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Sustainable Water Management in the City of the Future

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Inventory of agricultural demand and value of the application of ecosan fertilizers in SWITCH demonstration cities
-
Inventory of agricultural demand in Accra and Beijing

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SWITCH Deliverable Briefing Note

SWITCH Deliverable 4.1.5 entitled **Inventory of agricultural demand and value of the application of ecosan fertilizers in SWITCH demonstration cities**
Author(s) and Institution(s): F. Tettenborn, S. Wang, M. Winker, R. Otterpohl Institute for wastewater management and water protection, Hamburg University of Technology, TUHH, Hamburg, Germany
Audience This document is targeted as background document for engineers, and planners, dealing with implementation of sanitation systems, trying to make the leapfrog from wastewater to agriculture, especially in low income or developing countries.
Purpose For two SWITCH demonstration cities an inventory report of the agricultural demand for ecosan nutrients in and around the city was prepared in order to demonstrate the potentials of linking wastewater production and agriculture. Studies were performed for Accra and Beijing in the context of Deliverable 4.1.5. As for Beijing, the results also include an analysis of scenarios based on urine processing to produce fertilizer (struvite production and ammonia steam stripping), followed by use in and around the city.
Background Ecosan systems offer new solutions to urban sanitation shifting the paradigms in wastewater treatment from an approach with mixed systems to systems based on source control and separate treatment and / or reuse of concentrated and diluted household wastewater flows. A potential advantage compared to the 'end-of-pipe' paradigm is enabling the nutrient recovery for agricultural use and preserving water for groundwater recharge, irrigation and other purposes. This study aimed to show the potential for agricultural use of ecosan products. Accra, the capital of Ghana is characterized by rapid urban growth and lacking reliable sanitary infrastructure. The prevailing sanitation systems like pit and bucket latrines, public toilets and open defecation do not provide safe sanitation to the population. Attempts to improve the sanitary situation by installing conventional wastewater treatment plants have not been successful. same time, fertilizer use in urban agriculture is insufficient in Accra. Fertilizer is expensive due to a weak import and supply infrastructure. Constraints for the farmers to use fertilizers are among others a high risk of crop failure, a lack of finances and a lack of agricultural expertise.

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New sanitation concepts, such as Ecological Sanitation, as a resource oriented approach to sanitation, provide the possibility to reuse nutrients from human excreta in agriculture. In order to cover the nutrient demand of all farming sites in Accra by fertilization with human urine about 13500m³ of urine would be needed per year. That amount could be generated in 360 public toilet blocks each containing two urinals. The nutrient value of one m³ of urine is calculated at $ 7,3. If the urine could be sold to urban farmers at that price, expenses for transportation and storage could be covered. In case of a collection of the whole amount of urine in the city, e.g. by use of urine diverting toilets on household level, treatment methods would be needed to reduce its volume before transporting it to farming sites outside the city.

Theoretically a large fraction (85% of N and 64% of P) of the nutrient demand in Beijing's agriculture could be covered by fertilizing products from new sanitation concepts. The two developed scenarios both proofed to be more energy (by at least a factor of 2) efficient than a conventional system with nutrient elimination at the wastewater treatment plant and fertilizer production abroad (transportation costs for fertilizer transport for a conventional scenario were not discussed although they might be high). Scenario 1 with many small units showed, that it is advantageous to reduce volumes at an early stage to reduce transportation costs. With only a few larger treatment plants, as in scenario 2, operation and maintenance is better controllable and most likely more safe. In the end a combination of both scenarios would be the ideal situation.

Since Beijing already has an existing sanitation infrastructure, any new system would need to be implement-able step by step. Some districts offer good boundary conditions for an implementation, e.g. a sanitation system that needs to be renewed, and higher population density to capture larger quantities with the same effort.

Potential Impact

New sanitation concepts offer solutions for cities without proper sanitation as well as for cities that will undergo changes towards more sustainability in the future, especially when a connection to (urban) agriculture can be made. Analysis of the points of transportation and distribution of the final products like in the example of the Mega city Beijing can help in finding solutions that will allow to implement new sanitation systems in larger scale into cities or to integrate them step by step into existing systems on a long term.

Recommendations

With the existing knowledge and given thoughts to consider, a larger pilot project for Accra and /or Beijing should be planned and realized combined with scientific documentation to further develop and improve the system.

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1. State of sanitation and urban agriculture in Accra - Can Ecological Sanitation help to improve both?

Keywords: Accra, new sanitation systems, agriculture, nutrients

Abstract

Accra, the capital of Ghana is characterized by rapid urban growth and lacking reliable sanitary infrastructure. The prevailing sanitation systems like pit and bucket latrines, public toilets and open defecation do not provide safe sanitation to the population. Attempts to improve the sanitary situation by installing conventional wastewater treatment plants have not been successful. Most plants are not functioning and the sewerage network is underdeveloped. At the same time, fertilizer use in urban agriculture is insufficient in Accra. Fertilizer is expensive due to a weak import and supply infrastructure. Constraints for the farmers to use fertilizers are among others a high risk of crop failure, a lack of finances and a lack of agricultural expertise.

New sanitation concepts, such as Ecological Sanitation, as a resource oriented approach to sanitation, provide the possibility to reuse nutrients from human excreta in agriculture. In order to cover the nutrient demand of all farming sites in Accra by fertilization with human urine about 13500m³ of urine would be needed per year. That amount could be generated in 360 public toilet blocks each containing two urinals. The nutrient value of one m³ of urine is calculated at $ 7,3. If the urine could be sold to urban farmers at that price, expenses for transportation and storage could be covered. In case of a collection of the whole amount of urine in the city, e.g. by use of urine diverting toilets on household level, treatment methods would be needed to reduce its volume before transporting it to farming sites outside the city.

1.1. Introduction

Accra is the capital of Ghana, a West African country located at the Gulf of Guinea between Ivory Coast and Togo. 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. AMA represents the original city center, where urban development started just after Ghana became independent in 1957. 20 years later, urbanization was still limited by the border of AMA and the surrounding districts were still rural in character. From 1985 on, growth also took place in the two neighboring districts GA and Tema (Figure 1), forming a new administrative boundary called GAMA. Yankson (2004) states that the urban area of Accra grew from a size of 216 km² in 1985 to 555 km² in 2002, and at present grows at a rate of 25km² 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 today the shape of the city limit is similar to the one on the bottom right side of Figure 1. The size of urbanized area in 2008 is about 705km² covering 45% of the total area of GAMA.

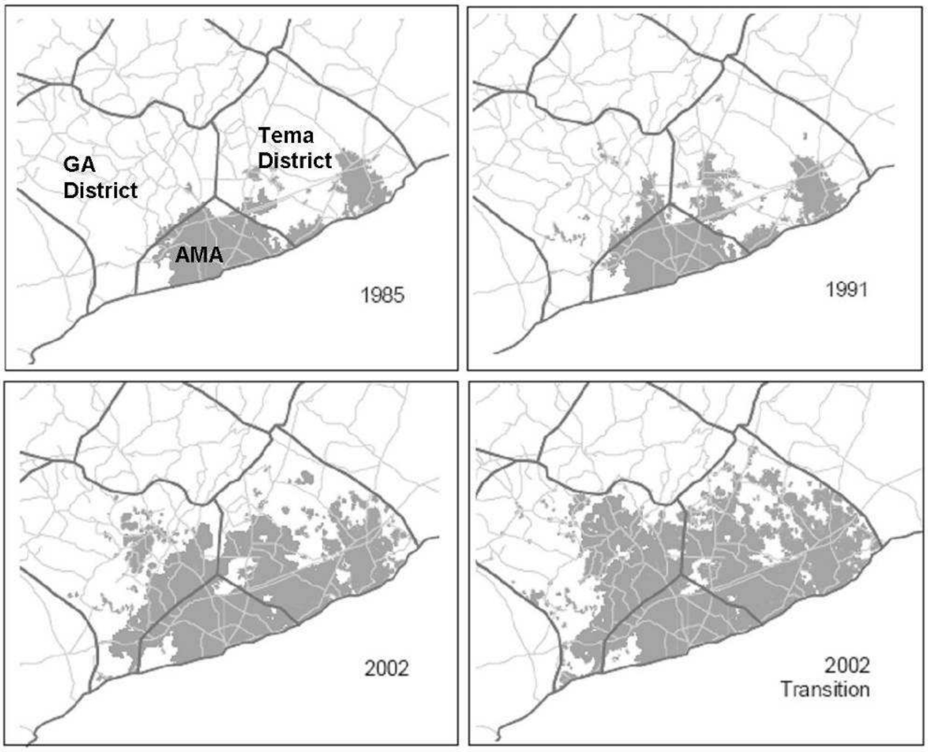

Figure 1: Accra urbanized area and area under transition into urban use (Yankson 2004)

Accra is a 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. Due to this primacy, the city has always been the center of attraction for many Ghanaians. Between 1957 and 1970 Accra’s population grew from 190 000 to 637 000 citizens [Yankson (2004)].

At the time of 1984, when Accra had reached the critical size of one million citizens, a new period of growth began. The endogenous growth by immigration from the surrounding rural areas and small towns was now exceeded by the natural indigenous growth of the urban population. At the same time, rents started to rise in the inner city, because the housing sector was liberalized by the Economic Recovery Program (ERP). Hence, this second period of growth (1984-today) is characterized by movements from downtown to the periphery, namely to the districts Ga and Tema. These movements are well reflected by table 1. While growth was moderate in the city center (AMA) with 3.4% p.a. between 1984 and 2000, Ga and Tema grew at notably higher rates of 6.3% and 9.3% respectively. Since the latest population census in Ghana was carried out in 2000, the 2008 population for the single districts is calculated on the basis of the latest yearly growth rates.

Table 1: Accra Population Development 1970-2008

District	Year				
	1970	1984	2000	2008	Growth p.a. (1984-2000)
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	190 017	506 400	1 031 466	9.3%
Dangme East	n.a.	n.a.	93 112	131 404	4.4% (est.)
Dangme West	n.a.	n.a.	96 809	136 622	4.4% (est.)
Greater Accra	n.a.	n.a.	2 905 726	4 358 937	5.2% (est.)

The physical growth, especially in Ga and Tema, proceeds in an unplanned and uncontrolled way. It is characterized by arbitrary development of open urban spaces which are mainly found in the periphery of Accra. Most houses are built illegally with no urban planning involved and so they lack of basic infrastructure like electricity, access to roads, water supply and sanitation. Figure 2 shows one of these houses, which has been built on the middle of a road. Even newly built middle and high class houses on the outskirts of Accra normally are not connected to the electricity grid and/or the freshwater/sewerage network. For house owners size and location of land are more important than access to such facilities. Instead, generators are used for electricity production and freshwater/honey trucks replace the connection to the water and sewerage network.

Figure 2: New house constructed on the middle of a road (Yankson 2004)

1.2. Sanitary situation in Accra

1.2.1. Wastewater collection

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 wastewaters directly into the ocean. Domestic wastewater is disposed off in many different ways, mainly depending on the location of a house and the income of the dwellers. Only a small share of houses in Accra is connected to a sewer system (less than 5%) so that a water based toilet (W.C.) can be used. For the remaining households the following toilet facilities and means of wastewater collection apply:

- W.C. with underground septic tank
- Improved pit latrine (KVIP) or simple pit latrine
- Bucket latrine
- Use of public toilets

Among the citizens a W.C. in combination with a septic tank is considered to be the most sophisticated and modern sanitation system. The next best choice is the Kumasi improved pit latrine (KVIP) followed by a simple pit latrine. Bucket latrines are mainly used in low income households. Finally, those households that cannot afford any domestic toilet facility are forced to use public toilets as a permanent sanitation system. Figure 3 shows the fractions of each system in Accra.

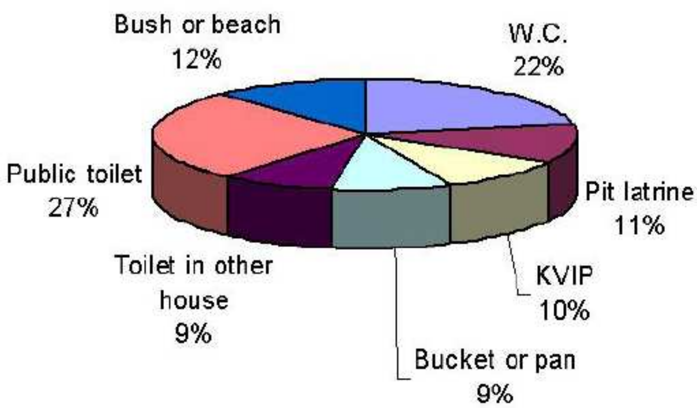

Figure 3: Sanitation facilities in Greater Accra (Source:Ghana (2002))

1.2.2. W.C. and septic tanks

The combination of a W.C. and a septic tank for excreta storage is used by 22% of Accra's population. For flushing the toilet a reliable inhouse water connection is required. 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 are flushed into the tank together with urine and flush water. Solids and liquids are then separated in the tank. The sediment (faeces) is collected at the bottom in form of sludge while liquids (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 depending on the number of users. Among on-

site facilities the combination of flush toilets and septic tanks is the most convenient but also the most expensive one. Septic tanks are predominantly found in high and middle income areas either in the center of Accra or in newly developed villas on the outskirts.

According to the Waste Management Department in Accra the initial costs for setting up a septic tank range between $1500 and $2000, depending on the size of the tank and the ground conditions. The tanks are cleared by vacuum trucks, which 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. Every day between 80 and 100 trucks discharge at Lavender hill while about 40 trucks discharge at the treatment plants. Even though none of the treatment plants is presently working and stabilization ponds are entirely filled up, faecal sludge is still dumped there.

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 and 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 breakdowns of the water supply system are very frequent. 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 would not be enough water to flush all the toilets. Another critical issue is that septic tanks are installed underground. Possible leakages remain unnoticed and often contaminated water can infiltrate into the soil and contaminate the groundwater. 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 (see next section).

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

1.2.3. 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 and a superstructure that may vary in design and quality (e.g. bricks, metal, wood). The functioning of a pit latrine is very simple: the excreta drop into the the pit by gravity; while solids (faeces) accumulate at the bottom liquids (urine) infiltrate into the soil. When a pit latrine is highly frequented it fills up quickly and must be cleared by a vacuum truck.

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 latrine through the chimney effect and a fly screen which hinders flies to enter the pipe [Mara (1996)].

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 soil and groundwater pollution is too high. Nevertheless, (11%) of the population in GAMA use conventional pit latrines and (10%) use KVIP's.

In general, pit latrines offer a good alternative to waterborne sanitation facilities. In Accra's poor areas water is expensive and standpipes are not in place, so that people have to buy freshwater from commercial water sellers. As the water is relatively expensive and must be transported into the houses by hand, it is too precious to use it for flushing. The crucial advantage of pit latrines is that they work waterless and in this respect do not cause any daily operating costs. Shortcomings of pit latrines are the high initial costs, high costs of maintaining (paint, rust prevention, etc.) and high costs for clearing the pit by a vacuum tanker. Additionally, pit latrines do not apply for densely populated areas like Accra, because the infiltration of contaminated liquids into the soil in a high-density area would dramatically increase the risk of groundwater and surface water pollution.

1.2.4. Bucket latrines

Bucket and pan latrines are the simplest way to collect human waste. The excreta drop from the toilet into a bucket placed in a small vault underneath the toilet. The vault usually has a door towards the street, so that it can be emptied from outside during night time. 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 common. For many years, 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. Bucket latrines are not considered as applicable sanitary solutions as they are neither convenient nor safe. The risk of contamination with pathogens is too high for the collector and for the user. The system is not even cost-effective. The annual costs for excreta collection are higher compared to the septic tank system.

1.2.5. Public toilets

The municipality tries to convince people to install their own private sanitation facilities, so that public toilets would mainly be used by travelers, visitors and the high number of vendors, who come to work in Accra every day. But in reality, many residents use public toilets permanently, because they cannot afford to build their own facilities at home. That explains why 27% of the population declare public toilets as their own sanitation facility. Most toilets are located in the AMA district, close to busy public places like markets and bus stations. There are about 150 toilet blocks in the city, each block containing 20 seats in average.

The toilets are predominantly pit latrines and 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 often observed at the toilets, especially during the rush hours. Therefore some private

operators 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). The urine is usually piped into the open drains. Though they have no official admission and compete with municipal toilets, the small businesses are tolerated by the officials. At the moment, 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. 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. 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 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.

1.3. Wastewater transportation and treatment

1.3.1. Drainage System

Paved roads in Accra 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. The Odaw River is the most important natural drain as it receives about 60% of Accra's stormwater. It runs through the city from north to south and empties into Korle Lagoon, which has an artificially maintained opening to the ocean.

Almost all houses that are not connected to the central sewer system use the drains for greywater disposal. That means that washing water, kitchen waste and water from showers and basins is directed into the drains. It is a very convenient way to get rid of greywater 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. During the dry season, almost all open drains are choked with rubbish. In areas where adequate sanitation facilities are not available, open gutters also serve for urinating and defecating. This is particularly problematic, if the downstream water is used for irrigation by urban farmers. The situation is even worse when drains that are used for defecation fill up when it is raining, because they are blocked with rubbish. Then streets are flooded with contaminated stormwater which may cause diseases among the citizens. The problem has been addressed by the municipality and newly built drains are now completely covered.

Assuming that all drains can be covered so that they are only used for channelling the greywater into open water bodies, the drains could serve as an interim solution for greywater disposal in Accra.

1.3.2. Sewerage System 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 has its own separate 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 6). It is the only public system in the city to which households can make connections. The network was constructed and financed by The World Bank in 1973 with a total length of 28.5 km [Porter et al. (1997)]. Since then, it has seen only little maintenance and no extension. Though the network covers almost 10 km² in an area of high population density (more than 10,000 houses) only 800 houses are currently connected (0.27% of total houses in Accra). Porter et al. (1997) give the following reasons for such a low connection rate:

- most houses do not meet the standard for connection
- the rich do not want to connect, because they already have adequate septic tank systems
- the poor cannot afford to connect

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 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 000m³ of sludge per day, but due to the low connection rate it received only 5 000m³ [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. The breakdown was mainly due to the insufficient inflow. So today, the effluent of the sewers is discharged directly into Korle Lagoon and from there it goes into the ocean untreated.

At present, those households who make use of the central sewer pay 35% of the freshwater tariff to the Ghana Waste Department (GWD), which is equivalent to \$0:22 per m³ [Wonder (2007)]. There are three more public treatment plants in Accra that are not connected to a sewer. They are supposed to treat faecal sludge from private septic tanks. The sludge is collected and dumped into ponds nearby the treatment plants by vacuum trucks (so called honey trucks). The biggest plant is located at Achimota (250m³/day) followed by Teshie-Nungua (80m³/day) and Korle Gonno (50m³/day) (figure 4).

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)]. In 2007 none of the municipal treatment plants was operating.

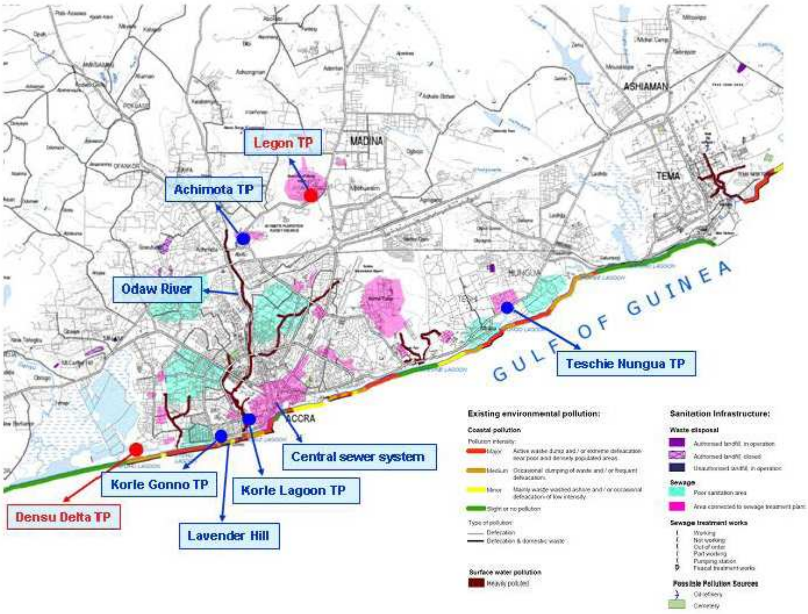

Figure 4: Sanitation Infrastructure and Marine Pollution in Greater Accra Metropolitan Area

The main shortcomings of sewerage based sanitation in Accra are:

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

Supposing that these problems can be solved in future, a sewerage system might be a reasonable sanitation solution for the central part of Accra, where housing density is high and new building development has come to an end. Even if a certain fraction of the population will be served by a functioning sewerage system in the city centre in future, still an alternative safe sanitation solution is needed for the majority, who live outside of this area.

1.3.3. Conclusion

In 2008 the sanitary situation in Accra is alarming. Every day almost 1000m³ of faecal sludge accrue in the city, none of it is treated. Instead, about 80% are dumped on the beach and about 20% are discharged at the settling ponds of the broken treatment plants, which are already filled up. 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. The overall insufficient sanitary conditions in the city lead to an increased number of people suffering from 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) and 60% use off-site systems (sewerage system, septic tanks, bucket latrines). For 27% of the population public toilets are the preferred 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, the rich use WC's in combination with septic tanks followed by KVIP's, 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.

1.4. Agriculture and fertilizer use in Accra

1.4.1. Urban agriculture in Accra

Accra is located in the coastal-savanna zone, which is a rather unfavourable 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. The production of vegetables and fruits within the city allows low transportation costs and fresh products on the markets. 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. 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 of urban farmers in Accra

amounts up to $45 per month. Most urban farmers use N-P-K (15-15-15) fertilizers, which they buy in so called agro-shops for $25 per 25 kg bag. Some farmers apply additional ammonium sulphate (AS).

1.4.2. Fertilizer Supply

As mentioned before, no fertilizer is produced in Ghana. The whole demand must be covered by imports, mainly from Europe. Year by year private companies buy large amounts of fertilizer abroad and resell it to wholesalers and retailers in the country. The companies determine the import quantities, based on last year's demands, whether conditions, policy environment and their own credit availability [Camara (2006)], which makes the market rather inflexible As fertilizer storage facilities are limited, demand fluctuations are very hard to compensate.

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 already 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). In total, there are about 600 to 800 wholesalers and retailers in the country, most of them concentrated in urban centers, since the low volume of the fertilizer market makes outlets in rural areas unprofitable [Bumb (2002)].

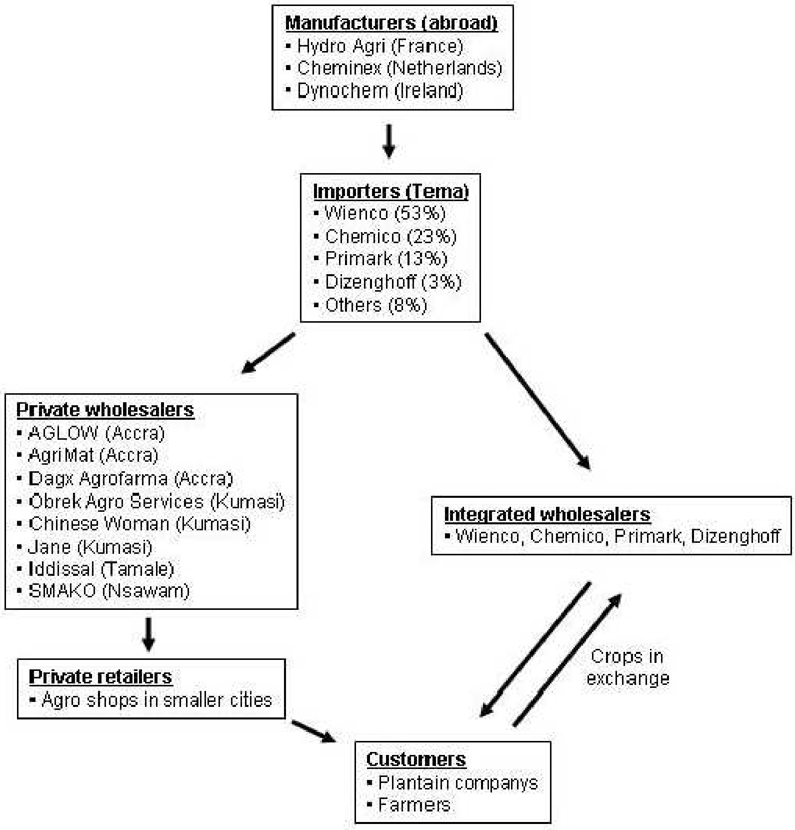

Figure 5: Fertilizer trade in Ghana (based on Bumb)

In sum, there is a well functioning supply system, which operates at low capacity and with no 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. The next subsection will show 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. in form of urine-based fertilizer) would not increase the fertilizer consumption in the country (all other equal).

1.4.3. Fertilizer demand

The population of Ghana, and therewith the demand for agricultural products, almost tripled from 6.7 millions in 1960 to 18.5 millions in 2000. A growing demand for agricultural output normally induces a growing demand for agricultural input factors like fertilizers. Instead, the fertilizer consumption in Ghana shows wide fluctuations between 1960 and 2000 and today is still on a relatively low level. The volume of agricultural production seems not to be the determining factor for fertilizer use. Instead, external factors like agricultural reform programmes, exchange rate fluctuations, fertilizer subsidies and fertilizer aid by donor countries have a direct influence on the amount of fertilizer consumed.

Fertilizer consumption is generally low in Ghana. A FAO-study from 2003 revealed that every year 58 kg of nutrients per hectare are removed by agriculture. Figure 6 shows nutrient balances for crops with high

rates of nutrient removals. For most crops the amount of nitrogen removed is highest, followed by potassium and phosphorus.

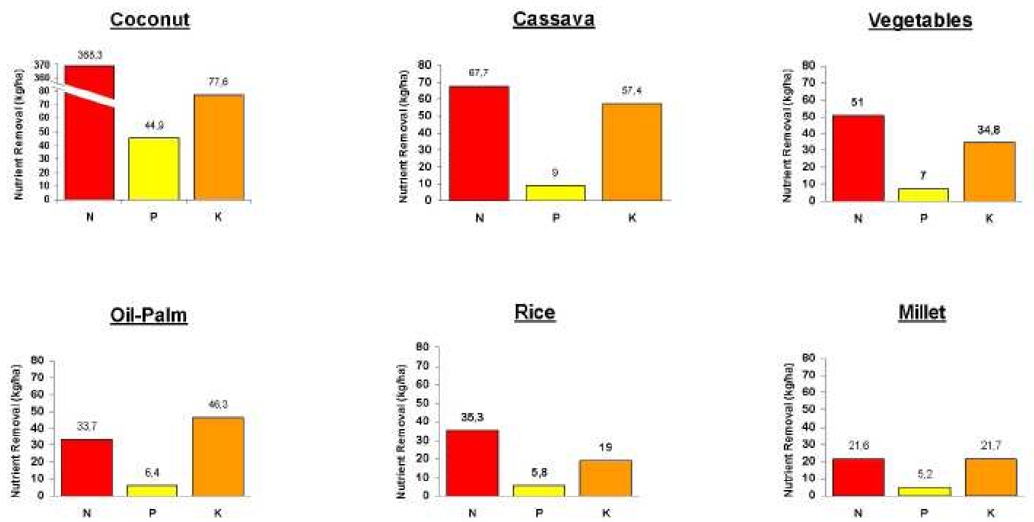

Figure 6: Nutrient balances for major crops in Ghana (FAO 2004)

In 2005 31,500 nutrient tonnes of N-P-K fertilizer were consumed in Ghana, which corresponds to an average of 5 kg/ha of cultivated land [www.unstat.un.org]. The real natural demand (averaged recommended fertilization for major crops times the area of cultivated land) was 170 kg/ha, which is about 34 times higher than the actual consumption. In the long term, such a large gap between natural fertilizer demand and actual fertilizer input leads to a continuous loss of soil fertility and declining yields, which can already be observed in the Ghanaian agriculture. But why do farmers not use more fertilizer which would increase their yields and sustain the fertility of their land?

1.4.4. Constraints to fertilizer demand

Farmers generate output in terms of agricultural products by combining their farming practices with input factors like seeds, water and fertilizers. Their objective is to maximize their profits, which means to generate the highest revenues with given optimal input costs. But this implies that the farmer is able to invest into the optimal amount of agricultural inputs at the beginning of the cropping season. He either needs to raise enough money by himself or to have adequate access to credit. For most farmers in Ghana none of the two possibilities apply.

In Ghana, farming is predominantly on a smallholder basis and the average farm size is about 3 ha. With such small farm sizes farmers usually are forced to spend their whole income on living expenses and cannot save any money for investments. Hence, at the beginning of the cropping season farmers are not able to bring up the optimal amount of fertilizers, even if they know they can increase their profits by such investments.

Besides the ability to invest into fertilizers, there are three more major constraints to fertilizer use. First of all the ***input/output price ratio (I/O)*** is relatively unfavourable in Ghana, because of high fertilizer prices. The I/O shows how many kilograms of output a farmer must sell to buy one kilogram of fertilizer. While outputs (agricultural products) are sold at domestic markets, inputs (fertilizers) are imported mainly from European markets at higher European prices. The costs for import, transportation and distribution make the fertilizer even more expensive. Gregory and Bumb (2006) found out that these handling costs can amount up to $ 3 for a 25 kg bag of N-P-K fertilizer in West African countries. Hence, in many cases fertilizer is just too expensive to make it a profitable investment for farmers.

The second constraint is the ***high risk*** Ghanaian farmers are confronted with. In Ghana less than 1% of arable land is under irrigation. The risk of crop failure due to too little rainfall during the cropping period is very high. Additionally, there is hardly any food processing industry or storage facilities for crops, so that in years of good yields prices for agricultural products decrease sharply, while in years of drought food prices increase dramatically. Hence, at the beginning of the cropping period, when farmers need to make a decision about the intensity of fertilizer use, they know neither about the quantities of their expected output nor about the prices, which makes decisions on fertilizer investments very difficult.

According to [Camara (2006)] the final constraint on fertilizer use is a ***lack of knowledge*** among farmers about how to use fertilizer effectively. 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. Full information on the fertilizing effect must also be available so that the farmer can calculate whether fertilizer use will be profitable or not. 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 natural nutrient demand of the plants leads to maximum profits, while farmers perceive the actual consumption already as the optimum.

The fertilizer market in Ghana is thin and underdeveloped. The further market development is hindered by a dilemma. Because of the weak demand for fertilizers a production inland would not be profitable and regarding the import, no economies of scale can be realized in transport and distribution. Consequently, fertilizer prices are high, and in turn high prices keep the demand on a low level.

1.5. Linking EcoSan and agriculture in Accra

The situation analysis shows that there is both a sanitary and a soil fertility problem in Accra. The EcoSan approach may help to solve both problems. The approach allows building toilets that are independent from sanitary infrastructure like sewers and water pipes. Such flexible solutions are of special importance in an unplanned developing city like Accra. In that way safe sanitation can be realized without the need to invest into the decaying water supply system or into the sewer system. With their relatively low investment costs urine diverting dry toilets can serve as a safe and affordable sanitation solution to many citizens. At the same time they provide the opportunity to recover nutrients from human excreta and to make these nutrients available again in urban agriculture. Recycling the nutrients in form of a cheap and indigenous fertilizer could help to mitigate the soil degradation.

In the following, two possible EcoSan implementations are discussed. The small scale implementation considers the reuse of urine as a fertilizer only on farming sites within the city boundaries of Accra. In

that case the required amount of urine can be gained from public urinals only. The large scale implementation implies that all citizens of Accra, who currently do not have access to safe sanitation, are equipped with urine diverting toilets. The collected urine then must be transported to farming sites and plantations outside of Accra. In order to evaluate the economics of both implementations, the potential value of the collected urine is determined in the next section.

1.5.1. Nutrient value in urine

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 European literature values, since the average uptake of nutrients via food in Ghana is generally lower than in Europe. For example Ghanaians consume less meat per capita, which causes 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 (https://www.uni-hohenheim.de/respta) have shown nutrient loads of

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

Based on that data the nutrient value for 1m³ 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/g for P and $0.21/g for K. Multiplying the prices with the nutrient contents of one liter of urine a nutrient value of $0.73 per liter or $7.3 per m³ results.

1.5.2. *Small scale implementation*

In order to estimate the amount of fertilizers used by urban farmers in Accra, interviews were carried out at urban farming sites in September 2007. Table 2 shows the average annual nutrient demands based on the interview results. The corresponding amount of required urine for fertilization is calculated with phosphorus as the limiting factor.

Table 2: Annual nutrient demands on farming sites in Accra

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

According to the Accra Waste Management Department 37.5 m³ urine per year accrue in one public toilet block containing two urinals (400 visitors per day, 312 days opened per year). 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. The urine tanks (500 litres) must be emptied every 4th day and the collected urine must be transported to the farming sites. De Silva (2007) assumes that within the boundaries of Accra emptying and transportation of one m³ urine can be realized for $5.

Certainly, farmers will not be able to use the urine at the 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. A market survey carried out in 2007 showed that urine can be stored in polyethylene tanks for $5 per m³ and year. Hence a final price that accrues for the farmers of $ 5.25 per m³ urine ($ 5 for transportation and $ 0.25 for storage) results. This is 72% of the nutrient value of one m³ urine which is similar to the price of one kg fertilizer with the identical nutrient composition.

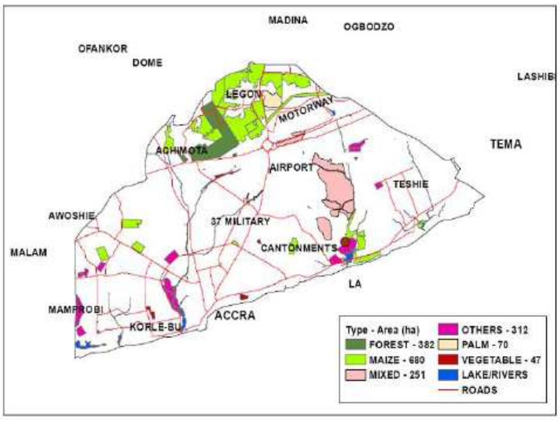

Figure 7: Urban farming in Accra (Oubuobie 2006)

1.5.3. Large scale implementation

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 m³ urine per year, which is equivalent to about 4,000 tonnes of nitrogen, 300 tonnes of phosphorus and 1,220 tonnes of potassium. Taking an average ecological demand for nutrients of 70-30-70 kg/ha 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 m³ per km, a transport distance of 200km would raise the costs of one m³ 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 value of urine.

If such large quantities of urine are collected, it becomes profitable to recover nutrients or to reduce the volume in a local treatment plant and then transport the product to farming sites outside the city. At present, no such treatment plants have been so that cost estimations are hard to make. Considering only the energy costs of two treatment processes that qualify for Ghana N and P recovery by zeolite and struvite production would cost $0.53 per m³ urine and $2.10 per m³ would accrue 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 m³, which makes transportation profitable again. Thus, if urine is collected in large-scale, treatment processes present a feasible option to save storage and transportation costs and to provide the possibility to keep product costs below the actual nutrient value.

1.6. Conclusion

Accra is a fast and uncontrolled growing city with the majority of citizens not having access to safe sanitation. Due to insufficient water supply and lacking financial means not more than 5% of the population are served by a central sewer system. Trials to establish conventional wastewater treatment methods in recent times have not been successful. More than 95% of faecal sludge that accrues in the city remains untreated. At best it is disposed off into the ocean, otherwise it remains in the city e.g. in open water bodies, channels or other open spaces, which is a huge health risk for the population.

At the same time, agricultural production on urban farming sites is limited by insufficient fertilizer use. High prices for imported fertilizers, high risks of crop failure and insufficient knowledge of fertilizer use keep the fertilizer demand on a low level.

Ecological Sanitation addresses both problems. On the one hand it offers safe and affordable sanitation to the majority of citizens. On the other hand EcoSan provides the possibility to recover the nutrients from human excreta and to reuse them in urban agriculture as a cheap fertilizer. On a small scale basis, where urine from public urinals is transported for short distances (within the city boundaries) and stored for not more than 14 days, transportation and storage costs do not exceed the nutrient value. In case more urine is collected in the city, e.g. in form of additional quantities from private households, transport to farming sites outside the city becomes too costly. In that case, nutrient recovery from urine using treatment methods such as steam stripping or MAP-precipitation is necessary to make long distance transportation cost-effective. Further research is needed to determine the most applicable urine treatment method for Ghana and to allow cost estimations for the treatment plants.

1.7. References

Bumb (2002) An Action Plan for Developing Agricultural Input Markets in Ghana. IFDC, Muscle Shoals, AL35662, USA, 2002

Camara (2006) Overview of the fertilizer situation in Africa, Background Paper prepared for the African Fertilizer Summit (June 9-13, Abuja, Nigeria), 2006

FAO (2005) Fertilizer use by crop in Ghana. Food and Agricultural Organization of the United Nations, Rome, 2005

Ghana (2002) 2000 population and housing census, Ghana Statistical Service, 2002

Kelly (2006) Factors affecting demand for fertilizer in Sub-Saharan Africa. Agriculture and Rural Development Discussion Paper 23, The World Bank, Washington, D.C., 2006

Lunani (2007) Analysis of the public health risks of the urban water system in Accra by microbial risk assessment. Master Thesis, UNESCO-IHE Institute for Water Education, Delft, The Netherlands, 2007

Mara (1996) Low-cost urban sanitation, John Wiley and Sons Ltd, England 1996

Obuobie et al. (2006) Irrigated urban vegetable production in Ghana: Characteristics, benefits and risks. IMWI-RUAF-CPWF, Accra, Ghana, 1 edition, 2006

Porter et al. (1997) The economics of water and waste in three African capitals, Ashgate Publishing Limited, England, 1997

Wonder (2007) Assessing the challenges of water supply in urban Ghana: The case of north teshie, Master's thesis, Department of Land and Water Resources Engineering, Royal Institute of Technology (KTH) Stockholm, Sweden, 2007

Yankson (2004) Monitoring urban growth: urbanisation of the fringe areas of Accra, Department of Geography and Resources Development, University of Ghana, Working Paper, 2004

2. Study on the Feasibility to Apply EcoSan Products from Urine and Faeces in Beijing's Agriculture

Keywords: Beijing, new sanitation systems, agriculture, nutrients

Abstract

New sanitation concepts offer solutions to different but interconnected problems of today's and tomorrow's world. They are designed to provide save water, while not wasting or polluting water resources, and providing sustainable nutrition, especially in highly dense populated areas, by nutrient redirection to agricultural areas.

In this study Beijing area was investigated in respect of the potential for new sanitation concepts. The demand of nutrients in agriculture was evaluated and compared to the nutrient potential from new sanitation concepts. Different scenarios of treatment allocation and distribution were compared, based on data from population statistics, agriculture and water infrastructure.

2.1. Introduction

Beijing is on a long term in urge for solutions targeting sustainable water and nutrient infrastructure.

While in many small projects worldwide new sanitation concepts, such as ecological sanitation, proved to be a feasible solution, assuring safe water and improving soil fertility, the application on a larger scale asks for in depth investigations of details such as transport and distribution of the products of new sanitation concepts. The applicability of the fertilizing products from these sustainable sanitation systems has to be evaluated from case to case.

Additionally, large but highly dense populated areas require preoperational feasibility studies. Only if the connection between water infrastructure and agriculture can be made, new sanitation systems will bring the promised benefits of a sustainable solution with growing population and thus more and more nutrient demanding agriculture and safe water. This link allows in the end the economical feasibility of the new sanitation concepts.

In the following work the agricultural demand for products from new sanitation concepts is evaluated for the region of Beijing, China, as well as the feasibility to recover nutrients from human urine and faeces in this area, and further to apply these products of new sanitation concepts, the recovered nutrients, in the agriculture of Beijing's suburban area.

Following topics are evaluated and discussed:

- detailed information on the nutrient demand in the region of Beijing
- nutrient demand in Beijing's agriculture that can be fulfilled by products from new sanitation concepts (the terms 'EcoSan' and 'new sanitations systems' are used synonymously)
- estimation of the influence of the extra transportation systems for collecting source separated wastewater products, and further for distributing them to the agriculture
- definition of a reasonable size of infrastructure system that should be used in Beijing
- evaluation of the influence of future change of population and agriculture for each system

- development of reasonable target visions, and possible pathways
- To answer the above questions, a model was generated, based on data from population statistics, agriculture and water infrastructure.
- In the scenario development focus was laid on nitrogen and phosphorous as nutrients only. It was aimed to give an overview of the feasibility of application of the EcoSan concept, detailed treatment technologies were not the main focus.

This study and model development is mainly based on a project work of Shen Wang, master student at TUHH. For more details, which can be found in her work, please contact the institute of wastewater treatment and water protection of Hamburg University of Technology.

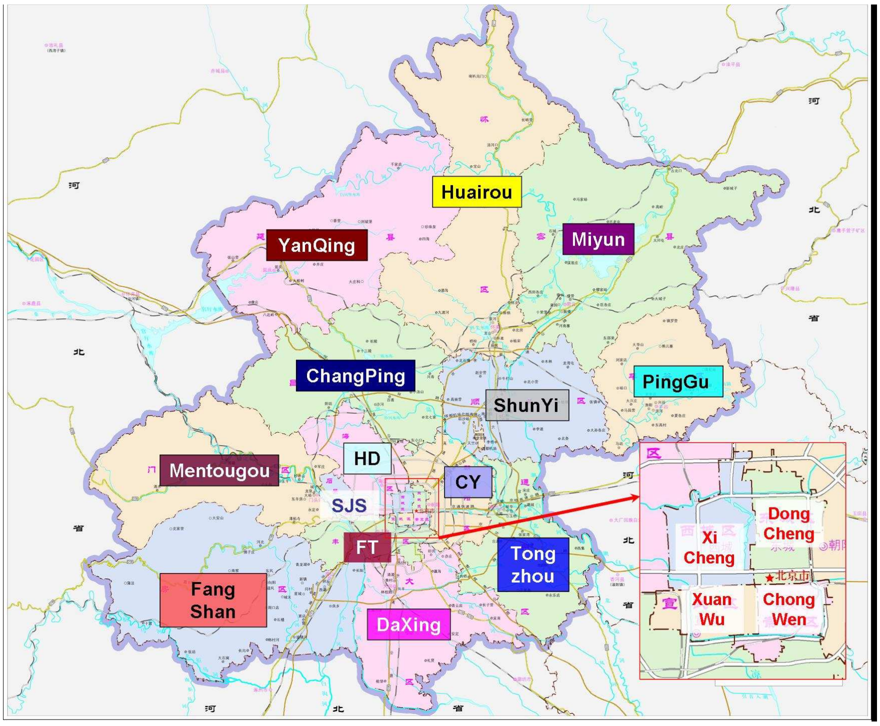

Figure 2.1: Beijing's Agriculture: arable land, Modified from [*BJGHW, 2007*]

2.2. Geographic and agricultural land distribution

The total area of Beijing is about 16.4 thousand km^2 and spread over 18 districts (Figure 2.1). According to Beijing city overall plan (2004-2020) they can be separated in four different functional groups according to the direction of future development:

- 4 core districts of capital function:
  Dongcheng (DC), Xicheng (XC), Xuanwu (XW) and Chongwen (CW);
- 4 extended districts of urban function:
  Chaoyang (CY), Haidian (HD), Fengtai (FT) and Shijingshan (SJS);

- 5 new districts of urban development:
  Fangshan (FS), Tongzhou (TZ), Shunyi (SY), Daxing (DX) and Changping (CP);
- 5 development districts of ecological preservation:
  Mentougou (M), Huairou (HR), Pinggu (PG), Miyun (MY) and Yanqing (YQ).

While the importance of agriculture has decreased in the last years, due to the development of the urban city of Beijing, in 2006 still 67% of the total land of Beijing was used for farming in general (11,000 km^2), 2,320 km^2 of that was arable land (21%). Due to topography distribution of agriculture over the districts is uneven. (*Beijing Municipal Bureau of Statistics 2007*).

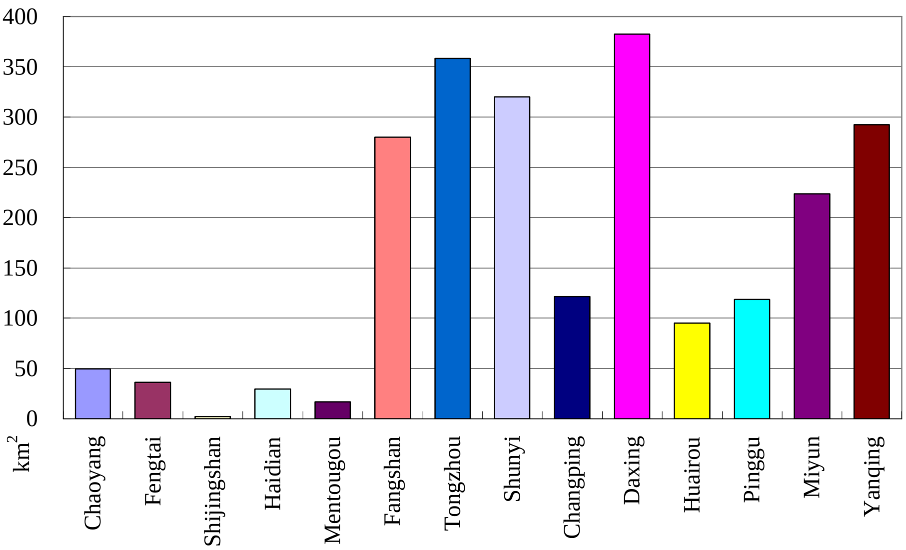

Figure 2.2: Distribution of arable land in Beijing, 2006 (*Beijing Municipal Bureau of Statistics 2007*)

Most of the agriculture is in the suburban area, namely the new districts of urban development and development districts of ecological preservation. These 10 suburban districts cover about 92% of the total area of Beijing (*Beijing Municipal Bureau of Statistics 2007*). Within this area, the planting industry is mainly distributed in the plains in the south east of Beijing, namely Daxing, Tongzhou, Shunyi, and Fangshan where there is sufficient water supply. The districts of Miyun and Yanqing contribute also a lot to the planting industry, because the two main reservoirs, Miyun reservoir and Guanting reservoir are located there. Figure 2.2 shows the detailed distribution of arable land in the different districts of the region of Beijing.

2.3. Agricultural background and Fertilizer demand

The nutrient demand in agriculture is depending on the types of crops planted. For this study more than 20 different types were evaluated for each individual district. An extract from this and also the overall demand is shown in Table 2.1.

Main products of Beijing's agriculture are different types of grain (rice, wheat, corn, tubers/potatoes, soybeans, etc.), cotton, oil-bearing crops (mainly peanuts), traditional Chinese medicine (drugs), vegetables, melons, forage, and flowers. Therein, as shown in Figure 2.3, grain, vegetable and forage cover by far the largest part of sown area. From the view of quantity, vegetable enjoys the highest percentage comparing to other main crops. However, in the last 4 years, around 20 % of the production output has been reduced, from 5.3 million tons in 2003 to 3.9 million tons in 2006. Grain and melons rank the second and third. At the same time, there was an increase of the grain output, from 0.58 million tons to 1.1 million tons between 2003 and 2006.

Table 2.1: Distribution of crop yield & nutrient consumption [t/yr]

2003/2004	Grain	Vegetables	…	N	P	K
Chaoyang	2.798	92.922		455	105	362
Fengtai	1.815	52.044		323	82	268
…						
Fangshan	89.845	265.083		4.353	1.537	4.494
Tongzhou	133.016	896.691		8.066	2.545	7.788
Shunyi	92.229	1.122.617		8.234	2.341	7.391
Daxing	122.795	1.310.324		9.572	2.692	8.459
…						
Total	641.033	5.082.471		45.120	13.664	41.935

According to (*BJCTCC 2008*), most of the arable land of Beijing suburb area has low to medium fertility, mainly due to lack of organic fertilizer. The total yearly consumption of fertilizer in Beijing area has reached 150,000 tons in 2004 and 2005, which equals an average consumption of 500 kg/hectare farming land, and which is much higher than the average of the national level (*BJCTCC 2008*). The average yearly consumptions of pure substances were 80,000 tons nitrogen, 12,000 tons phosphorous, 5,800 tons of potassium, and about 50,000 tons compound fertilizers (*AGRI 2008*). The main part (about 43 %) of the total chemical fertilizer consumption was used for vegetables and melons.

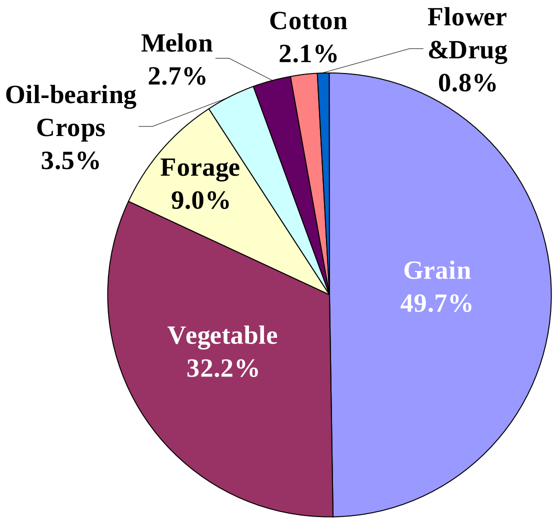

Figure 2.3: Beijing's agriculture: Crops, Sown area for main crop products 2004, Source: Beijing statistic year book 2005, In terms of quantity: Vegetable enjoys the highest percentage (80%)

The average utilization ratio is 15 % - 20 % which means, that about 80 % of the nutrients are not taken up by plants but lost from the system. The ratio is much lower compared to levels of developed countries, where they can reach up to 60 %. To allow targeted fertilization and to reduce over-fertilization, it is now encouraged by the local governments to analyze soil conditions prior agricultural use.

In the past 5 years prices of fertilizer were continually increasing although there was a certain price control from the Chinese government to protect the agriculture production. In the beginning of 2008, the prices of urea and compound fertilizers have surged to 1,725 Yuan/ton (157 EU/ton) and 2,600 Yuan/ton (236 EU/ton), respectively, for both an increase of more than 30% year by year (*Nextinsight 2008*). Analysts attributed the price increase in fertilizer to international market fluctuations, increased costs and China's lack of phosphorus and potassium resources. The offshore price of urea in the Black Sea has reached US$ 400/ton, 30% more than the year before. In China the ex-factory price of monoammonium phosphate has climbed to nowadays 3,100 Yuan/ton from 1,800 Yuan/ton early last year (*Chinagate 2008*).

All over China nearly 50 million tons of fertilizers are consumed, annually. By 2011, fertilizer production could top 63.5 million tons, according to China's National Agricultural and Rural Economic Development. Of this, China hopes to produce 42 million tons of nitrogen fertilizers (*Marketoracle 2007*). However, increasing energy prices are a large obstacle.

2.4. Potential, Objectives, and Scope

For applying new sanitation concepts, or improving the existing one in the area of Beijing, there are several drivers: There is a high urge to ease the severe threat of water scarcity. The current water resources can provide about 5 billion m^3/year. Due to the high overall water consumption per capita of about 300 m^3/year (including losses due to leakages and others), a population of about 17 Million people

can be served. Since both, water consumption per capita and population increased dramatically within the last 10 years, new solutions to the water infrastructure system have to be found.

Additionally developing industrial activities are demanding water and especially energy, both aspects have to be included into new water respectively sanitation concepts.

China in general has a long history of using human/animal manure in agriculture *(Agroecology 2008)* and EcoSan pilot projects in inner-Mongolia and Shanghai have high reputation. The high population density facilitates collection systems of new sanitation concepts. On the other side hard and soft infrastructure is still missing to quite some extend.

The key questions now for this study were

- how to implement a new concept considering a switching of costs
- whether or not the demand in agriculture could be covered by products from new sanitation systems
- the influence of the extra transportation system
- the efficiency of the type of system (decentralized or centralized)
- the influence of changing of population and agriculture on the system
- and to develop a reasonable target vision

These questions were investigated within scenarios developed for N and P recovery only. The type of treatment technology was not matter of this study.

2.5. Methodology

The study consisted of six parts (see Figure 2.4) and was mainly based on literature research. Based on the available data, assumptions were made to develop different scenarios.

The nutrient demand in agriculture and the potential nutrient supply from a new sanitation concepts (extracting nutrients from wastewater) were compared to each other in different scenarios. For selected scenarios a transport and distribution model was derived to come up with information on the energy demand for transport only. This energy demand was also compared to the energy demand for nutrient recovery by selected processes. Finally within a sensitivity analysis different parameters were varied to find out about their individual impact on the whole system.

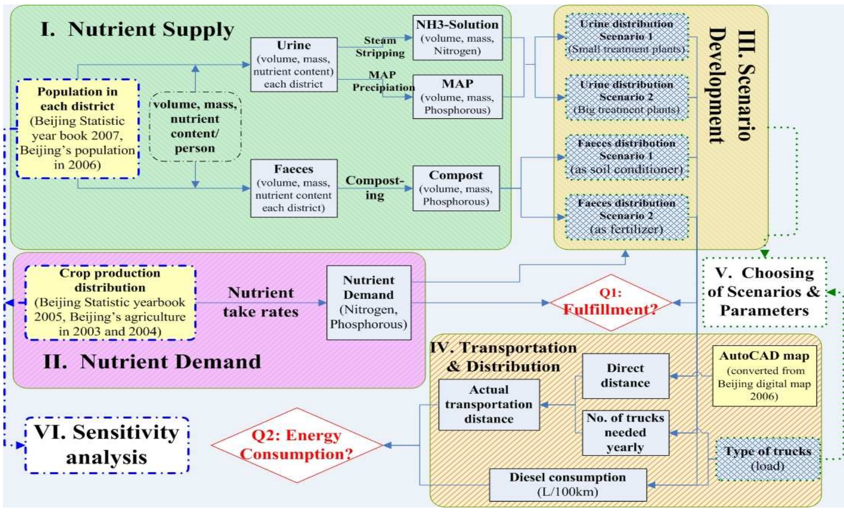

Figure 2.4: Flow chart of the data processing and analysis in the project work

Data processing was carried out in Microsoft Excel. A digital map was converted from the Beijing digital Map 2006 published by Sinomaps PRESS to an AutoCAD map, from which detailed distances were derived.

For the modelling three main datasets were used.

- population and population distribution in each district based on data from 2006
- overall crop production and planting distribution in 2003 and 2004
- AutoCAD map containing detailed distances

To answer the key-questions stated above, following steps were carried out:

- calculation of the potential nutrient supply from urine and faeces produced in Beijing (Part I)
- calculation of the nutrient demand from Beijing's agriculture (Part II)

In Part I (nutrient supply), two steps were involved, on one hand, the amount of nutrients available from urine and faeces (without considering nutrient losses during collection, transportation and treatment) were calculated for a general overview. On the other hand, the realistic amount of nutrients for supply, taking losses into consideration, was calculated for further scenario development. In both cases, the overall amount of available nutrients and the amount in each district were calculated.

In Part II (nutrient demand), based on the type and quantity of crops planted in each district as well as the nutrient up-take rates of each crop, the demand of nutrient for the agriculture in each district and the overall demand was derived.

In Part III (scenario development) redistribution of nutrient was modelled based on the demand and supply of nutrient evaluated in Part I and II. Therefore, scenarios for different new sanitation systems, considering nutrients from urine and/or faeces, were developed for further evaluation.

After the development of the scenarios, a detailed transportation system with distances and transport volumes was derived in Part IV.

With above derived information the two following key questions can be answered:

- Coverage of the demand of nutrient in Beijing’s agriculture by EcoSan products
- Energy consumption by the extra transportation involved in new sanitation systems

To allow a more detailed discussion of the topics stated in the introduction, detailed comparisons between the established scenarios and discussion of different transportation units were conduced in Part V, taking feasibility, energy consumption and other factors into consideration.

In Part VI a sensitivity analysis of additional parameters, such as possible change of population, agriculture and the connection rate of the total population in the EcoSan system was carried out.

Finally feasible target visions were proposed in the end, and possible implementation procedures were discussed.

Calculations were carried out based on data of population and average quantity of nutrients in urine and faeces in respect to each district. As no reliable values of nutrient content were available for China, nutrient contents were converted from (*Jönsson & Vinneras 2003*) based on different t food supply. The urine volume was assumed as the same as the European value while faecal mass was according to *(Feachem et al. 1983)* which was based on a Chinese study. The given values are assumed for all people in Beijing, regardless of the region being urban city or suburban area.

Table 2.2: Nutrient content in wastewater

Loads [kg/(p*yr)]	Urine	Faeces
Q	456 [2]	91 [3]
N [1]	3,5	0,5
P [1]	0,4	0,2
K [1]	1,3	0,5

[1] Nutrient Content: (*Jönsson & Vinneras 2003*)

[2] 1.25 L Urine/ (person*day): different sources, overview in *(Tettenborn et al. 2005)*

[3] Faeces mass for Chinese value: 91.25 kg/p.year. *(Feachem et al. 1983)*, values differ compared to (*Vinneras et al. 2006*): 51 kg per capital per year

The data of population distribution is based on the year 2006, from (*Beijing Municipal Bureau of Statistics 2007*) In the main part of the calculation and scenario development, it was assumed that 100% of the population was connected to a new sanitation system. Nutrient losses during transportation and treatment were neglected at first. These factors were included in the separate calculation for urine and faeces later on. Quantities of nutrients of the whole population were derived for each district.

More in depth details about procedures and assumptions of above stated parts are given in (*Wang et al. 2008*).

2.6. Scenario developments (here, focus on Urine only)

For utilization of the nutrient potential from separately collected human urine in Beijing's agriculture, two different scenarios, -one more decentralized and one more centralized-, were developed. In the Scenario 1, urine is collected regionally by pipelines to small treatment facilities with 45 m^3/day capacity each, after treatment, the products are distributed to the demand area. In the Scenario 2 urine is collected the same way, but first transported to larger treatment plants with 900 m^3/day capacity each, which are located further away from the city centre.

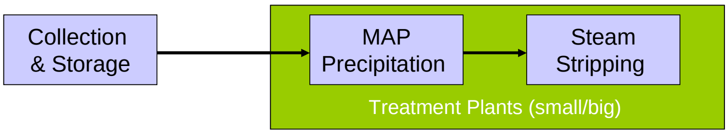

Figure 2.5: Principle Sketch of scenario 1 and 2

In both scenarios, the treatment of urine was assumed to be yielding nutrient extraction by MAP precipitation for phosphorus recovery and steam stripping afterwards to concentrate Nitrogen.

In both scenarios, the local demand was first covered by the local supply. The remaining surplus nutrients and the remaining extra demand were considered in redistribution.

For nutrient distribution a central fertilizer warehouse was assumed to be present in each district. Inner-district transportation was not considered. The starting and the end point of the outer district transportation as well as the location of the small plants were assumed to be in the middle of each district.

Both scenarios concentrated on nitrogen (N) and phosphorous (P) only.

Overall mass and volume and concentration changes of the products during collection, transport, and treatment were calculated according to the data in (*Tettenborn et al. 2005*).

Thereafter the supply situation of N and P in each district was calculated and the area of each collection point (according to 45 m^3/day volume), the number of required treatment plants (large or small), and the product volumes before and after treatment in each district were derived. The results were used for determining the required transportation system.

The energy demand of the transportation system was derived by diesel consumption per distance. The direct distances from the AutoCAD map were converted into real transportation distances by conversion factors of 1.4 for transport within the eight main districts and 1.2 for the outer districts.

From the total quantity of product transport the number of required transport vehicles was derived. As transport vehicles trucks with 20 tonnes load were assumed with a diesel consumption of 61 Litre per 100 km (average of loaded and unloaded tours) (*JTT 2007*).

According to the quantity of urine produced in each district the number of the required large treatment plants was calculated. The location of the larger treatment plants in the second scenario was assumed to be in the more rural areas. To optimize the plant distribution and reduce transport distances, capacity was varied between 100 and 130%.

While both processes, MAP precipitation and steam stripping were assumed to be located at the same plant, the distribution of the final products was planned individually, according to the different demand situation of nitrogen and phosphorous.

In this second scenario, two different types of transport vehicles were considered. For inbound transportation (transport of the fresh urine from the collection points to the large treatment plants), trucks with 20 tonnes load were used. For outbound distribution (from the large treatment plants to the product distribution points) trucks with 40 tonnes load were used. The diesel consumption was assumed to be 61 and 82 Litre per 100 km (average of loaded and unloaded tours) (*JTT 2007*).

For the nutrient utilization from faecal matter a very different scenario was developed based on large scale composting sites. Details can be found in (*Wang et al. 2008*).

2.7. Results – nutrient supply from urine and demand in agriculture

The potential nutrient supply from new sanitation concept based on the population derived for each individual district is shown exemplary in Table 2.3 on the example of nitrogen and the Core Districts of Capital Function. This was done for all districts as well as for the nutrients phosphorous and potassium. The overview for nitrogen is shown in Table 2.4.

Table 2.3: Potential nutrient availability (exemplary shown for nitrogen) from selected source separated waste water streams exemplary shown for the core districts of capital function of Bejing

District	Land* Area	Population Density* (permanent)	Population	N		
				Urine	Feaces	total
	(sq.km)	(person /sq.km)	(person)	(Mg/year)	(Mg/year)	(Mg/year)
Core Districts of Capital Function	92	22.308	2.061.000	7.214	1.031	8.244
Dongcheng	25	21.744	551.000	1.929	276	2.204
Xicheng	32	21.063	666.000	2.331	333	2.664
Chongwen	17	18.220	301.000	1.054	151	1.204
Xuanwu	19	28.715	543.000	1.901	272	2.172

The nutrient demand in agriculture was derived based on the different types of crops, their individual nutrient demand (see exemplary for different grains and nitrogen in Table 2.5), and the crop intensity in the individual districts.

Table 2.4: Potential nutrient availability (shown exemplary for nitrogen) from selected source separated waste water streams for the districts of Beijing

District	Population	N		
		Urine	Feaces	total
	(person)	(Mg/year)	(Mg/year)	(Mg/year)
Core Districts of Capital Function	2.061.000	7.214	1.031	8.244
Urban Function of Extended Districts	7.736.000	27.076	3.868	30.944
New Districts of Urban Development	4.247.000	14.865	2.124	16.988
Ecological Preservation of Development Districts	1.766.000	6.181	883	7.064
Total	15.810.000	55.335	7.905	63.240

* (*Beijing Municipal Bureau of Statistics 2007*): Chapter 3-4, Population Density (2006)

Table 2.5: Nutrient demand exemplary for grains and nitrogen

Item	Year 2004[2]		Year 2003[2]		Average Yield	N		
	Planted Areas	Total Yield	Planted Areas	Total Yield		N Uptake Rate[3]	N Need	Avrage N Uptake Rate
(Unit)	(hectare)	(ton)	(hectare)	(ton)	(ton)	(kg N /ton crop)	(kg)	(kg N /ton crop)
Grain total [1]	154.491	701.789	141.344	580.276	641.033		18.262.797	28,5
Rice	822	5.033	1.615	10.058	7.546	22,0	166.001	
Winter Wheat	39.136	202.562	35.789	184.097	193.330	30,0	5.799.885	
Corn	93.535	435.120	75.207	321.990	378.555	25,2	9.539.586	
Tubers	3.702	22.067	5.443	28.777	25.422	5,0	127.110	
Soybean	13.625	29.805	16.442	28.243	29.024	82,5	2.394.480	
Others	3.671	7.202	6.848	7.111	7.157	32,9	235.735	

Table 2.6 is the summarized result of the calculation for the total supply and demand of nutrient in the region of Beijing, without considering the nutrient losses in collection, transportation, and treatment.

According to these results Beijing has a yearly demand of 45 million kg nitrogen, 13 million kg phosphorous, and 42 million kg potassium, based on the agricultural situation in 2003 and 2004. According to (*AGRI 2008*) in reality the actual yearly consumption of chemical fertilizer in 2003 and 2004 in Beijing was about 78 million kg nitrogen, 12 million kg phosphorous, and 6 million kg potassium. Taking a factor of misuse and over-fertilizing of nitrogen into account, and neglecting the importance of potassium in Beijing's agriculture, the results from above calculation methodology are in a reasonable range.

Table 2.6: Nutrient potential of new sanitation concepts compared to nutrient demand in agriculture

	Nutrient potential			Agricultural Demand [mil kg/yr]	Potential demand coverage [%]
	Urine [mil kg/yr]	Faeces [mil kg/yr]	Total [mil kg/yr]		
N	55	8	63	45	140
P	6	3	9	14	69
K	21	8	28	42	68

With urine and faeces as a sum, without considering any nutrient losses within process of collection, transport, and treatment, there would be 63 million kg of nitrogen, 9 million kg of phosphorous and 28 million kg of potassium available every year. These could theoretically cover the demand of nutrient demand from agriculture by 140%, 69% and 68% respectively.

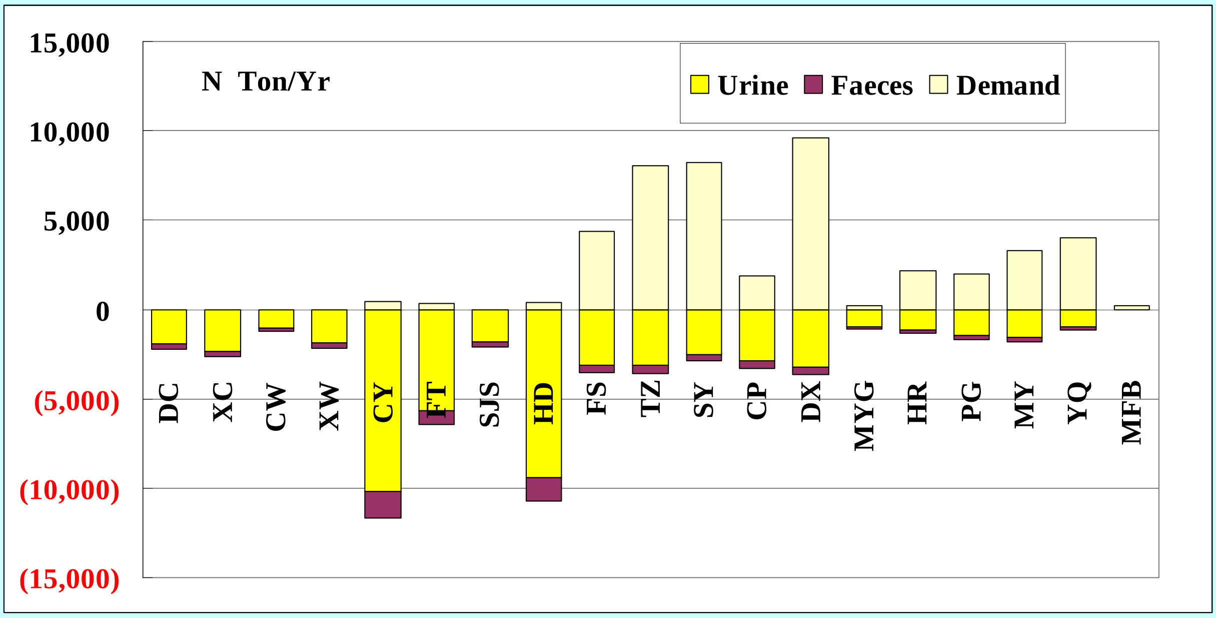

Figure 2.6: Potential N supply and demand in each individual district (idealized scenario)

However, when looking at the individual districts, it is obvious that demand and potential nutrient availability do not match, because of discrepancy of population density and agricultural land use intensity. The potential supply is converged in the urban city and the demand is mainly from the suburban area where agriculture is carried out. The districts of Chaoyang, Haidian and Fengtai have the highest population, hence, highest amount of nutrients available for supply. Daxing, Shunyi, Tongzhou and

Fangshan have the highest demand of nutrient for their agriculture (see Figure 2.6 exemplary for nitrogen).

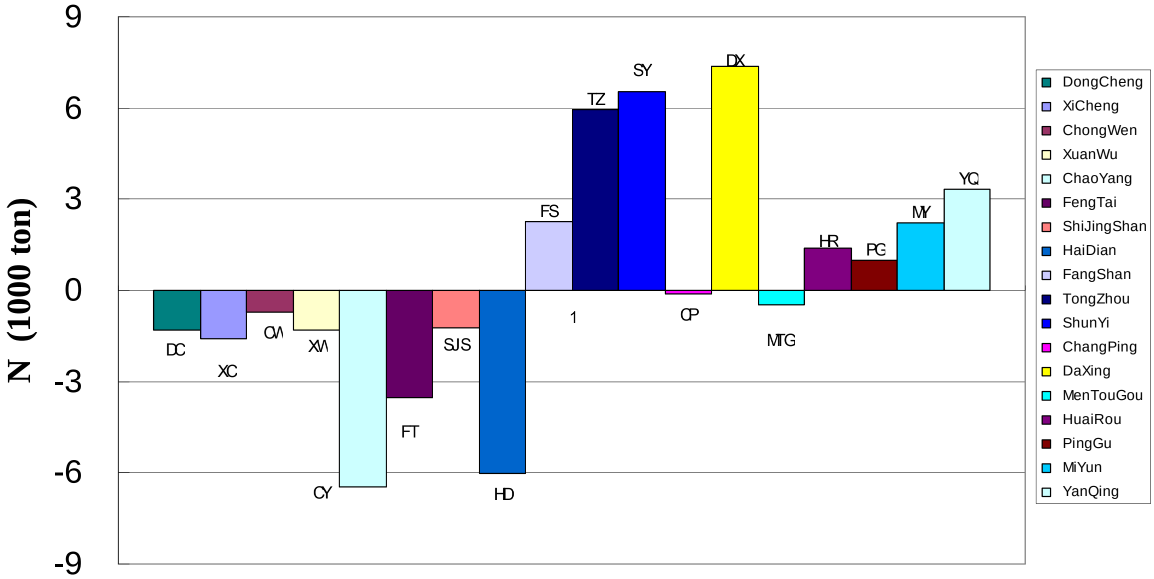

Figure 2.7: Nitrogen demand in each district after coverage of supply from own district

Table 2.7: losses, reduction, and final content of nitrogen and phosphorous after collection, storage, and treatment

	losses / reduction			content of final	
	during collection and storage (*)	during precipitation (*)	by steam stripping (*)	MAP-product	NH3-solution
Volume			96 %		4 %
N	25 %		3 %	4 %	68 %
P	5 %	2 %		93 %	

(*) assumed respectively according. to (Tettenborn et al. 2005)

In a next step detailed volume, mass, and nutrient content changes during collection and treatment were calculated. Assuming fresh urine comprising 100% of volume and nutrients, Table 2.7 summarizes the remaining percentage of the volume and nutrient content in both MAP and NH_3-solution, taking losses during collection and treatment into consideration. Losses during transportation were neglected respectively integrated into the collection and storage fraction.

The actual nutrient supply from each district after collection and treatment was derived. In total, after treatment, there were 38 million kg of nitrogen and 6 million kg of phosphorous available for agriculture use, which could cover 84% and 43% of the demand. The potential supply was opposed to the individual

demand in each district, which is shown in Table 2.8. Especially in the Core Districts of Capital Function little to no demand is facing a high potential supply, while in the outer districts the situation is vice versa. The extra demand/supply of nitrogen and phosphorous of each district after utilization of the nutrients produced in its own area was derived from this. In Figure 2.7 the final result is shown exemplary for nitrogen. A similar plot can be derived for the other nutrients. Values below zero reflect a nutrient surplus, which can be distributed to other districts with higher demand than the coverage by its own nutrients, the inner-district distribution. As shown in the graph, the districts of Daxing, Shunyi, Tongzhou, Yanqing and Fangshan have the highest extra demand while Chaoyang, Haidian and Fengtai have the highest nutrient surplus. This result was considered as a main factor to redistribute the nutrient in the scenario development.

Table 2.8: General potential of nutrient supply and demand exemplary for nitrogen within the individual districts. Negative numbers show a nutrient surplus that needs to be transported to areas with higher agricultural demand

District	Potential supply after treatment [Mg/year]	Demand [Mg/year]	Demand - Supply [Mg/year]
DongCheng	1.310	-	- 1.310
XiCheng	1.590	-	- 1.590
ChongWen	720	-	- 720
XuanWu	1.290	-	- 1.290
ChaoYang	6.940	460	- 6.480
FengTai	3.850	320	- 3.530
ShiJingShan	1.240	-	- 1.240
HaiDian	6.400	370	- 6.030
FangShan	2.110	4.350	2.240
TongZhou	2.130	8.070	5.930
ShunYi	1.710	8.230	6.520
ChangPing	1.980	1.870	- 110
DaXing	2.190	9.570	7.380
MenTouGou	660	200	- 460
HuaiRou	790	2.160	1.370
PingGu	1.010	2.010	1.010
MiYun	1.070	3.300	2.230
YanQing	680	4.000	3.310

Two scenarios were developed, one with 439 small treatment plants (each with a capacity of 45 m^3 Urine/day) distributed according to the demand (scenario 1). Small plants were planed on the collection

and storage sites. The products would be transported directly to the demand areas. The numbers of plants needed were based on the population of each district and size of the plant assumed.

Table 2.9: Number of treatment plants in Scenario 1 and 2

Districts	Scenario 1	Scenario 2	Districts	Scenario 1	Scenario 2
DongCheng	15	0,77	ChaoYang	81	4,04
XiCheng	19	0,93	FengTai	45	2,24
ChongWen	8	0,42	ShiJingShan	15	0,73
XuanWu	15	0,75	HaiDian	75	3,73
Core Districts of Capital Function	**57**	**2,86**	**Urban Function Extended Districts**	**215**	**10,74**
FangShan	25	1,23	MenTouGou	8	0,38
TongZhou	25	1,24	HuaiRou	9	0,46
ShunYi	20	1,00	PingGu	12	0,59
ChangPing	23	1,15	MiYun	13	0,63
DaXing	26	1,28	YanQing	8	0,40
New Districts of Urban Development	**118**	**5,90**	**Ecological Preservation Development Districts**	**49**	**2,45**
			Total	**439**	**21,96**

In the other scenario (scenario 2) 24 larger treatment plants with approximately 900 m^3 Urine/day capacity were spread out over the area ob Beijing. Since there is no agriculture demand in the 4 districts in central city and to avoid nuisance impacts in very dens populated areas, all urine is transported out of these districts and treated in Fengtai and Chaoyang. The location of the plants was decided on an even distribution within each district to optimize the collection, and on short transport distances. For simplification the plants in the suburban area were located directly in the centre of each district.

2.7.1. Scenario 1

In Figure 2.8 the distribution of nitrogen is roughly shown. After redistribution, all the remaining nutrients after inner-district coverage can be redistributed to the further demanding districts. With inner-district and inter-district distribution together, 84% of the total demand of nitrogen for Beijing's agriculture could be covered by a product from urine (NH_3-solution). The demand of all the districts except Yanqing, Miyun and Huairou could be covered. Huairou, as it is on the very north part of Beijing, was not considered in the final redistribution.

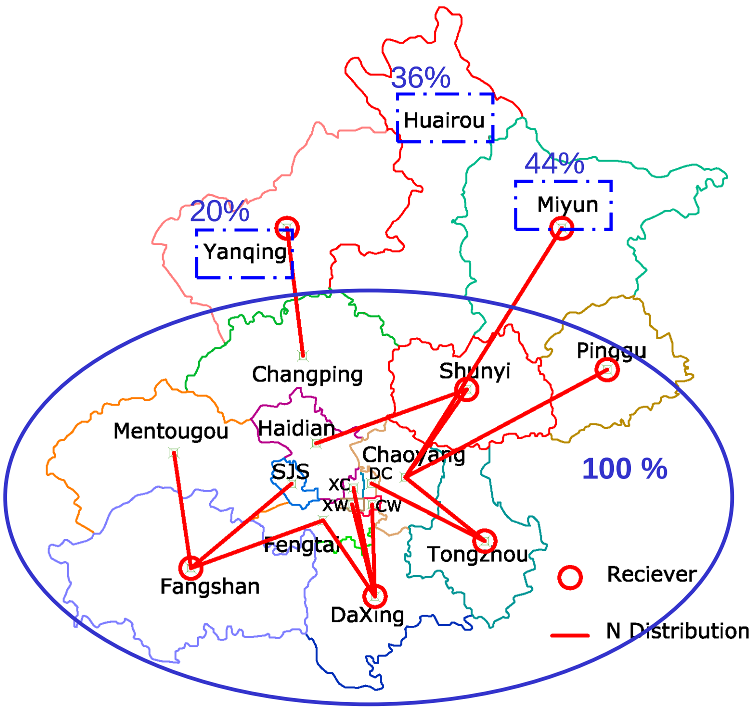

Figure 2.8: Product distribution Scenario 1 (small plants): results N

A similar distribution map can be drawn for phosphorous. Here about 45% of the total phosphorous demand of Beijing's agriculture could be covered by a product (MAP) from urine.

By a calculation of the yearly total distance of transportation, the number of trucks needed and the diesel consumption could be estimated for Scenario 1. As a result, a total number of 8.720 respectively 1.340 trucks would be needed for the distribution of a NH_3-sollution and MAP product respectively. As a total yearly consumption of diesel about 261,000 million L can be estimated.

2.7.2. Scenario 2

In Figure 2.9 the distribution of a nitrogen product from urine for Beijing's agriculture is shown for scenario 2. Urine is transported firstly from the collection sites to the large plants. The products are transported after treatment to the demand areas.

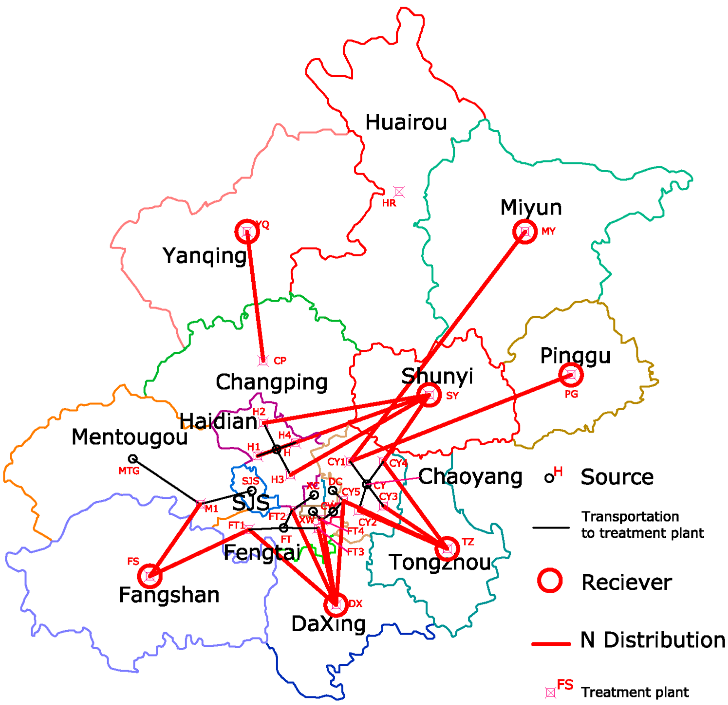

Figure 2.9: Product distribution Scenario 2 (small plants): results N

In Table 2.10, the number of trucks, the yearly total one-way transportation distances, and the diesel consumption are listed. As a result, a total consumption of 1.53 million Litres of diesel was estimated for this scenario. 90% of the consumption was for the transportation of fresh urine to the large treatment plant since piping urine over longer distances did not seem an option, and because of the relatively large volume of untreated urine.

Table 2.10: Summary of the number of trucks and diesel consumption needed for Scenario 2

	Type of trucks (ton/truck)	No. of trucks /times	Total distance (km/year)	Diesel Consumption (L)	% of total diesel consumption
Collection	20	216,900	2,248,000	1,375,600	90%
NH3 distribution	40	4,360	166,000	135,600	9%
MAP distribution	40	670	23,000	19,000	1%
Total				1,530,200	100%

2.8. Discussion and Analysis

When comparing the energy demand for nutrient recovery including transport from collection to agriculture with figures for nutrient elimination at a wastewater treatment plant added to energy demand for fertilizer production, both according to (*Maurer, Schwegler, & Larsen 2003*), in both scenarios about only 40% of the energy was required for transport and treatment in a nutrient recovery system (see Table 2.11). The comparison was based on a total nitrogen amount of 37.7 million tonnes and an amount of 5.89 million tones of phosphorous.

Table 2.11: Energy demand for nutrient elimination at WWTP and for fertilizer production according to (*Maurer, Schwegler, & Larsen 2003*) in conventional system, Energy demand in Scenario 1 & 2 for transport and treatment

	Energy demand in conventional system			Energy demand in Scenario 1			Energy demand in Scenario 2		
	Fertilizer production [MJ/kg]	Nutrient eli. at WWTP [MJ/kg]	Total Energy [MJ/yr]	Treatment [MJ/kg]	Transport [MJ/kg]	Total Energy [MJ/yr]	Urine Transport [MJ/kg]	Product Transport [MJ/kg]	Total Energy [MJ/yr]
N	45	45	3,39 * 10^9	1,32 * 10^9	8,84 * 10^6	1,33 * 10^9	5,33 * 10^7	5,3 * 10^6	1,35 * 10^9
P	29	49	0,45 * 10^9	0,27 * 10^9	1,29 * 10^6	0,27 * 10^9		0,7 * 10^6	0,38 * 10^9
total			3,85 * 10^9	1,59 * 10^9	10,1 * 10^6	1,60 * 10^9	5,33 * 10^7	6,0 * 10^6	1,65 * 10^9

Within the two scenarios the energy consumption needed for treatment and the energy for transportation was compared. In scenario 1 only 0.63% of the total energy consumption were needed for transportation, while in scenario 2 about 4% of the total energy demand were needed for transportation.

When comparing the two scenarios with each other, it can be seen that with localized small urine treatment facilities, the volume can be reduced dramatically on an early stage (96% volume reduction). Thus, the numbers of trucks needed for transport to the receivers is much smaller than in scenario 2. The number of trucks becomes relevant especially when looking at the loaded road infrastructure. Additionally, the number of tours are smaller in scenario 1, resulting in a 6 times lower energy consumption for transport.

However, larger centralized treatment plants will enjoy higher efficiency in the treatment process compared to small plants. Also managed and operation can be controlled more efficiently, as only certain amount of people with good understandings and experience of these system are required. For many smaller plants, a lot of people need to be trained to ensure a good operation and maintenance of the system.

Additional affects including odour and psychological acceptance of the people also would have to be considered in the choice of system, especially within the districts inside the 5th ring, where the city centre is located and the population density is very high. Moreover, most of the historical sites are located here.

2.9. Conclusion and Proposals

Theoretically a large fraction (85% of N and 64% of P) of the nutrient demand in Beijing's agriculture could be covered by fertilizing products from new sanitation concepts. This is quite interesting, since the agriculture in and around is supplying mainly being area itself.

The two discussed scenarios both proofed to be more energy (by at least a factor of 2) efficient than a conventional system with nutrient elimination at the wastewater treatment plant and fertilizer production abroad (transportation costs for fertilizer transport for a conventional scenario were not discussed although they might be high). When looking closer at the two different scenarios, both revealed individual advantages. Scenario 1 with many small units showed, that it is advantageous to reduce volumes at an early stage to reduce transportation costs. With only a few larger treatment plants, as in scenario 2, operation and maintenance is better controllable and most likely more safe. In the end a combination of both scenarios would be the ideal situation.

However, when thinking about realization of a new sanitation concept obstacles come into mind. Since Beijing already has an existing sanitation infrastructure, any new system would need to be implement-able step by step. Some districts offer good boundary conditions for an implementation, e.g. a sanitation system that needs to be renewed, and higher population density to capture larger quantities with the same effort, according to (*Wang et al. 2008*) who discussed different implementation strategies. On other aspect would be to start from areas with high population and high demand for nutrients in agriculture at the same time.

Further studies on the design of detailed logistic systems regarding frequency and the time point of collection as well as the routes should be carried out to avoid adding too much additional transport burden on the already quite crowded roads in Beijing, especially in the urban city. Education and training need to be carried out to enable the local citizens to accept and use new concepts. Soft infrastructure should be established to guarantee the safe and successful stepwise implementation of new concepts in Beijing. In addition, further studies on the adjustment of the function of the existed and on-plan WWTPs should be made.

Overall this study was based not completely on reliable and fresh data. Quite some simplifications, assumptions, and educated guesses were necessary, and population development in the nearer future are uncertain. Still, the outcome shows that there is quite some potential in new sanitation concepts which seems to be worth to be further investigated and implemented at larger scales than in the existing pilot projects.

One of the big advantages of the new systems is its flexibility over time and its adaptability to specific local conditions.

2.10. References

AGRI. China agriculture statistic summary, 2001 - 2006 (in Chinese). 2008. http://www.agri.gov.cn/sjzl/nongyety.htm.

Agroecology. Using Human Manure "nightsoil" in the Tai Lake Region of China. 2008. http://www.agroecology.org/Case%20Studies/nightsoil.html.

Beijing Municipal Bureau of Statistics. Beijing statistic year book 2007. www.bjstats.gov.cn . 31-12-2007. 2007.

BJCTCC. Soil fertilizer using technology handbook. 2008. http://www.bjctcc.cn/Admin/File/UploadFiles/2008125132713240.doc.

Chinagate. China Extends Price Intervention to Fertilizer. 23-1-2008. http://en.chinagate.com.cn/news/2008-01/23/content_9571648.htm.

Feachem, R. G., Bradley, D. J., Garelick, H., & Mara, D. D. 1983, *Sanitation and Disease. Health Aspects of Excreta and Wastewater Management* John Wiley and Sons, New York.

Jönsson, H. & Vinneras, B. "Adapting the nutrient content of urine and faeces in different countries using FAO and Swedish data", in *2nd International Symposium on Ecological Sanitation*, Deutsche Gesellschaft für Zusammenarbeit GmbH (GTZ), Lübeck, Germany.

JTT. Research on the restructure of the carry force in Zhejiang Province, China (in Chinese). 13-2-2007. http://jtt.zj.gov.cn/node82/200702/con142809.htm.

Marketoracle. Ethanol, Fertilizer & Higher Natural Gas Prices. 29-4-2007. http://www.marketoracle.co.uk/Article891.html.

Maurer, M., Schwegler, P., & Larsen, T. A. 2003, "Nutrients in urine: energetic aspects of removal and recovery", *Water Science and Technology*, 48 [1], pp. 37-46

Nextinsight. CHINA XLX FERTILIZER: Cost leader in largest farming province. 12-3-2008. http://www.nextinsight.com.sg/content/view/269/60/.

Tettenborn, F., Gulyas, H., Behrendt, J., & Otterpohl, R. 2005, *Resource Recovery from Yellow Water - Part of the SCST-project of the KWB*, KWB, Berlin,

Vinneras, B., Palmquist, H., Balmér, P., & Jönsson, H. 2006, "The characteristics of household wastewater and biodegradable solid waste - A proposal for new Swedish design values", *Urban Water Journal*, 3 [1], pp. 3-11

Wang, S., Tettenborn, F., Winker, M., Eckart, J., Langenbach, H., & Otterpohl, R. Study on the Feasibility to Apply EcoSan Products from Urine and Faeces in Beijing Agriculture (Transportation and Distribution). 2008.