Case study of sustainable sanitation projects

Co-composting of faecal sludge & organic solid waste Kumasi, Ghana

Fig. 1: Project location

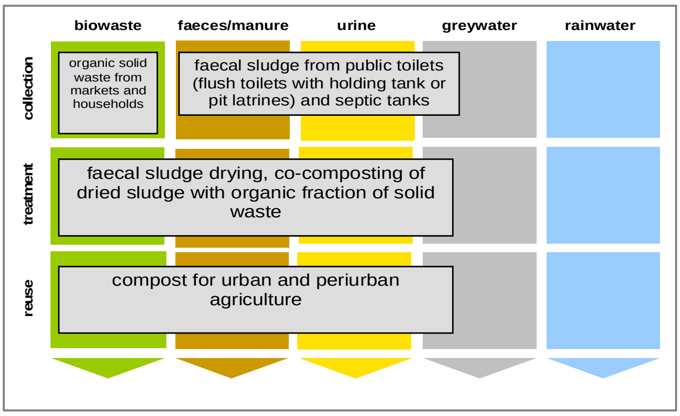

Fig. 2: Applied sanitation components in this project (urine and faeces are mixed with some flush water from pour flush toilets and with some anal washwater).

1 General data

Type of project:

Research and demonstration project: Combined treatment of faecal sludge and organic solid waste for reuse in agriculture (pilot scale in urban area).

Project period:

Start of planning: July 2001
Start of construction Oct. 2001
Start of operation: Feb. 2002 (not continuously in operation, depending in research phase)

Project scale:

Total land area covered: ~500 m²
Faecal sludge treated: 45 m³ per month
Capital investment costs: EUR 16,500

Address of project location:

Buobai, 15 km East of city centre of Kumasi, Ghana

Implementing institutions:

Joint planning by 4 institutions led by International Water Management Institute (IWMI):

- International Water Management Institute (IWMI); executive institution, Accra, Ghana
- Department of Water and Sanitation in Developing Countries (SANDEC) of the Swiss Federal Institute for Aquatic Science and Technology (EAWAG), Dübendorf, Switzerland
- Kwame Nkrumah University of Science and Technology (KNUST), Accra, Ghana
- Waste Management Department of Kumasi Metropolitan Assembly (KMA), Kumasi, Ghana

Supporting agencies:

- Ministry of Foreign Affairs, France
- National Centre of Competence in Research (NCCR) North South, Switzerland (e.g. funding of PhD students)
- KEZO, Switzerland (Waste Disposal Services Zurich Oberland, German name is: Zweckverband Kehrichtverwertung Zürcher Oberland)

2 Objective and motivation of the project

The objectives of the project were:

- To gain scientific knowledge on the technical and operational aspects of co-composting (co–composting refers to having two input materials: organic solid waste and faecal sludge).
- To evaluate socio-economic aspects of co-composting as well as the impact of compost utilisation on crop and soil
- To raise awareness and know-how of co-composting as a waste recycling option
- To train people in being able to operate co-composting plants (capacity development component)

The main focus of the project is the production of hygienic and nutrient rich compost made from organic solid waste and faecal sludge and its utilisation in agriculture for sustainable food production.

The co-composting plant was designed as a fully functioning small-scale facility; however it is operated at pilot scale with the objective to serve as an experimental site rather than having a high waste turnover and compost output. The ultimate aim of this process is to contribute to improving the faecal sludge management situation in Kumasi and hence improve public health.

3 Location and conditions

Kumasi is the second largest city in Ghana, West Africa. The city has 1 million inhabitants (growth rate of 3% per year).

Fig. 3: Co-composting facility (open windrow system) in Kumasi (source: IWMI, 2003).

The city is an industrial centre with formal industries in timber, food processing and soap manufacturing, together with informal activities in woodwork, vehicle repair, footwear, furniture manufacture and metal fabrication.

About 38 % of Kumasi residents use public toilets: There are about **400 public toilet facilities** in Kumasi, equipped with either flush toilets with a holding tank or KVIP latrines[1] with two pits per latrine (used alternatively) or one pit per latrine. Another 26% of the population use household water closets linked to septic tanks and seepage pits. Only 8 % of the population is connected to a sewerage system and the remaining 28% of the population have no toilet facilities at all (practising open defecation instead).

The residents in Kumasi produce daily 860 tons of solid waste and 500 m^3 of faecal sludge (human excreta and water) collected from on-site sanitation systems (septic tanks, pit latrines and unsewered public-toilets). Approx. 70% of the produced solid waste is biodegradable (organic) which can be co-composted together with the faecal sludge and utilised as a fertiliser and soil conditioner.

Of the 500 m^3 /d of faecal sludge produced, only 1.5 m^3/day is treated in the pilot plant. Kumasi has a full-scale faecal sludge treatment plant (formerly, the faecal sludge treatment plant at Buobai was used; currently, the FSTP at Dompoase is the main plant used). The pilot plant was only established to investigate the aspect of co-composting. And it is not a daily operation as the FSTP.

The overall faecal sludge treatment situation in Kumasi is as follows, according to Vodounhessi and von Münch (2006) (see Section 13): "*The collection companies discharge the collected FS at the privately operated FS treatment plant (FSTP) at Dompoase and there is now no longer illegal FS dumping in the city. This has been successful through the strictness of the District Assembly rules and the community participation in denouncing defaulters. The FSTP is located at the Dompoase solid waste landfill site and consists of five anaerobic, one facultative and two maturation ponds to treat FS and landfill leachate. The facility became operational in January 2004. The treated liquid effluent is mixed with the underground drainage from the solid waste landfill and discharged into Sisai River without further treatment, despite questionable effluent quality (based on visual observation; no analytical data available)."*

The former FSTP, a pond system at Buobai, was in operation during 2001-2003, but is currently no longer operational because the sedimentation ponds are full and yet to be emptied. Also, the community surrounding the plant was not satisfied with the quality of the effluent discharged in the neighbouring river."[2]

The climate is sub-equatorially wet with two rainy seasons, the major one from late February to early July and the minor one from mid September to early November.

Crop production is practised at different sites: approx. 70 ha in open space urban farming (vegetables, tubers[3] and cereals) while more than 12,000 ha in peri-urban farming. Backyard gardening is also commonly practised within the city as well as peri-urban cultivation of maize and plantain.

The under-five child mortality rate[4] in Ghana is currently 115 children per 1000, and the trend since 1999 is sadly in an slowly increasing direction
(http://www.childinfo.org/mortality.html).

4 Project history

The drivers for this project were IWMI and Sandec together with the project partners, led by IWMI (see Section 14). Significant milestones were building the plant, acceptance by the community and first batch of compost produced.

The pilot co-composting plant is located within the **Buobai faecal sludge treatment plant** which was built to treat part of the FS generated in the city. The Buobai faecal sludge treatment plant has two anaerobic, two facultative and one maturation pond (currently it is no longer in use for faecal sludge treatment as mentioned in Section 3).

The construction of the pilot plant started in October 2001 and the operation started in February 2002. The plant has been in operation ever since then. Over the years, considerable knowledge was gained and large quantities of compost were produced for field trials. The plant is seen as a facility to gather useful information for future upscaling by the municipal assembly.

The plant is currently not operational because the research funds for this project are currently depleted and KMA has not taken the pilot plant over. Therefore, no more composting is taking place since January 2009. IWMI still keeps one worker in charge while IWMI develops the next research steps on the one hand and engages the waste management department in discussion for next steps

IWMI is continuing with scientific investigations and is preparing a guideline on co-composting which will be made available to the municipal assembly (KMA). Whether a full-scale co-composting plant will be built or not depends on KMA. Currently, KMA does not consider it a high priority (one problem is that the reference point for composting in Ghana is still the failed large scale Teshi plant in Accra).

5 Technologies applied

The basic technology chosen for this project consists of two main process steps:

1. Faecal sludge drying on unplanted drying beds and
2. Windrows co-composting of dried faecal sludge (FS) and organic solid waste (oSW).

[1] KVIP stands for "Kumasi ventilated improved pit latrine": an alternating VIP latrine (= double pit latrine in the USA) while a conventional VIP is not alternating.

[2] In August 2009: There is currently no discharge at Buobai faecal sludge treatment plant. There is a KMA staff member who guards the place though. KMA still plans to use it but according to the waste management director, they are still searching for fund to adequately compensate the community.

[3] A tuber is a type of crop with the edible part under the soil surface (examples include yam, cassava, cocoyam).

[4] The under-five mortality rate is the probability (expressed as a rate per 1,000 live births) of a child born in a specified year dying before reaching the age of five if subject to current age-specific mortality rates.

Co-composting of FS and oSW is advantageous because the two materials complement each other well: FS has a relatively high nitrogen content while oSW is high in organic carbon and has good bulking properties.

FS (excreta mixed with water) is collected from unsewered public toilets (type of toilet is described in Section 3) and household septic tanks by vacuum trucks within the city of Kumasi and transported to the project site for drying on sludge drying beds. Due to its too high moisture, fresh FS is unsuitable for direct aerobic composting. Hence a solid-liquid separation is needed to produce sludge of adequate water content for co-composting. For solid-liquid separation, sludge drying beds including a sand-gravel filter medium for drainage were built. They are loaded with the faecal sludge (a mixture of public toilets sludge and septic tanks FS in the ratio of 1:2). The drying process is enhanced by evaporation and gravity percolation.

Fig. 4: Faecal sludge drying beds (source: Olufunke Cofie, 2002).

The dried FS is removed from the drying beds once it has become spadable (after 10 days) and stored prior to co-composting.

The **leachate** (also called drainage or percolate) from the drying beds is collected in a percolate storage tank and discharged into the facultative stabilisation pond of the Buobai faecal sludge treatment plant before final discharge into a nearby stream.

Municipal solid waste from markets or residential areas is collected and delivered by trucks to the composting site. This waste is sorted manually. The organic fraction of the SW and the dried FS are mixed in a ratio of 3:1 and composted using an open windrow system where the feedstock is aerated by manual turning. During a composting cycle, the following activities are carried out: turning, watering, temperature measurement, weighing, sampling and laboratory analysis (analysed for physicochemical and microbiological properties). The matured compost is sieved, packed in bags (50 kg each) and stored prior to reuse e.g. in field trials.

This technology has been chosen because it is easy to build and operate, has low costs, can be implemented on a decentralised basis, no energy supply is needed and it is suitable for tropical regions such as Ghana. The drying bed is a more efficient solid-liquid separation system than the settling/thickening ponds commonly used in Ghana. Its efficiency however depends on climatic conditions and of the type of both filter material and feedstock.

Thermophilic conditions (i.e. temperatures greater than 50℃) are achieved through the composting process. These high temperatures are effective in killing pathogens such as Ascaris eggs contained in excreta. Thus, both wastes are converted into a hygienically safe soil conditioner and fertiliser.

6 Design information

Two unplanted drying beds were built with a surface area of 25 m^2 each (to hold 15 m³ excreta with a depth of 30 cm). They consist of different layers of a gravel-sand filter material of different thickness and particle sizes. Design criteria and assumptions used for the pilot plant in Kumasi are shown in Table 1 below.

The composting area is a roofed and sealed composting pad of 10 x 12 m. The composting pad has a slight slope of 1% towards the centre where a narrow drainage channel is located. This serves as a drainage system in case of leachate generation. The maturation area is a roofed and sealed pad of 7 x 6 m. Further technical details are provided in Fig. 5 and Table 2 below. These can be applied for similar climatic conditions and faecal sludge characteristics in other countries.

Table 1: Design criteria and assumptions used for pilot plant in Kumasi

Faecal sludge dewatering

- volume of FS treated: 15 m^3/cycle = 45 m³/month = 1.5 m³/d
- 3 dewatering cycles/month
- 3 faecal sludge truck loads/cycle (1 truck carries ~5m^3)
- ratio of public toilet sludge to septage sludge = 1:2
- surface of sludge drying beds: 50 m²
- hydraulic load on drying beds: 30 cm/cycle
- FS volume reduction through dewatering assumed: 90%
- dried sludge produced: 1.5 m^3/cycle = 4.5 m^3/month

Co-Composting

- ratio of organic SW to dried FS = 3:1 (by volume)
- 1 month thermophilic composting + 1-2 months maturation
- 1 composting cycle starts each month
- required volume of organic SW: 3 x 4.5 = 13.5 m³/month
- assumed organic fraction in household waste: ~50% (being less than 70% indicated in Section 3 for taking into account a safety margin because waste composition may vary in time)
- required volume of unsorted SW delivery: approx. 27 m^3/month
- raw compost produced: 4.5 + 13.5 = 18 m^3/month
- volume reduction through co-composting: 50%
- mature compost produced: ~9 m^3/month = 4-5 t/month (density = 0.5 t/m³)

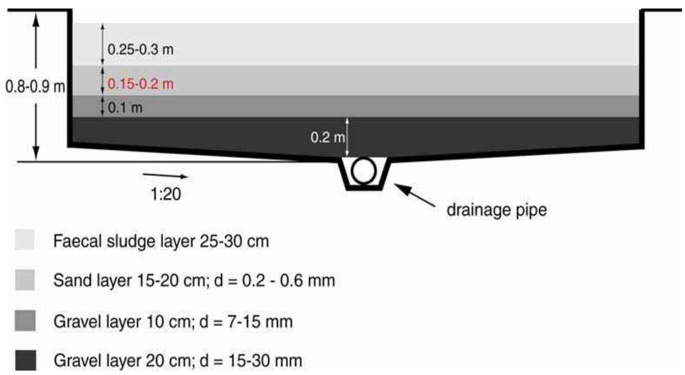

Fig. 5: Structural principle for a drying bed profile (for faecal sludge dewatering).

Table 2: Technical details and characteristics recommended for faecal sludge dewatering in drying beds.

Sizing of the beds
• 15 days drying cycle
• 25 – 30 cm sludge layer on beds
• 100-200 kg TS/m² / year (TS stands for total solids)
• 0.08 m^2/cap
Raw sludge characteristics
• Partly stabilised (septage or mixture of septage and public toilet sludge with ≤ 30 % share of public toilet sludge)
Sand characteristics
• Sand particles do not crumble
• Sand easily available locally
• Sand thoroughly washed prior to application onto the gravel base
Production of filter layers
• Reduce pressure flow via splitting chamber, inlet channel, and splash plates
Drying bed removal efficiency
• 97% SS (suspended solids), 90% COD (chemical oxygen demand), 100% HE (helminth eggs)
Biosolids
• 0.1 m³ per m³ fresh FS
• Hygienisation necessary prior to use in agriculture as biosolids
Percolate
• Quality fairly comparable to tropical wastewater
• Salinity too high for irrigation
• Percolate treatment e.g. waste stabilisation ponds or constructed wetlands

7 Type and level of reuse

The compost has been tested for its impact on the germination capacity and early growth of selected vegetables commonly grown in the urban and peri-urban areas (tomato, sweet pepper, lettuce, cabbage, spring onion and carrot). The germination capacity varied between 70-100% for all vegetables, which is an acceptable range. Some of the compost was given to selected urban farmers from the Gyenyasi Farmers Association in Kumasi for its application on their farms. The feedback received was encouraging. There was no difference in performance between this compost and poultry manure for lettuce production.

Furthermore the compost was tested on a demonstration field with maize and compared with a control field without compost application. The field with compost achieved a significantly higher crop yield than the control field.

The compost has been used to grow cereals and vegetables. Also the composting plant operators use it for their own production. This is a demonstration plant to convince policy makers, researchers, farmers, city planners and waste managers of the merits of compost production from faecal sludge.

It is important to find out the perceptions of the farmers as the direct beneficiaries and to determine if a project of this nature is financially and economically viable. Therefore, a study on farmers' perception of excreta-based compost and willingness to pay was carried out. The results of this study were that a large number of farmers (83%) were willing to use excreta-based compost. However, the actual amount that farmers were willing to pay was low (between EUR 0.1 to 2.5 per 50-kg bag)[5] which was far below a price which would cover production costs.

The farmers who were skeptical (17%) feared that the excreta component could still spread infections and thought that consumers might avoid crops being fertilised with excreta-based compost (there is however no evidence that consumers would avoid crops that were fertilised with excreta-based compost).

Fig. 6: Lettuce farm fertilised with compost at Gyenyasi farmers Association in Kumasi (source: Nikita Eriksen-Hamel, 2002).

Research on the produced compost has shown that the compost quality is within an acceptable range. The composting process is efficient in reducing the Ascaris eggs concentration to a safe level. Ascaris eggs viability is reduced from 40-60% in the raw FS to less than 10% in the final compost with a total count of <5 Ascaris eggs/gTS (TS stands for total solids). The viable Ascaris eggs are <1 viable Ascaris eggs/gTS, thereby complying with the WHO guidelines of 2006 for the safe use of excreta[6]. The macro- and micro-nutrients as well as heavy metal contents are within an acceptable range.

Thus this compost made of FS and organic SW will not pose health risks to farmers and consumers. The necessary health and safety plans are available on site. Safety equipment (boots, overalls, gloves and nose masks) are always used by the workers. Hands are thoroughly washed with soap and disinfectants. The workers periodically undergo medical check-ups. SW rejects (non-organic component) are properly land filled by the KMA Waste Management Department.

Compost is not sold to farmers but given to them for free or used by the plant operators for field tests. The reason why it is given away for free is because the plant was not for commercial use but just meant to gain technical knowledge on co-composting of faecal sludge and organic solid waste. However the farmers are willing to use excreta-based compost provided its nutrient content is high enough and it is available at an affordable price.

[5] For comparison: Common compost used in Kumasi is poultry manure which at the time of calculation was free except for transport cost.

[6] http://www.who.int/water_sanitation_health/wastewater/gsuww/en/index.html

8 Further project components

Due to the implementation of this project, an increased awareness can be observed among farmer groups in using excreta-based compost. Many farmers understood that co-compost made from human excreta and organic solid waste is a safe product and poses no health risk to them. Scientists and engineers carried out training of project assistants and MSc and PhD students who also worked on various system components. The project offered many Northern and Southern students the opportunity to do applied research on this subject.

The scientific investigations were carried out by IWMI and other research partners from Eawag/Sandec and KNUST, coordinated by the project leader.

9 Costs and economics

Total investment costs were about EUR 16,500 which were funded mainly by the Ministry of Foreign Affairs (France). Operation costs (PhD students, video documentary, initial operation and maintenance costs) were funded by NCCR North-South and KEZO (in Switzerland).

The first phase (2001-2004) was funded by France and the project partners own budgets, in particular, IWMI and Sandec (funding from KEZO). The second phase (2005- 2008) was funded by NCCR North-South through PhD research. Funding for 2009 has been a constraint.

Operation of the co-composting plant is labour intensive. Solid waste sorting is the most costly activity contributing to approx. 30% of the total operation and maintenance costs.

It was estimated that the amount of compost produced from the pilot plant will be approx. **37 tons/year**[7]. A subsequent study valued the compost produced at the plant to be approx. EUR 3.5 per 50-kg bag.

If the plant was working at full scale the production costs would decrease or possibly increase (e.g. in cases where manual shoveling had to be replaced by machines). These figures however refer to this demonstration project only and are not applicable for other full-scale projects.

The operation and maintenance costs include mainly just labour. There are normally no electricity or chemicals costs (except for research activities). The labour costs vary for different activities at the plant e.g. waste sorting was about 30% of total cost. The labour costs vary with the number of compost heaps under investigation during the different research phases.

The combined process of FS drying and co-composting is costly for a private company and hence requires a considerable government subsidy especially for the initial investment. Sales revenues would hardly cover operating expenses.

The economic analysis showed that the plant is economically viable, though financially it is not. However, the project has numerous external benefits (such as reducing waste volume, transport costs, increasing the agronomic value of compost and improving public health). Thus compost production - even without a market - saves money at other places which in turn could be used to subsidise such a co-composting plant.

10 Operation and maintenance

Collection and transportation of excreta and solid waste to the project site are performed by the Waste Management Department of KMA (Kumasi Metropolitan Assembly).

The plant manager is responsible for the management and supervision of the operation of the plant. Two labourers work under the supervision of the plant manager. The labourers are not employed by KMA but normally paid by the project (although there is currently a problem with the funding). Hence, KMA is currently not paying for the O&M costs of the plant.

The operational activities can be summarised as follows:

- FS delivery
- FS loading on drying beds
- De-sludging of drying beds
- Solid waste delivery
- Solid waste sorting
- Mixing and piling of co-composting feedstock (dried FS and organic SW)
- Turning of windrows and watering
- Sieving and bagging of the compost
- Sampling (for analysis and agronomic field trials)

The maintenance activities consist of a periodic changing of the filter medium of the drying beds when it is clogged: The top layer (sand) is then removed from the drying bed, the underlying gravel layer is washed and the top layer replaced by new sand. Time intervals for changing of the sand filter can range from several months to more than 15 years depending on the sand quality: In order to reduce the risk of clogging, sand with no or a low amount of silt/clay has to be used (to be obtained e.g. by washing).

General cleaning of the site is carried out periodically to keep it tidy. Grass is planted to beautify the place and to minimise erosion.

11 Practical experience and lessons learnt

Functional improvements of the drying beds are necessary to guarantee a continuous and sustainable compost production: Improvements are needed on the filter quality and how to control the effect of rainfall.

The co-composting plant has experienced the following operational problems:

- Occasionally, long delays in waste delivery to the site occur (due to logistical problems with the waste collectors) which consequently cause a disruption of the operation.
- If there is excessive rain then the sludge drying process takes longer than the usual 10 days, as the drying beds are not covered (clogging of the beds may also occur in this case).
- It has been observed that the nitrogen content of the compost is lower than would be required for high yield of short duration crop production as practiced in the urban areas. This is due to nitrogen losses during both faecal sludge drying and the composting process itself.
- Some measures (e.g. reduction of the compost turning frequency, fertiliser enrichment) are taken in order to reduce

[7] The plant was not operated continuously to full capacity due to the research focus. Information about the exact amount of compost produced over the years is currently not available.

these nitrogen losses. An enriched form of the compost called *Comliser* (mixture of compost and chemical fertiliser) is prepared and tested with farmers (see references in Section 13).

Addition of pure urine to the compost to increase the nitrogen content was considered but not carried out yet. IWMI, as one of the research partners, is in the process of developing a follow up research

The compost is generally of high quality as sorting of the solid waste (to removed inorganic matter, e.g. pieces of plastic and metal) is done very carefully and diligently be the plant workers.

Social problems faced were as follows:
- A few years ago, the residents of the Buobai community prevented trucks from delivering waste to the site on several occasions, making operation of the plant impossible. They claimed that KMA had used their land for setting up a faecal sludge stabilisation pond without compensating them for the land. So they used their power on this co-composting project to force KMA to act. It took a combined effort of IWMI and KMA to solve the conflict by meeting with the chief and the community.

12 Sustainability assessment and long-term impacts

The fact that this pilot plant has been operating for 7 years can be taken as a good sign for sustainability. However, for financial sustainability, external support or subsidies are needed.

A basic assessment (Table 3) was carried out to indicate in which of the five sustainability criteria for sanitation (according to the SuSanA Vision Document 1) this project has its strengths and which aspects were not emphasised (weaknesses).

The long term impacts of this project are:
1. The erection of a demonstration plant has served to demonstrate to policy makers, engineers, farmers, city planners and waste managers the merits of co-composting.
2. This co-composting demonstration plant has become well-known and served as a basis for similar projects in Senegal and Mali funded by Sandec.

Improved public health of residents in Kumasi would be a long-term impact if the plant was upscaled to treat a significant proportion of the faecal sludge produced in Kumasi. This is the ultimate goal.

Table 3: Qualitative indication of sustainability of system. A cross in the respective column shows assessment of the relative sustainability of project (+ means: strong point of project; o means: average strength for this aspect and – means: no emphasis on this aspect for this project).

	collection and transport			treatment			transport and reuse		
Sustainability criteria:	+	o	-	+	o	-	+	o	-
• health and hygiene	X			X			X		
• environmental and natural resources		X		X			X		
• technology and operation			X	X			X		
• finance and economics			X		X			X	
• socio-cultural and institutional			X	X				X	

Sustainability criteria for sanitation:

Health and hygiene include the risk of exposure to pathogens and hazardous substances and improvement of livelihood achieved by the application of a certain sanitation system.

Environment and natural resources involve the resources needed in the project as well as the degree of recycling and reuse practiced and the effects of these.

Technology and operation relate to the functionality and ease of constructing, operating and monitoring the entire system as well as its robustness and adaptability to existing systems.

Financial and economic issues include the capacity of households and communities to cover the costs for sanitation as well as the benefit, e.g. from fertilizer and the external impact on the economy.

Socio-cultural and institutional aspects refer to the socio-cultural acceptance and appropriateness of the system, perceptions, gender issues and compliance with legal and institutional frameworks.

For details on these criteria, please see the SuSanA Vision document "Towards more sustainable solutions" (www.susana.org).

13 Available documents and references

A video documentary entitled "Co-treating faecal sludge and solid waste: the Buobai co-composting pilot project, Kumasi, Ghana" was prepared in 2003 describing the activities and operation of the project and giving an overview of the sanitation situation in Kumasi and Ghana at large (Maradan, J. and Schaffner, R. (2003) Co-treating faecal sludge and solid waste. The Buobai Co-composting Pilot Project, Kumasi, Ghana, video documentary)[8].

Various documents (reports, theses, papers) are available as listed below (shown in reverse chronological order, starting from 2004).

Published papers

- Olufunke, C., Doulaye, K., Silke Rothenberger, Daya Moser and Chris Zurbrügg (2009) Co-Composting of Faecal Sludge and Organic Solid Waste for Agriculture: Process Dynamics. Water Research Abstract and pdf file available at

[8] It is available to order from this website: http://www.nccr-north-south.unibe.ch/document/document.asp?ID=1907&refTitle=NCCR&Context=NCCR

http://www.sciencedirect.com or doi:10.1016/j.watres.2009.07.021
- Noah Adamtey, Olufunke Cofie, Godfred K. Ofosu-Budu, Seth. K. A. Danso and Dionys Forster (2009). Production and storage of N-enriched co-compost. Waste Management: 29 (2009) 2429–2436. Abstract and pdf file available at http://www.sciencedirect.com.
- Miezah, K. Ofosu-Anim, J. Budu, G.K.O., L. Enu-Kwesi and O.Cofie (2008) Isolation and identification of some plant growth promoting substances in compost and co-compost. International J. of Virology. 4 (2): 30-40. Abstract and pdf file available at http://www.sciencedirect.com.
- Kuffour, A.R., Awuah, E., Anyemedu, F.O.K., Strauss, M., Kone D. and Cofie, O. (2008) Effect of using different particle sizes of sand as filter media for dewatering faecal sludge. In: Richards B.S and Schafer, A.I. (eds). Water and Sanitation in International Development and Disaster Relief. Proceedings of International Workshop Edinburgh, Scotland, (UK), 28-30 May 2008. 347 – 354. http://www2.gtz.de/Dokumente/oe44/ecosan/en-filter-media-for-dewatering-faecal-sludge-2008.pdf
- Adamtey, N., Cofie, O., Ofosu-Budu, G. K. and Forster, D. (2008) Turning Waste into a Fertiliser. Sandec News 9: 16. http://library.eawag-empa.ch/sandecnews/sandecnews_9.pdf
- Nikita S. Eriksen-Hamel and George Danso (2008) Urban Compost: A Socio-economic and Agronomic Evaluation in Kumasi, Ghana in Mark Redwood (ed) Agriculture in Urban Planning: Generating Livelihoods and Food Security Earthscan/IDRC. http://www.idrc.ca/en/ev-135127-201-1-DO_TOPIC.html
- Agbottah S., Awuah E., Cofie O and A. Montangero (2007) Anaerobic Treatment of Percolate from Faecal Sludge Drying Beds – Journal of the Ghana Institution of Engineers Vol. 5 (1&2): pp. 25-30
- Koné, D., Cofie, O., Zurbrügg, C., Gallizzi, K., Moser, D., Drescher, S., Strauss, M. (2007) Helminth eggs inactivation efficiency by faecal sludge dewatering and co-composting in tropical climates. *Water Research* 41(19), 4397-4402. Abstract and pdf file available at http://www.sciencedirect.com.
- Cofie, O., Agbottah, S., Strauss, M., Esseku, H., Montangero, A., Awuah, E. and Koné, D. (2006) Solid-liquid separation of faecal sludge using drying beds in Ghana: Implications for nutrient recycling in urban agriculture. *Water Research* 40(1), 75-82. Abstract and pdf file available at http://www.sciencedirect.com.
- Vodounhessi, A. and v. Münch, E. (2006) Financial Challenges to Making Faecal Sludge Management an Integrated Part of the Ecosan Approach: Case Study of Kumasi, Ghana, Water Practice & Technology, 1(2), http://www.iwaponline.com/wpt/001/wpt0010045.htm

MSc Theses (soft copies are available on request)
- Vodounhessi, A. (2006) Financial and Institutional Challenges to Make Faecal Sludge Management Integrated Part of Ecosan Approach in West Africa. Case Study of Kumasi, Ghana. MSc thesis, UNESCO-IHE Institute for Water Education, Delft, the Netherlands. http://www2.gtz.de/Dokumente/oe44/ecosan/en-financial-institutional-challenges-ecosan-2006.pdf
- Quarshie, S. (2005) Filter material and loading rate for the optimal dewatering of faecal sludge. M.Sc. thesis in Water Supply and Environmental Sanitation, Dept. of Civil Engineering, KNUST, Ghana
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Case study of SuSanA projects

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SuSanA 2009

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[9] In the future, KMA should become the owner and operator of this facility once it is completely handed over (currently, KMA is a partner in the operation).