and Strategies (1986-88), the Agricultural Services Rehabilitation Project (1987-1990) and the Medium Term Agricultural Development Programme (1991-2000). Not every single program Today, policy makers in Ghana still have a great influence on the development of agricultural productivity and therewith on the effective demand for fertilizers, though the last years there is a trend away from governmental interference towards private sector participation in agriculture. It is not clear at the moment whether the Ghanaian government will promote investments into agriculture in the coming years or whether the focus will be put on industrial development again. But in the long run there might be a trend to neglect agriculture in favor of industry, since industrial development is considered to be economically progressive and since cheap food imports become more and more available from the European Union or China.

5.1.2 Volatile Exchange Rate

All fertilizer requirements in Ghana are covered by imports. The prices paid for fertilizers not only depend on the actual product price but also on the exchange rate between the local currency (cedi) and the currency of the trade partner. Foreign exchange are needed for each fertilizer purchase, so that fertilizer competes with other imported investment goods such as machinery and spare parts. Until 1983 Ghana used a fixed exchange rate system, which means that the cedi was linked to the US$ in a fixed rate of 2.8 cedis for $ 1. The system guaranteed stable fertilizer prizes as long as prices were stable in the US as well. However, under the Economic Recovery Programme (ERP) in April 1983 Ghana switched from the fixed exchange rate system to a flexible system, meaning that the cedi was no longer linked to the US$. The result was that the value of US$ 1 increased within eight years to 350 cedis in 1990, and accordingly the price of ammonium sulfate rose from 500 cedis per tonne in 1983 to the astronomical price of 62,000 cedis per tonne in 1990 [Bumb (1994)]. Though with the depreciation of the cedi fertilizer prices were certainly compensated by rising output prices for food crops, such an unstable economic environment effects fertilizer demand, since prices become intransparent and trade is hampered when money, as a medium of exchange, loses its value so quickly. The negative effect becomes clearly visible in the low fertilizer demand from 1984 on.

5.1.3 Fertilizer Subsidies

The general purpose of fertilizer subsidies is to reduce fertilizer prices paid by farmers below the actual market price. Fertilizer subsidies are discussed controversy under developing aid experts. On the one hand they promote fertilizer use very effectively as they improve the ratio of output prices to input prices for farmers and thus they represent good incentives for fertilizer use.

On the other hand no developing country can afford to keep up high subsidies in the long run and artificially low kept prices reduce incentives for cost savings in the production, distribution and marketing of fertilizers and encourage smuggling and wastage. Morris (2007) reviews the experiences made with fertilizer subsidy removals in the mid 1980s in some African countries. He constitutes that the removals had positive effects in countries like Ethiopia, Kenya and Zimbabwe, because private investors were encouraged to invest into fertilizer distribution networks and importers, retailers and wholesalers started operating all over the country. Particularly in Kenya the transportation and transaction costs for fertilizers declined and it became cheaper and more convenient for farmers to purchase fertilizers [Ariga et al. (2006)]. In Benin, Tanzania, Nigeria and Ghana fertilizer-to-crop ratios doubled and the subsidy removals had overall negative effects on fertilizer use. To cut it short, there is no clear pro or contra for fertilizer subsidies and a careful investigation of the specific circumstances is essential, before subsidies are introduced or removed.

In Ghana fertilizer subsidies were introduced in 1979 in order to compensate the rising world fertilizer prices resulting from the big energy crises in 1973 and 1979. High subsidies in the beginning (80% in 1980, Bumb (1994)) successfully led to constantly low prices. In 1983 the government decided to slowly phase out the subsidies untill 1990, a rather inappropriate point in time as the fertilizer demand was already weakened by the depreciation of the cedi. Both effects together explain the stagnation in fertilizer use untill 1994.

5.1.4 Fertilizer Aid

Like many other African countries Ghana received fertilizer aids between 1960 and 2002, and even today some programs are still running. For example, in 1989 100% of the fertilizer imports were financed through donor sources like the European Community, the Canadian International Development Agency or the African Development Fund [Bumb (1994)]. Beneath its negative effect on natural competition in the fertilizer market fertilizer aid has two major short comings: first, the receiving country has no influence on the date and amount of supply which makes long term planning with fertilizer inputs very difficult. Second, the nutrient composition of the fertilizer is determined by the donor country, so that farmes often receive a product that does not suite their needs [Bumb (1994)]. Fertilizer aid certainly had a great influence on the consumption pattern of the recent decades in Ghana, but since the liberalization of the fertilizer market in 1991 most programes were phased out and the impact of fertilizer aids on the market behaviour is considered to be negligible in future.

5.2 Ghana Fertilizer Market

5.2.1 Demand

In Ghana the agricultural sector accounts for 37.3% of the GDP and employs 55% of the population. Though the share in GDP has been declining during the past decades (58% in 1980, 48% in 1990, 40% in 2000) agriculture is still an important part of the national economy and is supposed to form an essential foundation for further industrial development. Economists agree on the fact that the economic development of African countries depends on the growth of agricultural and agro-industry sectors.

This assumption is underlined by the fact that agriculture is still the main source of foreign exchange in Ghana. In 1999 it recorded total foreign exchange earnings of 2.1US$ which was about $\frac{2}{3}$ of total export earnings. Roughly 1 billion US$ (30% of total export earnings) were contributed by the Cocoa industrie which is the source of income for 25% of the population and covers 28% of the cropped land.[FAO (2005)]

Table 5.1 gives an overview of the principal agricultural commodities produced in Ghana. As expected the cultivation of Cocoa beans has the highest share of the area under cultivation. The other two crops that are produced for the export market are Oil palm and Pineapple, but they make up only 5.2% and 0.2% of the cropped land. All other commodities are produced for the local market with the highest production shares for the most popular staples like Cassava (11.8%), Yam (9.0%) Groundnut (7.1%)and Plantains (4.6%). Agricultural production takes place all over the country and mostly on a small scale, meaning that farm size normally do not exceed 3 ha (see section 5.2.1.2). As Ghana stretches almost 700 km from north to south, various agroecological zones determine the vegetation of the country. In the wet forest Zone in the southwest of the country cocoa and oil palm are the dominant crops. Maize, millet, sorghum and groundnuts grow in the drier Savannah Zone in the north, whereas Cassava can be found in between in the Transition Zone and in the southeast of the country. Vegetables are mainly grown locally in all zones, but a few larger farms are located in the north, where vegetables are cultivated under irrigation.

Table 5.1: Major agricultural products for Ghana 2005 in ’000 tonnes and planted area

Group	Crop	Production ('000 tonnes)	Area planted ('000 ha)	% of Area
Roots,Tubbers	Cassava	9567	750	11,8
	Yam	5788	575	9,0
	Groundnut	420	450	7,1
Fruits	Plantain	2792	290	4,6
	Orange	500	54	0,9
	Coconut	315	55	0,9
	Pineapple	71	12	0,2
	Banana	53	7	0,1
Cash Crops	Cocoa	740	1850	29,1
	Oil-Palm	2025	325	5,1
Cereals	Maize	1171	750	11,8
	Sorghum	646	305	4,8
	Millet	185	185	2,9
	Rice	287	120	1,9
Vegetables	Pepper/Chilly	329	100	1,6
	Sweet Potato	95	68	1,0
	Tomato	200	40	0,6
	Onion	43	6	0,1
Others		1014	412	6,5
Total		26241	6354	100

(Source: data derived from FAOSTAT 2007)

Figure 5.3 shows the N-P-K fertilizer consumption by region in 2005. As expected there is a clear north-south divide in fertilizer use. The three regions in the north (Upper East Region, Upper West Region and Northern Region) consume more than half of the national N-P-K fertilizer. Reasons for that are the irrigation schemes for vegetables in the north that make fertilizer use effective and the fact that the crops grown in in the north (maize, millet, sorghum etc.) have higher fertilizer demands than cocoa or oil palm in the south.

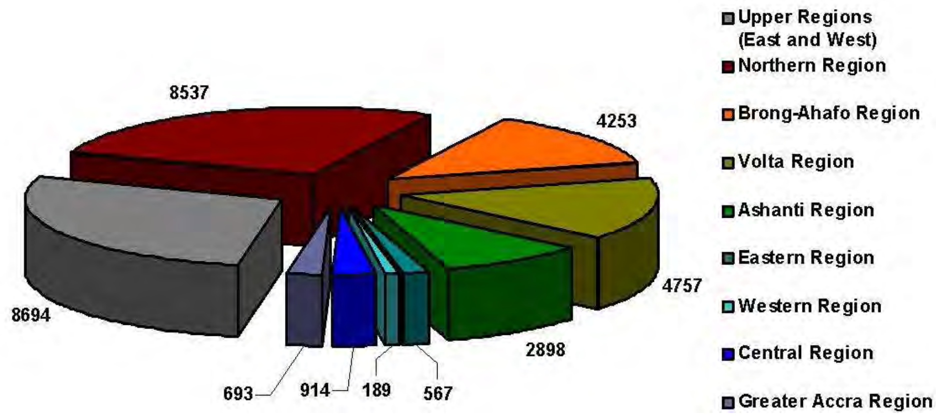

Figure 5.3: NPK Fertilizer Consumption by Region 2005 in thousand nutrient tonnes (Source: data derived from www.unstat.un.org)

In total 31,500 nutrient tonnes of NPK fertilizer were consumed in Ghana in 2005, of which 15,900 tonnes were nitrogen, 6000 tonnes phosphorus and 9,600 tonnes potassium. Comparing it to a total area under agricultural production of 6,354 ha as given in Table 5.1 an average nutrient input of 2.5 kg/ha can be calculated. This fairly low value already reflects that the actual fertilizer use in Ghana is substantially lower than the natural fertilizer demand of the crops. In order to get a more detailed insight to the fertilizing situation Table 5.2 compares recommended and actually applied dosages for the 12 major crops in the country. It was difficult to find reliable fertilizing recommendations for Ghana. The optimal fertilization depends on many factors, such as the soil quality, irrigation or rainfall quantities, temperatures, etc., so that the optimal fertilizer dosages for each crop must be calculated by experts under the specific circumstances. Only for six commodities values for Ghana were found in FAO (2005). It can be assumed that for many crops such recommendations do not exist at all. Anyway, regarding the differences between the recommended fertilizing dosages (if available) and the actual amounts of fertilizers applied to the crops, it becomes obvious that in general the dosages applied are lower than recommended.

Table 5.2: Recommended fertilizer demand and actual consumption by crop

Crop	Rec.demand $(kg/ha * year)$			Consumption $(kg/ha * year)$		
	N	P	K	N	P	K
Maize	60	40	40	7,5	3,8	3,1
Rice	-	-	-	5,6	3,5	4,2
Vegetables	-	-	-	3,6	1,6	1,8
Oil-Palm	-	-	-	0,7	1,3	1,2
Groundnut	-	-	-	0,8	1,1	0,5
Sorghum	25	25	0	1,8	0,9	1,7
Millet	-	-	-	3,0	2,3	0,3
Cassava	68	45	68	0,8	0,2	0,2
Plantain	-	-	-	0,4	0,2	0,8
Cocoa	0	18	22	0	0,1	0,1
Yam	75	0	75	0	0	0
Pineapple	200	50	200	0	0	0

Source: data derived from FAO (2005) and FAO (2004)

Table 5.2 points out that in the Ghanaian agriculture nutrient uptake and nutrient replenishment are highly unbalanced, and thus farmers do not operate sustainable at the moment. As a result farmers not only miss higher yields (and higher income) each year but the already low yields even tend to decline from year to year as the soil nutrient depletion increases. The low fertilizer inputs are particularly remarkable, because cocoa is the most important crop in Ghana and its production and export is the most commercialized. As mentioned above cocoa makes up almost one third of the agricultural land and thus the minimal use of fertilizers for that crop already explains a good part of the overall low fertilizer consumption. FAO (2004) claim that most cocoa farmers in Ghana operate on a small-scale and that they usually cannot afford to use fertilizers. Instead they decompose the cocoa-leaflitter which reduces the nutrient losses, but of course does not replenish the nutrients removed by harvest. The result is a declining cocoa production in Ghana over the recent years. In terms of fertilization with urine cocoa is a rather unsuitable crop, since the recommended fertilization ratio (0-18-22) does not at all correspond to the nutrient ratio in urine (9.5-0.8-1.9). Besides, most farmers traditionally consider cocoa as a low input crop, which means that it generates a reliable harvest each year even if no fertilizers or pesticides are applied [FAO (2004)].

5.2.1.1 Declining Soil Fertility

Ghana is not the only country that faces problems with declining soil fertility. In almost all African countries less nutrients are returned to the soils than removed. Regarding the annual soil nutrient losses with a rate of 58 kg per ha and year Ghana is ranked just above the average depletion rate of 54 kg/ha/year in Africa as shown in Table 5.3

Table 5.3: Soil Nutrient Losses (NPK) for African Countries, Cropping Season 2002-2004

Moderate/Low (less than 30 $kg/ha/year$)		**Medium** (from 30 to 60 $kg/ha/year$)		**High** (more than 60 $kg/ha/year$)	
	kg/ha		kg/ha		kg/ha
Egypt	9	Libya	33	Tanzania	61
Mauritius	15	Swaziland	37	Mauritania	63
South Africa	23	Senegal	41	Congo, Rep.of	64
Zambia	25	Tunisia	42	Guinea	64
Morocco	27	Burkina Faso	43	Lesotho	65
Algeria	28	Benin	44	Madagascar	65
		Cameroon	44	Liberia	66
		Sierra Leone	46	Uganda	66
		Botswana	47	Congo,Dem.Rep.of	68
		Sudan	47	Kenya	68
		Togo	47	Centr. African Rep.	69
		Côte d'Ivoire	48	Gabon	69
		Ethiopia	49	Angola	70
		Mali	49	Gambia	71
		Djibouti	50	Malawi	72
		Mozambique	51	Guinea Bissau	73
		Zimbabwe	53	Namibia	73
		Niger	56	Burundi	77
		Chad	57	Rwanda	77
		Nigeria	57	Equatorial Guinea	83
		Eritrea	58	Somalia	88
		Ghana	**58**		

Source:Henao (2006)

In 2003 the FAO analyzed in detail the soil nutrient losses by single crops in Ghana. Therefore a nutrient balance model was set up covering all nutrient flows that can influence soil fertility. The nutrient balances for each crop were then calculated by subtracting outputs from inputs. Table

5.4 gives an overview of the nutrient inputs and outputs that were considered in the study. The first two inputs (IN1 and IN2) as well as the first two outputs (OUT1 and OUT2) are directly controllable by humans, while the remaining three variables depend on natural conditions and cannot be influenced.

Table 5.4: Defined nutrient inputs and outputs

Inputs	**Outputs**
IN1: Mineral fertilizer	**OUT1:** Crop products (nutrient content of harvested crops)
IN2: Organic inputs	**OUT2:** Crop residues (nutrient content of crop residues removed from the field)
IN3: Wet and dry deposition (nutrient input related to rainfall and dust)	**OUT3:** Leaching
IN4: N fixation (symbiotic and non-symbiotic)	**OUT4:** Gaseous losses (denitrification and volatilization)
IN5: Sedimentation (nutrient input by irrigation water and erosion)	**OUT5:** Erosion

Figure 5.4 shows the crops that have high depletion rates and thus are particularly responsible for soil degradation. For the crops shown in Figure 5.5 the gap between fertilizer input and nutrient removal is not as big, so that they have less impact on soil degradation in the country. This can either be due to higher fertilizer inputs for these crops or a lower nutrient demand during the growing period.

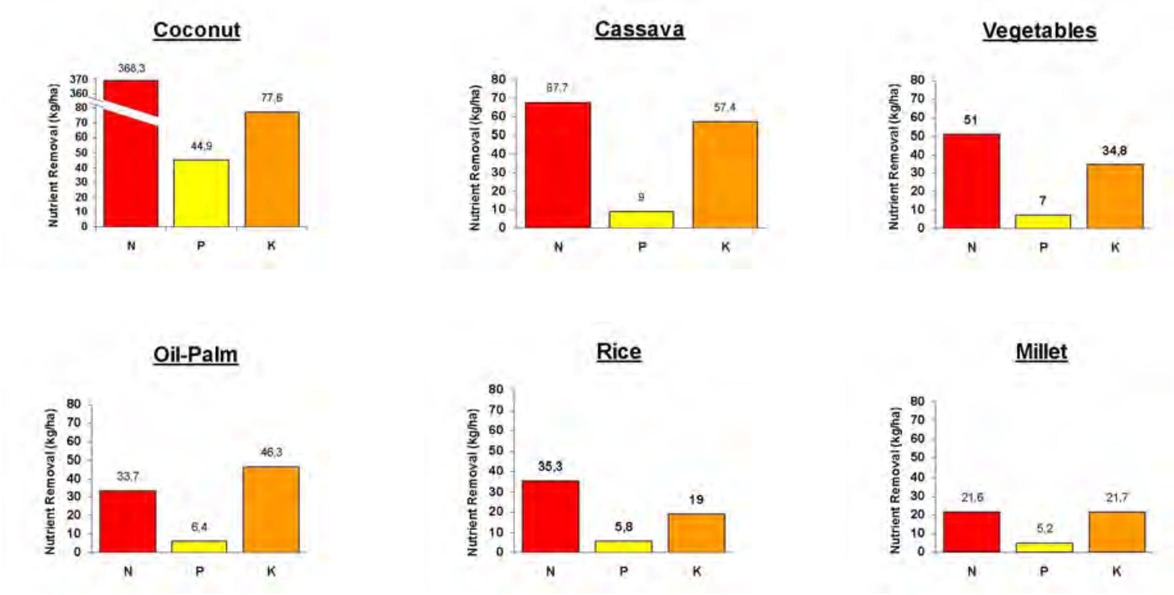

Figure 5.4: 2003 Nutrient Balances for Crops with high Nutrient Demand
(Source: data adapted from FAO (2004))

The figures reveal large differences between the single crops. Coconut, cassava and vegetables are highly depleting crops whereas the crops in whereas the depletion rates of maize, sorghum, cocoa and groundnut are much lower or almost neutral.

The outstanding rate of nitrogen removal for coconuts can be explained by a very high nitrogen content in the fruit ($OUT1 = 349kg/ha$), but as the coconut planted area only accounts for 0,9% of the agricultural area (see Table 5.1), the impact of the countries nitrogen balance is niglibable. Contrariwise Cassava has a great influence on the nitrogen balance because it is one of the major crops in Ghana (11,8% of cultivated land) and simultaneously has the second highest depletion rate ($67,5kg/ha$).

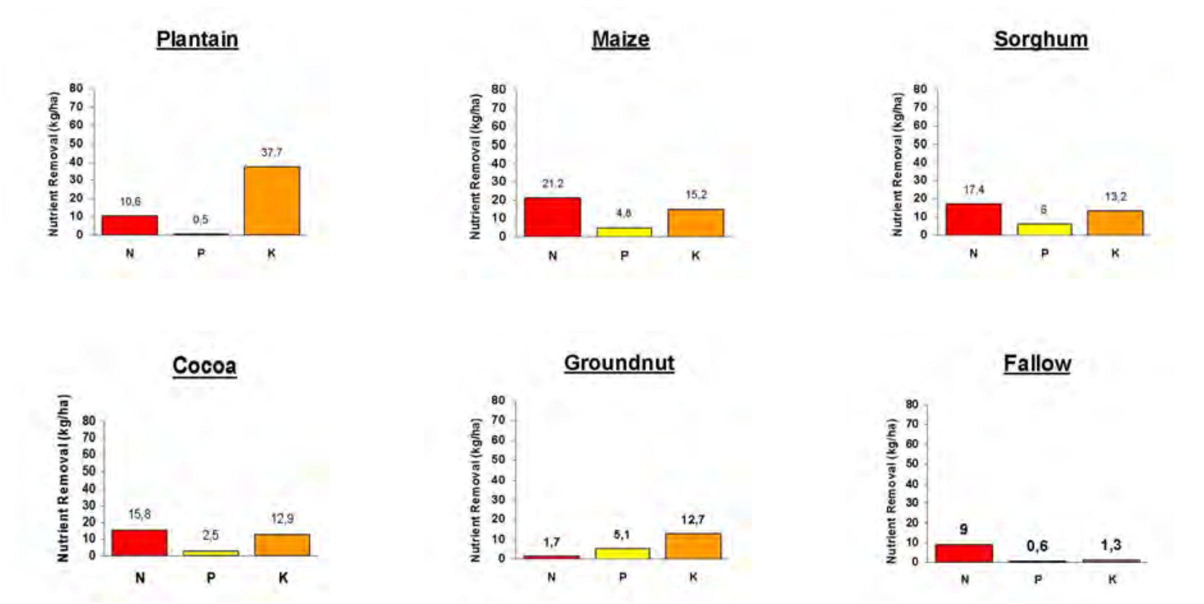

Figure 5.5: 2003 Nutrient Balances for Crops with low Nutrient Demand
(Source: data adapted from FAO (2004))

The data on agricultural land use and the individual nitrogen depletion rates of the major crops in Ghana were combined by a project team of the FAO. On this basis a map was generated that gives a rough overview of the total nitrogen balances in the country (see figure 5.7). As expected the highest nitrogen unbalances are in the southeast and the central-west parts of Ghana, which corresponds to the cassava area. These areas are located between 100km and 300km away from Accra. With regard to the reuse of urine from the city as a fertilizer the cassava region seems to be a suitable target area as the distances from the city are bearable and the nitrogen rich urine makes a good cassava fertilizer.

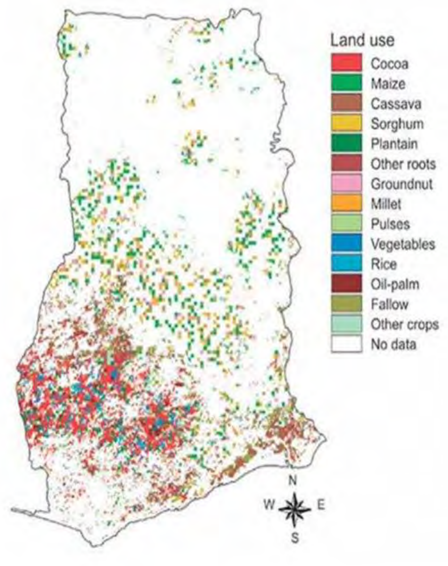

Figure 5.6: Land Use Map
(Source: FAO (2004))

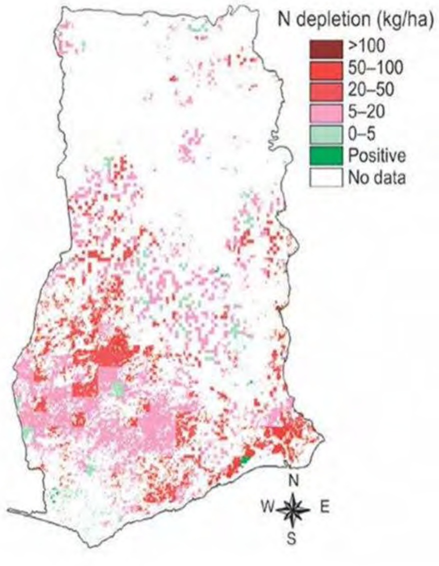

Figure 5.7: Nitrogen Balance Map
(Source: FAO (2004))

The FAO study is very detailed and covers the most important nutrient flows for the most important crops in Ghana. The data is up to date (2003) and gives a good overview of the current situation of soil degradation. Hence the results stand for the average amount of nutrients which a certain plant takes from the soil per hectare and year. To achieve an ecological equilibrium this amount of nutrients must be replaced. But it has to be considered that the model is static and only descriptive. For instance, the variable IN1 is also an input variable for the Outputs OUT3, OUT4 and OUT5, because the more fertilizer is applied to a crop the higher will be the nutrient losses by leaching, denitrification, volatilization and erosion. Therefore the study gives a realistic and detailed impression about which plants cause serious land degradation and which plants have less impact on soil fertility. But the values are not very suitable for the determination of the actual fertilizer demand. The actual demand for fertilizer is probably higher than the nutrient losses as stated in this study. Instead, for the calculation of a national fertilizer demand that comes close to the amount of nutrients needed to maintain soil fertility in Ghana, the recommended values from Table 5.2 are averaged and multiplied with the total agricultural area in the country. The result is a yearly national demand of 445,000kg N-fertilizer, 190,000kg P-fertilizer and 445,000kg K-fertilizer, which corresponds to an average N-P-K fertilization of 70-30-70 nutrient kilogram per hectare. This demand is referred to as the "ecological demand". At the same time the actual or "effective demand" in 2005 is given in Figure 5.3 with 15,900kg N-fertilizer, 6,000kg P-fertilizer and 9,600kg K-fertilizer.

Comparing the two different demands it can be concluded that there are some limitations on the fertilizer market that cause a gap between the ecological and the effective demand. The result is a very small market volume at the moment. Provided that the demand stays at its recent level it would not be profitable to enter the market with a new product. Even if a high market share could be gained by offering a urine-based fertilizer which is better and/or cheaper than the existent mineral fertilizer, the market volume would still be small. But the potential demand, and thus the potential market volume is high. If one succeeds in raising the effective demand to the level of the ecological demand, the introduction of a new fertilizer would be much more promising. Hence, the next section examines the reasons for the low fertilizer demand in Ghana. It is assumed that the reasons can be found on the farm level in form of lacking incentives for farmers to invest into this agricultural input.

5.2.1.2 The Farmer as a Profit Maximizer

Farming is predominantly on a smallholder basis in Ghana,Chamberlin (2007) states that the average farm size is 3,2 ha and that around 80% of producers are farming less than this national average. Former attempts by European agriculturists to introduce large scale farming to Ghana were not successful. Nowadays, with a better understanding of tropical farming, the need of smallholder subsistence farming is perceived [Diehl (2007)]. The few existing larger farms and plantations in the north predominantly produce rice maize and vegetables, but their share in the countries total crop production is marginal. There is hardly any food processing industry in the country, though there is some potential for flour production (made from cassava, rice and maize) and other value-added products.

The relatively small farm sizes influence the farmer's decision on fertilizer use. In economy, one assumption for profit maximizing decisions is, that there is sufficient credit available to do the investment that generates the maximum output. In case a farmer cultivates just a small piece of land, he usually must spend his whole income on living expenses and cannot save any money for investments. Even if he knew that he could maximize his profits by investing in fertilizers, he would not be able to realize the investment because of lacking financial means. Figure 5.8 illustrates some more variables that influence the farmer's decisions.

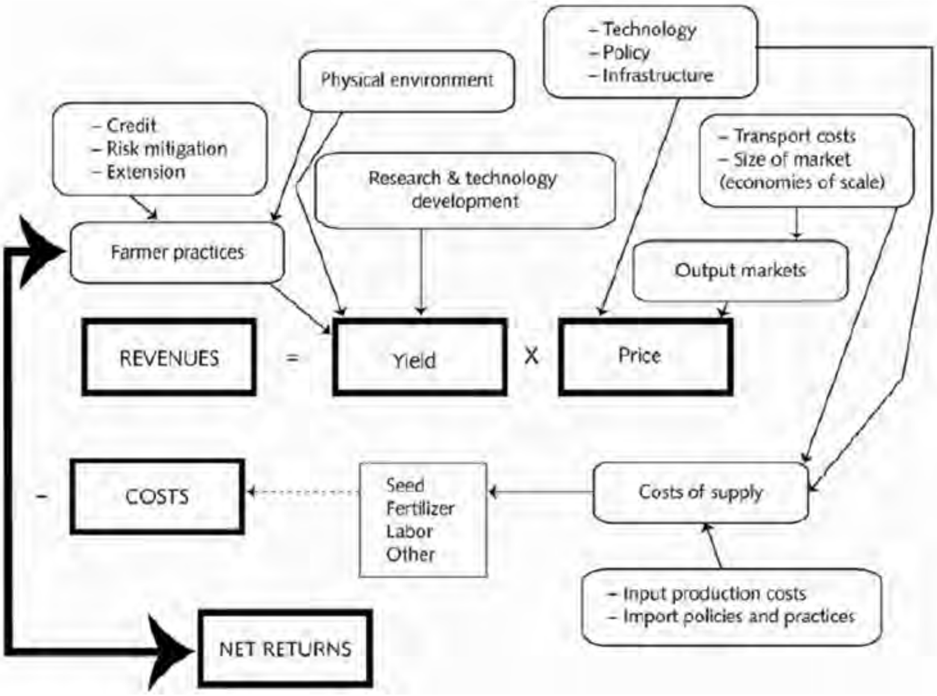

Figure 5.8: Variables influencing the farmer (source: Crawford et al. (2003)

Factors that affect the incentives to use fertilizer are mainly related to output prices of agricultural products and costs of agricultural inputs like infrastructure, marketing costs and market sizes, while capacity is largely influenced by credit availability [Kelly (2006)].

Besides the ability to make investments the most important points that reduce fertilizing incentives for a Ghanaian farmer are:

- Value cost ratios
- Risk
- Knowledge on fertilizer use

Value/cost ratios

Value/cost ratios (VCR) indicate the profitability of fertilizer use. The enumerator accounts for all fertilizer related costs, like the price, costs for transportation, storage, labor and application. The denominator stands for the additional profit that is attributable to fertilizer use, which is the additional yield times the market price. A VCR higher than 1 indicates profitability of fertilizer use, but studies have shown that at VCR's smaller than 2 the risk of fertilizer use is still too high for farmers which leads them to realize alternative investments instead [Yanggen et al. (1998)]. The VCR itself comprises two other ratios: The output/nutrient (O/N) ratio describes how many kilogram of output can be obtained from one kilogram fertilizer input ($kgoutput/kgnutrient$), and the input/output (I/O) price ratio ($inputprice/outputprice$) shows how many kilogram of output a farmer needs to sell to buy one kilogram of fertilizer. That means that an unfavorable VCR can be due to weak fertilizer response of the crops (O/N ratio), high fertilizer prices or low prices for agricultural products (I/O price ratio). In Ghana irrigated rice had a strong VCR of 10 in 2002, followed by cassava (4.9), groundnut (3.6) and maize (2.7) [FAO (2005)]. Yanggen et al. (1998) found favorable VCR's for rice and maize in West Africa and less favorable ratios for sorghum and millet. Kelly (2006) states that (O/N) ratios for West Africa are generally good and comparable to those in Asia. Extraordinary good ratios were found for maize ($O/N = 15$) and rice ($O/N = 12$). In terms of I/O price ratios, for maize the average across countries and years was 5 for Sub-Saharan Africa (SSA) and only 2.4 for other countries, meaning that fertilizer is twice as expensive for SSA maize producers. For sorghum and groundnut the SSA average is 5 compared to 3.4 for Asian countries [Yanggen et al. (1998)].

The major reasons for unfavorable input/output price ratios are the relatively high prices for fertilizer in Africa compared to relatively low prices for agricultural outputs. High fertilizer costs are caused by inefficient import, transportation and distribution processes within the country. The import often is expensive because no economies of scale can be realized with little fertilizer volumes being imported. Transportation is expensive, because fertilizer has a low value to volume ratio. In Ghana it is mostly transported by trucks, so that high petrol prices and inadequate road conditions (e.g. unpaved roads) increase the transportation costs. Gregory and Bumb (2006) compared the formation of fertilizer costs in USA and Nigeria. The free on board costs are the same for both countries ($135 per tonne). But after adding costs for the port, insurance, bagging, transportation, wholesale and retail margins the final price for the farmer is $197 in USA and $320 in Nigeria.

Risk

The presence of risk in agriculture is decisive for the profitability of fertilizer use. Generally, a high risk reduces the attractiveness of an investment. The two major risks for a farmer are crop failure and unstable product prices. In Ghana less than 1% of the arable land are irrigated [Aggrey-Fynn et al. (2003)]. Thus, the risk of crop failure because of too little rainfall during the cropping period is very high. Additionally the prices for agricultural products are subject to wide fluctuations. Due to the lack of food processing industry and the thin markets (many products are cultivated for own consumption) an oversupply in some years leads to sharp price decreases while in years of drought food prices increase dramatically. Hence, at the beginning of the cropping period the farmer does not have any knowledge about the expected yield nor about the prices, which makes decisions on fertilizer investments impossible. Figure 5.9 illustrates the fluctuations using food prices at a central market in Accra.

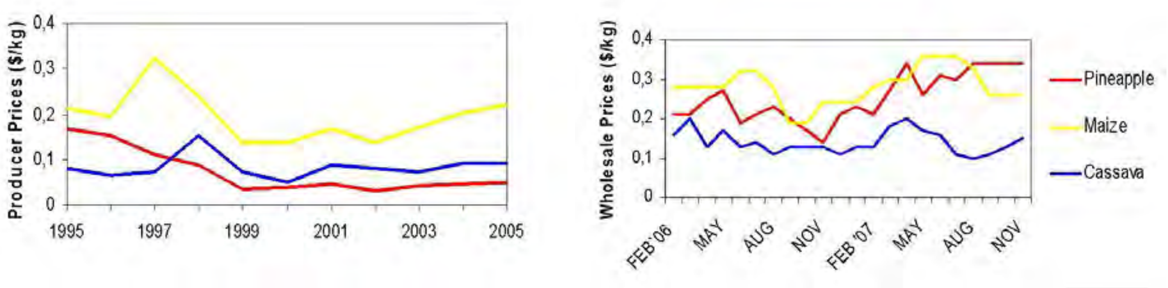

Figure 5.9: Price Fluctuations Yearly and Monthly at Makola Market (Accra) (Source:www.tradenet.biz)

Education/Knowledge

Another important aspect that affects fertilizer demand is the farmers knowledge of this agricultural input. The quality and quantity of information available on fertilizer use (composition, optimal dosage, application rate and time) influence the farmer's motivation to purchase fertilizer [Camara and Heinemann (2006)]. Full information on the fertilizing effect must also be available so that the farmer can calculate whether or not fertilizer use will be profitable. Today in Ghana researchers perceive a substantially higher yield response and profitability of fertilizer use than farmers do [Kelly (2006)]. Scientists are convinced that a demand close to the ecological nutrient demand of the plants leads to maximum profits, while farmers perceive the actual consumption as the optimum. If one succeeds in narrowing the gap between scientists and farmers, this would lead to a significant increase in fertilizer consumption.

5.2.2 Supply

As mentioned above, Ghana does not produce any fertilizer inland. The quantities consumed by farmers are imported each year through private companies, which makes the market rather inflexible. The companies determine the import quantities, based on last year's demands, whether conditions, policy environment and their own credit availability [Camara and Heinemann (2006)]. As fertilizer storage facilities are limited, demand fluctuations are hard to compensate.

Bumb (2002) has analyzed the supply structures of the Ghanaian fertilizer market in detail. Stakeholders that play a key role in the sector were identified as manufacturers, importers, wholesalers, retailers and farmers. Figure 5.10 illustrates the interactions between the single stakeholders.

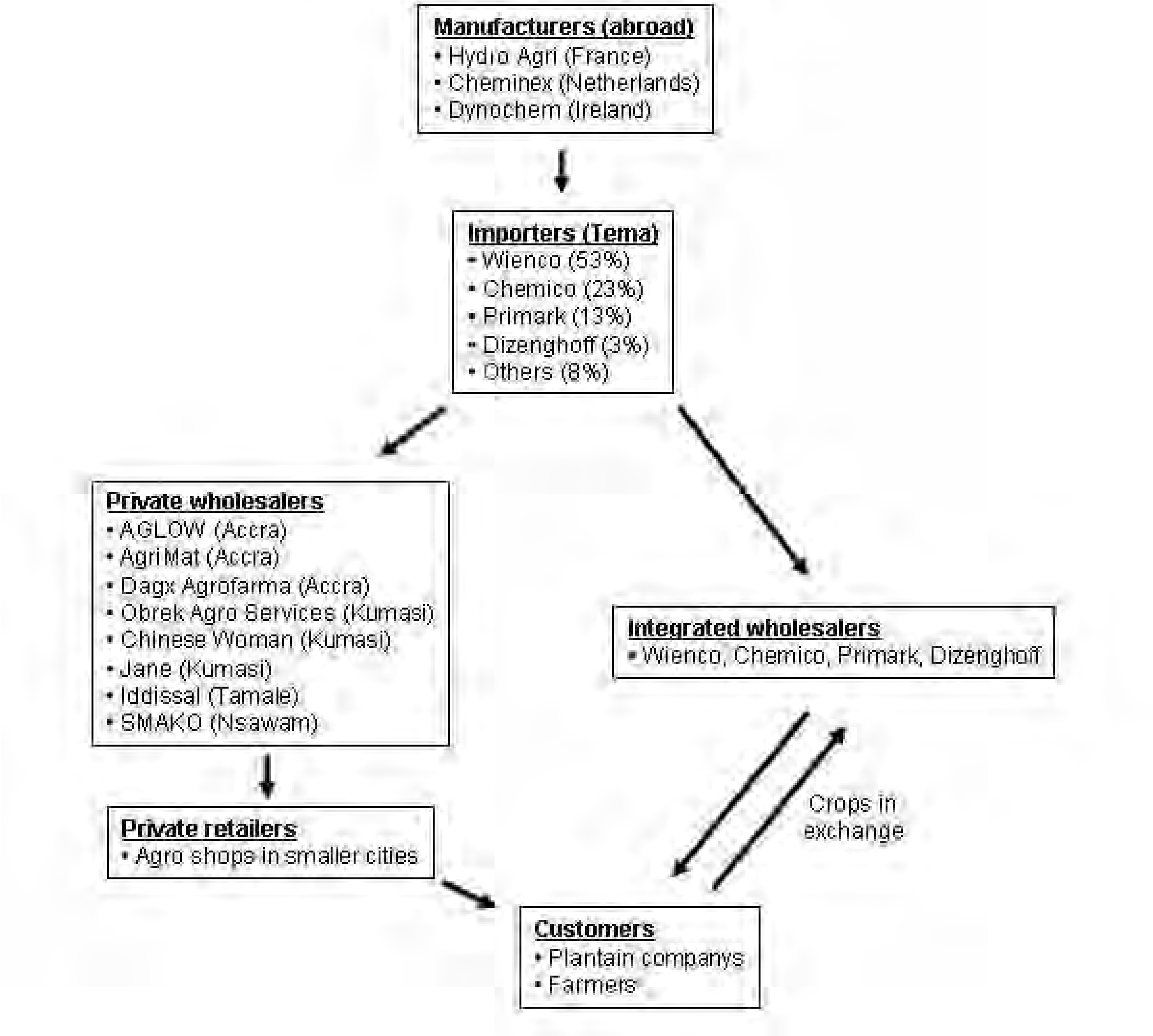

Figure 5.10: Fertilizer distribution structure in Ghana (source: based on Bumb (2002)

The Ghanaian fertilizer market was liberalized in 1991. Since then 4 private importers have established in the market, of which the largest (Wienco) holds more than 50% of the market shares. Fertilizer is imported by ship through the port of Tema and usually comes allready packed in 25kg or 50kg bags. Only Wienco has facilities to bag imported bulks of fertilizer. The bags are then transported inland and sold to wholesalers and retailers. The importers also run own wholesale stores. Some have swap agreements with companies running larger plantains to exchange fertilizer for crops (mainly export crops). The total number of wholesalers and retailers in the country is about 600 to 800, most of them concentrated in urban centers, since the low volume of the fertilizer market makes outlets in rural areas inprofitable [Bumb (2002)].

In sum, there is a well functioning supply system, that operates at low capacity and does not realize economies of scale. As a result the retail network in rural areas is underdeveloped and farmers often have to travel for long distances to purchase fertilizers. It is important to mention, that the low market volume is not due to a deficit in supply but to a deficit in demand. Thus, additional supply quantities (e.g. by urine-based fertilizer) would not increase the fertilizer consumption in the country (all other equal).

Table 5.5 shows the average retail prices for NPK and Urea fertilizers per kilogram in Ghana from 2005 to 2007.

Table 5.5: Ghana fertilizer retail prices

Type	Year		
	2005	2006	2007
15-15-15 ($\$/kg$)	0.6	0.6	0.65
Urea ($\$/kg$)	0.56	0.58	0.6

Source: data derived from: www.tradenet.biz

5.3 Conclusion

The analysis of the Ghanaian agricultural and fertilizer market revealed that there is a strong nutrient demand from the ecological point of view. Although most crops show good response to fertilizer use (good O/N ratios), the demand is presently not covered by inputs from mineral fertilizers, due to several constraints that make fertilizer use unprofitable for farmers. With ongoing agricultural production soil nutrient depletion continues which leads to a decline in productivity and to infertile soils in the long run. The main constraints are unfavorable value/-cost ratios, high risk in agricultural production and insufficient knowledge about fertilizer use among farmers. Due to the weak demand the supply side is also underdeveloped which causes high prizes for fertilizers. The result is a vicious circle of high prices due to weak demand and weak demand due to high prices, that cannot be broken by temporal fertilizer subsidies.

Generally, the agricultural situation in Ghana favors the introduction of a urine-based fertilizer, because it can help to stop the soil degradation in the country. For macroeconomic purposes, the urine-based fertilizer offers a good opportunity to escape the dependence on food and/or fertilizer imports. As the fertilizer is produced inland, the macroeconomic factors that limit fertilizer use in Ghana (particularly exchange rate fluctuations) will no longer affect fertilizer consumption. Additionally, ecosan fertilizer presents a good chance to strengthen the export market for agricultural products, and thus to earn foreign exchange. The advantage of a locally produced fertilizer is, that no foreign exchange must be spent on the agricultural input, so that the net earnings of foreign exchange increase. The crops that are most suitable for urine fertilization are cassava, rice, maize and vegetables, because of their high nitrogen demand and partly because of their favorable value/cost ratios. Because of the currently low soil fertility, substantial yield increases can be expected by urine application. Particularly the regions of high nitrogen depletion could benefit from a nitrogen rich fertilizer like urine. As urine-based fertilizer can be produced all over the country, the transport distances can be kept short, so that the costs for transportation are lower than for mineral fertilizer and farmers do not need to travel for long distances to purchase the fertilizer.

Concerning the introduction of a urine-based fertilizer it must be considered that the constraints for fertilizer consumption on farm level also exist for ecosan fertilizer. Hence, for a successful introduction of the product farmers must receive higher incentives to use fertilizer at all. First of all the system of small-scale farming must become more stable, so that the risk to invest into agricultural inputs is reduced. This should not be done by price regulations but by promoting improved agricultural practices such as irrigation and by provision of better infrastructure for farmers. Better access to input and output markets not only leads to lower input prices but also allows the farmers to reduce transport costs for their products. To reduce the price risk, storing facilities like grain depots are needed so that farmers can outbalance the seasonal price fluctuations. In order to raise the awareness of the profitability of fertilizer use among farmers, education about the fertiliz

6 Combining Ecosan and Agriculture in Accra

6.1 Urban Agriculture in Accra

Accra is located in the coastal-savanna zone, which is a rather unfavorable agricultural zone with low annual rainfalls of 800mm in average. Mean temperatures vary from a maximum of 28°C in August to a minimum of 24°C in March. The status of soil fertility is described by low levels of organic matter (0,1-1,7%) and also low nutrient contents of 5-90 mg/kg for nitrogen and 0,8-144 mg/kg for phosphorus. Only potassium is available in sufficient quantities of 14-470 mg/kg soil [FAO (2005)]. In recent years the increasing land value in Accra pushes back urban agriculture as land is used for housing or turned into commercial use. Nevertheless, urban agriculture is still practiced extensively and plays a major role in ensuring food security for the city. It is not unusual in Africa that growing cities also experience growing urban agriculture. The main advantage lays in the closeness to the customers, that allows low transportation costs and the possibility to keep vegetables fresh without any use of cooling facilities during transport. In Accra, altogether 1,048 ha are under cultivation within the city boundaries, of which 680 ha are under maize, 251 ha under mixed cereal-vegetable, 70 ha under palm and 47 ha under vegetables (Figure 6.1). Urban farming is mostly practiced by families, often without the benefits of modern methods of production. According to Obuobie et al. (2006) the majority of farmers are satisfied with their earnings and are not planning to quit their activities.

Vegetable production holds a high share of urban agriculture in Accra. Farmers often cultivate small plots of 0.01 ha to 0.02 ha within larger farming communities where they produce vegetables for commercial purpose. They sell their products directly to market women who regularly come up to the farming sites. The farming sites are usually located next to a small river or stream where water for irrigation is taken from. Cofie et al. (2004) state that about 80% of fresh exotic vegetables sold on Accra's markets stem from these farming sites and that about 1000 farmers are involved in the production. The average income an urban farmer in Accra amounts up to US$45 per month. Table 6.1 shows the major farming sites and the principal crops produced.

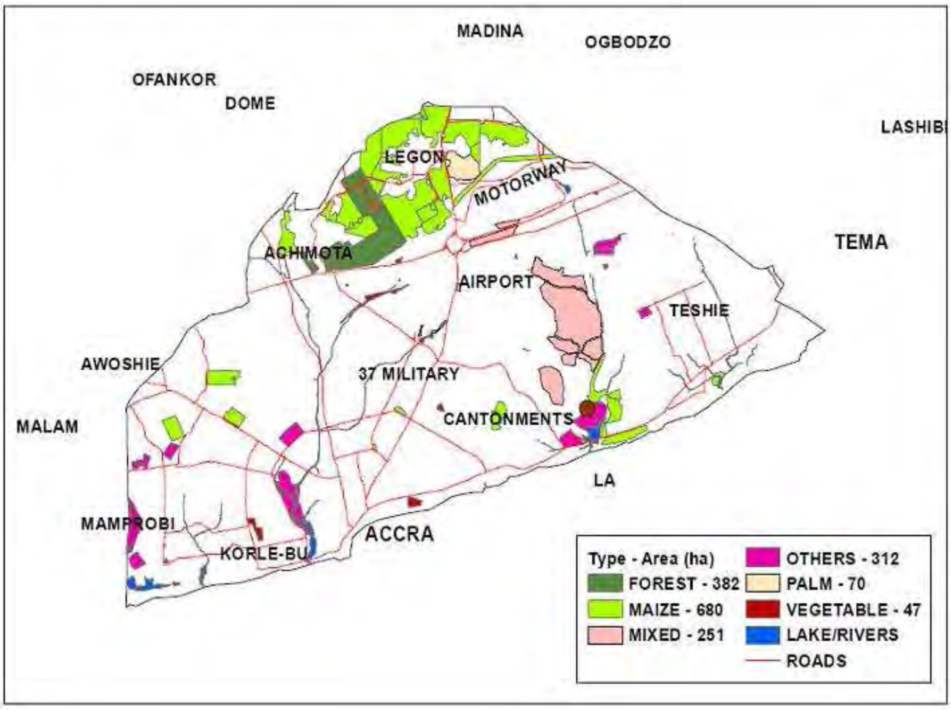

Figure 6.1: Farming activities in central Accra (Source:Obuobie et al. (2006))

Table 6.1: Major vegetable farming sites in Accra

Location	Size	Farmers	Produce
Marine drive	3.6 ha	98	lettuce, green pepper, spring onions, cucumber
Dzorwulu	15 ha	62	lettuce, cucumber, cabbage, cauliflower, spring onions
Korle Bu	10 ha	80	lettuce, cabbage, spring onions, ayoyo, alefu
La	100 ha	400	lettuce, sweet pepper, okra, maize

(Source: based on Suleiman (2007) and Obuobie et al. (2006))

The urban farmers in Accra represent potential customers for ecosan fertilizer produced in the city. As the transportation distances from households or public toilets in the city are small, it is likely that the direct application of urine onto the fields is the best solution. Therefore the farmers' attitudes on the use of urine as a fertilizer were examined by semi-structured interviews. Most of the farmers were surprised and a bit skeptic at the beginning, because they had never heard about the possibility to use human urine as a fertilizer. But after explaining the composition of urine and the amounts of nutrients contained, farmers were generally interested and the majority was wiling to try out the urine fertilization. Frequent concerns were related to the smell, hygiene and potential health risks for the farmers. Another important concern was that customers would not want to buy vegetables fertilized with urine or that market women

Figure 6.2: Farming site near Dzorwulu Power Station, Accra

might not buy their products anymore if they saw them applying urine onto the fields. In sum, farmers would use the urine, if it was 100% safe, did not affect their sales and was cheaper than the mineral fertilizer they used. All farmers use N-P-K (15-15-15) fertilizers, which they buy in a nearby agro-shop for $25 per 25 kg bag. Some farmers apply additional ammonium sulfate (AS).

6.2 The Product

In order to get an idea about the value and the fertilizing effect of urine, it is necessary to know the exact nutrient concentrations per liter. As the nutrient concentrations depend on the diet values for urine produced in Accra are presumably lower than the European values given in section 2.2.2. The average uptake of nutrients via food in Ghana is lower than in European countries. For example Ghanaians consume less meat per capita than Europeans, which results in lower nitrogen loads in the urine. There is not much data available on the average nutrient concentrations of human urine in Ghana, but first experiments within the respta project at the Valley View University (VVU)[1] have shown nutrient loads of

- 2,65 g/l N
- 0,2 g/l P
- 0,83 g/l K

[1]https://www.uni-hohenheim.de/respta

Based on that data the nutrient value for one m^3 of urine in Accra shall be calculated. Therefore the fertilizer price per nutrient is needed. Drechsel and Gyiele (1999) calculated a price ratio between the single nutrients of $N = 1.2$, $P_2O_5 = 3.3$ and $K_2O = 1$ (based on international prices for raw materials), meaning that the price for N is 1.2 times the price for K_2O and the price for P_2O_5 is 3.3 times the price for K_2O. Breaking it down to elemental values the price ratios are:

- $N = 1$
- $P = 5.4$
- $K = 1.4$

Thus phosphorus is the most expensive element in N-P-K fertilizer, followed by potassium and nitrogen.

One kg of N-P-K fertilizer costs $1 and contains 150g nitrogen, 66g phosphorus and 125g potassium, which is in price equivalents for nitrogen: $150g + 5.4 * 66g + 1.4 * 125g = 681g$. That means 681g of nitrogen are worth $1 which is 0.15 $cent/g$ of nitrogen. Taking the price ratios from above that makes 0.79 $cent/g$ for P and 0.21 $cent/g$ for K. Multiplying the prices with the nutrient contents of one liter of urine a nutrient value of 0.73 $cent/liter$ results. This is equivalent to $ 7.3 per m^3.

6.3 Scenarios

Finally two different scenarios of ecosan application in Accra are illustrated. The small-scale scenario involves only urban agriculture in Accra as customers and public urinals in the city as source of urine. It is assumed that the urine must not be stored for hygienization, since it does not get into contact with faecal matter. In the large-scale scenario domestic toilets and public UDD's are included into the production and cropland within a radius of 300 km of Accra is considered as possible application area. In this scenario urine must be stored at central storage sites.

6.3.1 Small-scale Scenario

In order to estimate the actual NPK consumption in Accra the following methods were used:

1. Literature based: Area of cultivated land in GAMA calculated in Obuobie et al. (2006) times estimated fertilizer application rate derived from FAO (2004)
2. Sample: Extrapolation of individual NPK doses of farmers interviewed in Dzorwulu

The sample is based on interviews carried out by the author at the Dzorwulu farming site in September 2007. The sample size is 10 farmers out of 60. Table 6.2 summarizes the results of the different calculations.

Table 6.2: Estimated Annual Nutrient Consumptions

Calculation method		Nutrient consumption in kg/year		
		N	P	K
GAMA theoretic	$kg/year$	6,375	3,234	2,661
	kg/ha	6.5	3.3	2.7
GAMA empiric	$kg/year$	68,273	20,543	38,752
	kg/ha	69.8	21	39.6

It is notable that the values based on the sample are between 6 to 15 times higher than the theoretical values. Inaccuracies in either of the two methods may always be a reason for such deviations. On the one hand the assumed theoretic values for fertilizer application by crop are not Ghana specific but general values for Sub-Saharan African countries and the actual values for Ghana might be above the average. On the other hand the sample size of 10 farmers is relatively small, especially regarding the total size of only just above 1 ha of farmland (compared to 978 ha in AMA), so the significance of the sample must be questioned. However the huge differences in the values suggest that the N-P-K fertilizer consumption in Accra Metropolitan Area indeed is between 10 and 15 times higher than rural areas. Additionally farmers in Accra are likely to use higher quantities of fertilizer than the average of the country, because

- they reduce the risk of crop failure by irrigation
- there is a strong constant demand for cereals and vegetables in the city, which results in relatively high and stable output prices
- urbanization
- fertilizer is easily available
- transport costs are low because of the closeness to the port

Thus the results of the interviews indicate that the actual rate of fertilizer application (and therewith the demand for N-P-K fertilizer) in the urban and peri-urban area of Accra might be far higher than quoted in the literature. Based on the empiric values per hectare the yearly nutrient consumptions and the corresponding urine demands for the four major vegetable growing sites in Accra are given in Table 6.3. As phosphorus is the limiting factor the amounts of urine calculated to cover the phosphorus demand, the demands for nitrogen and potassium are exceeded.

Table 6.3: Annual nutrient demands

Location	Size	Consumption $kg/year$			urine m^3
		N	P	K	
Marine drive	3.6 ha	251	76	143	380
Dzorwulu	15 ha	1,047	315	594	1,575
Korle Bu	10 ha	698	210	396	1,050
La	100 ha	6,980	2,100	3,960	10,500

In chapter 4 it was shown that 37.5 m^3 urine per year can be produced in one toilet block containing two urinals. From this it follows that for Marine drive 10 blocks are needed, for Dzorwulu 42, for Korle Bu 28 and for La 280 toilet blocks. Though the urine must not be stored for hygienization, farmers will not be able to use the urine every time when it is delivered. Supposing urine is applied at least every two weeks, storage facilities are needed for two week's production which is about 4% of the annual production. For the calculation 5% are used which allows to outbalance possible variations between delivery and application. Hence a final price that accrues for the farmers of \$ 5.25 per m^3 urine (\$ 5 for transportation and \$ 0.25 for storage)[2] results. This is 72% of the nutrient value of one m^3 urine which is similar to the price of one kg fertilizer with the identic nutrient composition.

6.3.2 Large-scale Scenario

In this scenario ecosan toilets on the household level shall be included into the calculation. As mentioned in chapter 4 it is likely that those households that currently use flush water toilets are not willing to switch to the ecosan system. Only households with presently no toilet, bucket latrines, pit latrines or KVIP's are included. Under these circumstances 78% (2,940 millions) of the population in GAMA produce urine that is collected for agricultural purpose. Assuming 500 liters per person and year this makes 1.47 million m^3 urine per year, which is equivalent to about 4,000 tonnes of nitrogen, 300 tonnes of phosphorus and 1,220 tonnes of potassium. Taking the average ecological demand for nutrients of 70-30-70 kg/ha calculated in chapter 5 the produced nitrogen is enough to fertilize 57,000 ha, the phosphorus lasts for 10,000 ha and the potassium lasts for 17,400 ha. Agricultural areas of that extent do not exist within the urbanized area of Accra. Therefore the urine must be transported to agricultural areas that are located 100km to 300km away. As the transportation costs accrue to \$ 0.5 per m^3 per km, a transport distance

[2]derived from chapter 4

of 200km would raise the costs of one m^3 urine up to \$ 100 compared to a nutrient value of \$ 7.3. Additionally, the urine must be stored for hygienization for at least one month, which leads to storage costs that exceed by far the urine value. If such large quantities of urine are collected, it becomes profitable to recover nutrients or to reduce the volume in a treatment plant in Accra and then transport the product to farming sites outside the city. At present, not many of such treatment plants have been realized and for the existing ones no investment costs could be obtained. As the estimation of set-up and operating costs for such a plant in Accra would be based on too many assumptions, here only the energy costs of the two treatment processes that qualified for Ghana (see chapter 4) are considered. These are \$ 0.53 per m^3 urine for N and P recovery by zeolite and struvite production (excluding the price for zeolite) and \$ 2.10 per m^3 urine for steam stripping plus struvite production. If for example a nutrient solution was produced containing 100g N per liter, the nutrient value based on Ghanaian fertilizer prices would be \$ 150 per m^3, which makes transportation profitable again. Thus, if urine is collected in large-scale, treatment processes present a feasible option to safe storage and transportation costs and provide the possibility to keep product costs below it's actual nutrient value.

7 Summary and Conclusion

Accra is a fast and uncontrolled growing city that is on its way to become a typical metropolis in a developing country. The majority of citizens live in low income areas where they do not have access to save sanitation. Lacking financial means, lacking freshwater availability and the uncontrolled sprawling of the city hinder the installation of a centralized sewerage system in the city, so that within the next 20 years not more than 5% of the dwellers will be served by a sewer. Sanitary alternatives that are presently used in Accra are septic tank systems, pit latrines and bucket latrines. But the produced faecal sludge cannot be treated, because too few treatment facilities are in operation. Instead faecal sludge is dumped onto the beach or into open water bodies in the city causing huge environmental problems and health risks for the population. Ecosan toilets provide a solution to these problems. They avoid faecal sludge production by separating and sanitizing human faeces and urine. Both forms of excreta can be reused in agriculture as a fertilizer.

This thesis analyzes the costs for each sanitation facility available in Accra and shows that ecological sanitation can be realized at the lowest per capita costs. This implies, that costs for transportation of excreta to the fields and possible storage costs can be covered by revenues from the sales of urine or a urine-based fertilizer to urban agriculturists. In order to assess the market chances of a urine based fertilizer the fertilizer market in Ghana is reviewed. The market review reveals that there is a strong ecological demand for fertilizers in Ghana that remains uncovered because of (1) macroeconomic constraints,(2) missing profitability of fertilizer use for farmers and (3) lacking knowledge about fertilizer use on farm level. Among the macroeconomic constraints exchange rate fluctuations and a general lack of foreign exchange limit fertilizer exports. Domestically produced urine-based fertilizer is independent from foreign exchange, which represents a competitive advantage. On farm level high fertilizer prices lead to unfavorable value-to-cost ratios for the farmer, meaning that the additional monetary output does not offset the additional fertilizer costs. If transported for short distances (< 10km) and stored for short times (< 14 days) urine can be sold at a lower price than mineral fertilizer which is another competitive advantage. The remaining constraints for fertilizer use also apply to urine based fertilizer. In order to create sufficient demand for urine-based fertilizer measurements must be taken to eliminate the existing constraints. Such measures are (1) the promotion of irrigation to reduce the risk of crop failure, (2) infrastructural improvements to reduce transportation costs for agricultural inputs and outputs, (3) the promotion of storage facilities and food processing industry to stabilize crop prices and not at least (4) raising awareness of the advantages of fertilizer use among farmers. Two major shortcomings of sanitized urine as fertilizer are identified in this thesis: First, some farmers have hygienic concerns about applying urine onto their fields and fear sales problems of crops fertilized with urine. Second, the concentration of nutrients is very low in urine, so that long-distance transportation is not cost-effective. Both problems can be solved by nutrient recovery from urine using treatment methods such as steam stripping or MAP-precipitation. These are promising techniques to produce highly concentrated fertilizer in grainy or liquid form of the same quality like mineral fertilizer. Further research is needed on this field to allow cost estimations on treatment plants and therewith on the profitability of such treatment methods.

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Appendix A

Interview Guidelines

The interviews with farmers were carried out in September 2007 at Dzorwulu farming site in Accra. The following questionnaire served as a guideline for the semi-structured interviews. It was designed to collect data about the possibility of using urine-based fertilizer in urban agriculture. The farmers' attitudes towards a urine-based fertilizer and the prices for mineral fertilizers used were of special interest.

Section 1: Facts

Q1: What is the size of your cultivated land?
Q2: How would you characterize the soil: e.g. sandy, loams, clays?
Q3: Which crops do you cultivate mainly?
Q4: How high are the yields per year?
Q5: Are you satisfied with the yields?
Q6: Do you use irrigation?
Q7: What kind of irrigation?

Section 2: Fertilizer Use

Q8: Do you use fertilizers?
Q9a: If not: Why not? -> Do you think you could increase your yields by applying fertilizers?
Q9b: If yes: How much fertilizer do you use per year?
What kind of fertilizers do you apply?
- Grainy or liquid? Which one do you prefer?
- Which Fertilizer for which plant?
- Do you use different fertilizers for different plants?

Section 3: Fertilizer Purchase

Q10: Where do you get the fertilizer from?
Q11: Is fertilizer always available?
Q12: Do you always get as much fertilizer as you need?
Q13: Do you have different suppliers?

Q14: Is the fertilizer supply regulated by the government?
Q15: How much do you pay per kg? Per bag?
Q16: Do think the price for fertilizer is: too low? too high? just right?

Section 4: Personal Attitude

The components of fertilizer are mainly nitrogen, phosphorus and potassium. These nutrients are gained from rock phosphate (phosphorus, potassium) or by chemical processes (nitrogen). Human urine also contains the mentioned nutrients and thus can be used for the fertilization of soils in agriculture. Another possibility is to recover the nutrients from the urine by a special treatment and use them for the production of a natural and organic fertilizer.

In average one adult human being produces approximately 1,25 liters of urine per day. The amounts of nutrients in this volume are:
1. Nitrogen: 10 g
2. Phosphorus: 1g
3. Potassium: 2,7g

Q17: Have you ever heard about the possibility to use urine for fertilizing?
Q18: Have you ever tried to fertilize with human excreta (urine)?
Q19: Do you have hygienic concerns about urine-based fertilizer?
Q20: Would you use pure urine as a fertilizer?
Q21: Would you use treated urine as a fertilizer?
Q22: Would you prefer liquid or grainy urine-based fertilizer?
Q23: Assume that urine based fertilizer is equally efficient as conventional fertilizer, would you pay less, more or the same amount for one unit of urine-based fertilizer?

Section 5: Consumers Attitude

Q24: Do you think your costumers have hygienic concerns about products fertilized with urine?
Q25: Do you think the consumers of agricultural products would prefer conventional fertilized products or urine-based fertilized products?