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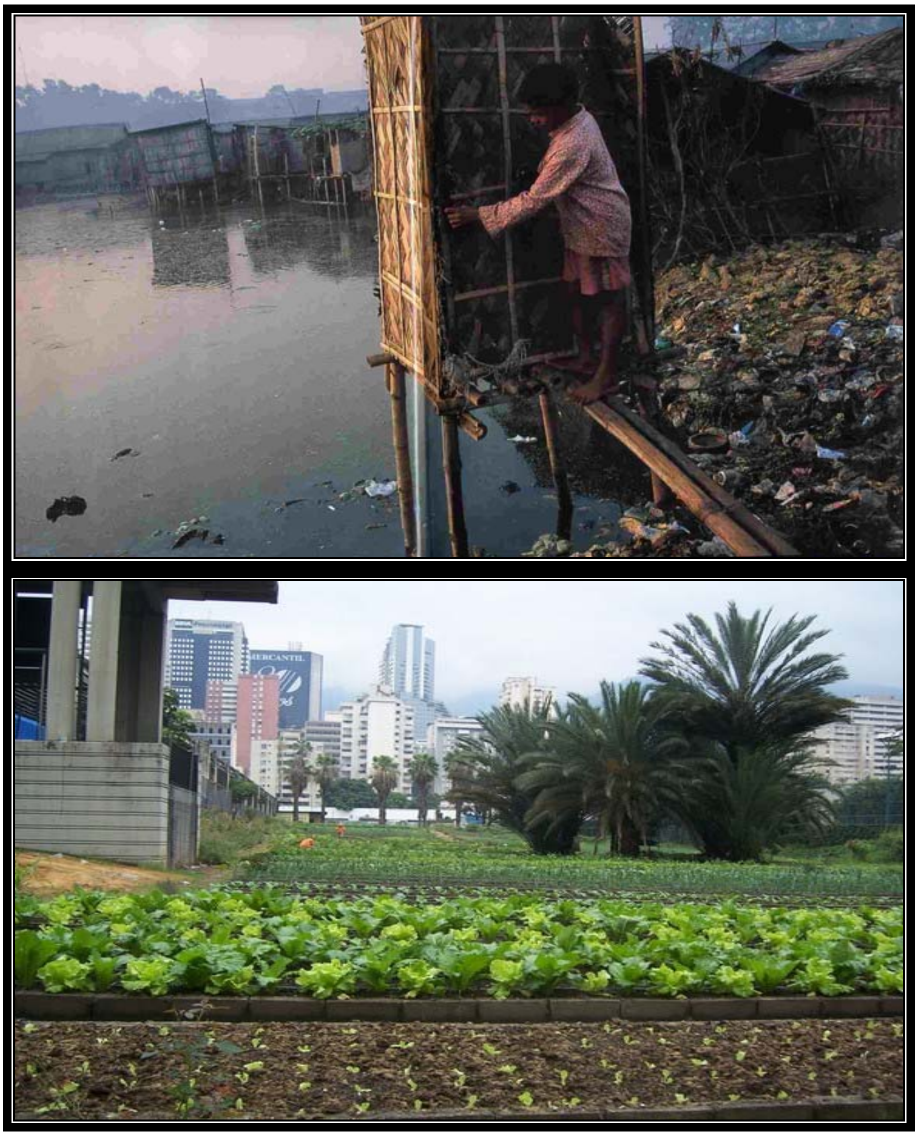

Multi-criteria analysis of options for urban sanitation and urban agriculture
-Case study in Accra (Ghana) and in Lima (Peru)-

N.K. De Silva
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Master of Science research
by
N.K. De Silva

Supervisor
Prof. Gary Amy

Mentors
Dr. Elisabeth von Münch
Dr. Adriaan Mels

Examinations Committee
Prof. Gary Army
Dr. Elisabeth von Münch
Dr. Adriaan Mels

This research is done for the partial fulfillment of requirements for the Master of Science degree at the UNESCO-IHE Institute for Water Education, Delft, the Netherlands

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April 2007

Dedication to

My loving parents

Abstract

The Millennium Development Goal 7 (Ensure environmental sustainability), target number 10 (halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation) was introduced to encourage better solutions for water and sanitation problems in developing countries.

The SWITCH (Sustainable Water management Improves Tomorrows Cities' Health) project, funded by the European Union, aims to provide a sustainable, healthy, and safe urban water system to the people. This research was conducted under sub-theme 4.1 of the SWITCH project (eco-sanitation and decentralised wastewater management in an urban context). Accra in Ghana is a "demonstration city" in the SWITCH project; Lima in Peru is a "study city".

The objective of this research, which was limited to a desk top study, was to find out the most suitable sanitation system for urban and peri-urban areas (considering urban agriculture) by using a multi-criteria analysis for comparing options. The case study was carried out for urban and peri-urban areas in Accra (Ghana) and in Lima (Peru) with the main focus being on the Accra Metropolitan Assembly (AMA).

The main water-related problems identified in Accra are lack of access to safe sanitation especially in poor areas, pollution of water bodies due to inadequate treatment and poor sanitation, and polluted wastewater use in urban agriculture. Law rainfall, not sufficient water for human use, and competition between water users are the main identified water-related problems in Lima.

The existing sanitation systems in urban and peri-urban areas in Accra and Lima are bucket latrines, pit latrines, flush toilets, and open defecation. The improved sanitation coverage for the urban population in Ghana was 13% in 2004 and 67% for the urban population in Peru.

The main urban agricultural systems identified in both cites are irrigated vegetable farming, backyard farming, livestock farming, and aquaculture farming, while especially Lima urban farmers are also practising hydroponics technology. People commonly use untreated wastewater for urban agriculture in both cities. The main constrains identified for development of urban agriculture are access to land, water, and lack of finance for fertiliser. Ecological sanitation (ecosan) can play an important role to ensure safe and comfortable sanitation at low cost and to provide fertiliser and safe water (treated greywater) for urban agriculture.

The detailed analysis of sanitation systems was carried out for only Accra Metropolitan Assembly (AMA) because of the lack of available data for Lima. The available low-cost sanitation options for AMA were short-listed to Option 1 (VIP-ventilated improved pit latrine with down-stream processing) and Option 2 (UDD-urine diversion dehydration toilet, double vault with the down-stream processing). The population to be covered in this design is 265,000 (this is 16% of the total population in AMA who engage in urban agriculture) and the average household size is 4.5 (assume one toilet per household).

In order to do a cost estimate, a concept design was developed for both options which covers all parts the sanitation system (i.e. toilet, transport from toilet to treatment plant/ storage, treatment, transport from treatment plant/storage to farm, and reuse).

According to the results of the financial model, the capital cost for Option 1 is € 27 per capita whereas the capital cost for Option 2 is € 39 per capita. The difference is mainly due to costs in Part A (toilet), which is for € 354 for a VIP toilet and € 447 for a double-vault UDD toilet. The NPV for Option 1 is € 10.5 million and for Option 2 it is € 13.5 million (12% discount rate, 10 year project lifetime).

A multi-criteria analysis (MCA) was carried out for both options to determine the best solution concerning social, technical, economic, environmental, health, and institutional aspects by five experts in the field. From the analysis results, Option 2 (UDD) obtained higher scores than Option 1 and hence more desirable for AMA.

The MCA used a number of indicators per aspect, which different for each part of the system; Weighting of each aspect could also be adjusted by the experts, who had to give scores from 1 to 5 for each indicator.

It seems that Accra and Lima are not on the track to meet the MDG target for sanitation coverage. The common constraints found for achievement of MDG targets are lack of finance (for people and government), lack of technology, lack of political will, and insufficient land. Ecosan approaches could play a major role in achieving MDG targets (1, 2, 5, 8, 10, and 11) at lower cost than conventional sanitation systems.

Main recommendations from this thesis include carrying out conceptual design with more specific detail for every part of the sanitation components (Part A to E), cost estimation with accurate quantities and costs especially for the toilet itself and urine storage, and designing and cost estimation for greywater management systems.

Acknowledgements

I would like to acknowledge the Dutch Ministry of International Cooperation and European Union, which are financing the WaterMill Project and SWITCH project respectively for providing me a Scholarship for studying the Master of Science degree programme in Sanitary Engineering UNESCO-IHE in Netherlands.

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Table of Contents

List of Abbreviations

AMA	Accra Metropolitan Assembly
CDB	Central Business District
EAWAG	Swiss Federal Institute of Environmental Science and Technology
Ecosan	Ecological sanitation
FAO	Food and Agriculture Organization
IWMI	International Water Management Institute
MCA	Multi-Criteria Analysis
MDG	Millennium Development Goals
RUAF	Resource Centre on Urban Agriculture and Forestry
SANDEC	Department of Water and SANitation in DEveloping Countries, Switzerland
SEI	Stockholm Environment Institute, Sweden
SIWI	Stockholm International Water Institute, Sweden
SWITCH	Sustainable Water Management Improves Tomorrows Cities' Health
UASB	Upflow Anaerobic Sludge Blanket
UDD	Urine Diversion Dehydration
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
UWM	Urban Water Management
VIP	Ventilated Improved Pit
WHO	World Health Organization
WWTP	Waste Water Treatment Plant

List of figures

List of tables

1. Introduction

1.1. Background

The Joint Monitoring Programme of the WHO and UNICEF reported in 2004 that the number of people lacking basic sanitation services rose from 2.1 billion to 2.6 billion by 2004. It is common knowledge amongst the experts that improved sanitation has a direct positive effect in reducing diarrhoea morbidity. “Still progress in improving sanitation for almost half the world’s population remains slow and diarrhoea from unsafe water, sanitation and lack of hygiene causes 1.8 million deaths per year, 90 % of which are children under 5 years age” (SIWI, 2005).

(SEI, 2005) states that conventional approaches to sanitation, even if successfully applied to the MDG target populations, do not address the present target sanitation services. This is a major source of health and environmental problems. Also, the existing conventional approaches to sanitation might not always be appropriate to the context of the MDG target population. Therefore, there is a necessity to look at new appropriate sanitation options using the principles of sustainability.

Collection and disposal of human excreta are a serious sanitation problem in most of the cities in developing countries. This is especially felt in low-income urban settlements and unplanned areas of those cities where establishing of a waterborne sewerage system is hampered by multitude of limitations.

Ecological sanitation (ecosan) is a new paradigm in the sanitation sector, which is an alternative to conventional sanitation systems, without being limited to any specific sanitation technology. (Winblad and Simpson-Hebert, 2004) states that ecological sanitation is based on three fundamental principles:

- Pollution prevention
- Sanitizing the faeces and urine
- Nutrients recycle by using the safe products for agriculture

Ecosan systems can be designed with or without urine diversion, and with or without the use of water for transport of excreta. According to (UNESCO-IHP and GTZ, 2006) the most common strategy applied in the ecosan system is to collect and treat faeces, urine, and greywater separately. That leads to minimize the volume of potable water needed to flush away excreta. In addition, it helps to minimize the energy and cost for waste water treatments and to prevent the pollution of water sources.

(Salifu and Doyen, 2000) state that in Africa rapid urbanization is largely taking place through the expansion of informal and peri–urban settlements. In fact, informal settlements absorb the largest part of urban growth; in the capital cities of the African region they account for 40% to 60% of the city population. Central governments, municipal agencies and utilities have failed to provide water and sanitation services to this segment of the urban poor. Alternatives that involve communities and informal services providers are, generally, inadequate and relatively expensive. Investments in urban sanitation services are wholly inadequate for many countries of the region and poor households of informal and peri-urban settlements which lead to ill health, unfit living conditions and lost opportunities.

According to (UNEP-IETC, 2005) Latin America area is extremely rich in water resources: the Amazon, Orinoco, Sao francisco, Parana, Paraguay and Magdalena rivers carry more than 30% of the world's continental surface water. However, two thirds of the region's territory is classified as arid or semiarid area, which includes Peru. Latin America has relatively high service levels but is characterized by large differences from one area to another. The total sanitation coverage is about 75%. In Latin America, about a quarter of the total population lives in water-stressed areas, along the Western coastline of the continent. Some people in Peru also live in this region.

1.1.1. MDGs and this research project

In September 2000, the United Nations (UN) General Assembly adopted the Millennium Declaration (Resolution 55/2) to crystallise the agenda of human development. International goals – the Millennium Development Goals (MDGs) were thus set, namely:

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat HIV/AIDS, malaria and other diseases
7. Ensure environmental sustainability
8. Develop a global partnership for development

MDG 7 is to ensure environmental sustainability. One of its targets is directly related to this research: "Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation”. In addition to that, this research is indirectly related to MDG 1 (eradicate extreme poverty and hunger) and MDG 4 (to reduce child mortality).

(SEI, 2005) states that the progress has been far from uniform across the world - or across the MDGs. There are huge disparities across and within countries. Within countries, poverty is greatest for rural areas, though urban poverty is also extensive.

1.1.2. SWITCH project and this research project

“The SWITCH project aims to achieve a paradigm shift in urban water management to get sustainable, healthy and safe urban water systems” (SWITCH, 2006).

The SWITCH project, which began in February 2006 and runs over 5 years, is divided in 6 main thematic areas, which all have research, training and demonstration components. The main thematic areas are:

1. Urban water paradigm shift
    - 1.1 Development of a strategic approach and of indicators for sustainability and risk assessment
    - 1.2 Modeling of urban water systems and the development of a decision support system
    - 1.3 Integration of existing infrastructure
    - 1.4 Strategic planning, implementation and performance assessment

2. Storm water management
   - 2.1 Technological options for storm water control under conditions of uncertainty.
   - 2.2 Decision-making processes for effective urban storm water management.
   - 2.3 Environmental change studies for storm water control and reuse options.

3. Efficient water supply and use
   - 3.1 Demand management for optimization of urban water services.
   - 3.2 Safe water reuse
   - 3.3 Urban water supply and use - other productive reuses

4. Water use in sanitation and waste management
   - **4.1 Eco-sanitation and decentralized waste water management in an urban context**.
   - 4.2 Management of industrial emissions

5. Urban water planning
   - 5.1 Urban Waterscapes - Planning and development in urban transformation processes
   - 5.2 Use of urban water (fresh and wastewater) for urban agriculture and other livelihood opportunities
   - 5.3 Maximizing the use of natural systems in all aspects of the municipal water cycle

6. Governance and institutions
   - 6.1 Governance for integrated urban water management
   - 6.2 Learning alliances
   - 6.3 Optimizing social inclusion
   - 6.4 Financing, cost recovery and institutional models

This research focuses on the sub theme 4.1- Eco-sanitation and decentralised waste water management in an urban context. This sub theme is directly linked with some other sub themes, which are:

- Demand management for optimization of urban water services (3.1)
- Use of urban water (fresh and wastewater) for urban agriculture (5.2)

The SWITCH project includes a number of demonstration activities, to be carried out in nine identified SWITCH Demonstration Cities (refer Appendix 1 for definition). The demonstration cities are: Hamburg, Birmingham, Lodz, Zaragossa, Tel Aviv, Alexandria, Accra, Beijing and Belo Horizonte (SWITCH, 2006).

The identified study cities (refer Appendix 1 for definition) by the SWITCH project are the Ruhr area in Germany, Bogota and Cali in Colombia and Lima in Peru (SWITCH, 2006).

Accra in Ghana from out of nine demonstration cities and Lima in Peru out of four study cities are selected as case study cities for this research because:

- They are developing countries
- They have urban agriculture potential
- There is a sanitation crisis (low level of MDG achievement)

I have selected two cities to be able to make comparisons between the two cities.

There are 32 partners worldwide in the SWITCH project while UNESCO-IHE plays a leading role. The SWITCH project budget, which is funded by the European Union, is about 25 million Euros over 5 year running period.

1.2. Problem Description in selected cities

1.2.1. Main identified problems in Accra, Ghana

The main identified problems by SWITCH researchers related to the research topic (sub-theme 4.1) are lack of access to safe sanitation especially in poor areas, pollution of water bodies due to inadequate treatment and poor sanitation, and polluted wastewater use in agriculture. Further details are provided in Section 3.1.

1.2.2. Main identified problems in Lima, Peru

The main problems and issues identified by SWITCH researchers in Lima are its arid climate, not sufficient water for human use, competition between water users, and alternative sources of water for agriculture use in the city. Further details are provided in Section 3.2.

1.3. Goals and objectives

The overall goal of the study is to contribute to objectives of sub-theme 4.1 (refer Appendix 1) of the SWITCH project. The specific objectives of this research are to:

- Analyse and compare the existing sanitation situation (and related aspects) for the selected cities Accra and Lima.
- Apply a suitable selection process (based on literature review) to assess the sanitation system options for one city (Accra) and determine the most suitable option by carrying out conceptual design and cost analysis (one for a conventional system and one for an ecosan system).
- Develop a methodology for multi-criteria analysis to critically compare the different parts of sanitation systems (from generation to reuse).
- Analyse implications for MDG achievement for Accra and Lima.

1.4. Scope of the research

This MSc research is focused on comparing possible sanitation systems for excreta management in urban and peri-urban areas considering the effect of the sanitation systems on urban agriculture. Greywater management is only included as a side issue due to time limitation.

The scope of this research excludes sanitation for rural areas, industrial wastewater management, and solid waste management in urban and peri-urban areas.

This MSc research was jointly funded by the Water Mill Project (the scholarship programme arranged by the Dutch government for students in developing countries for higher studies in water sector with an emphasis on analysing the MDG’s) and the SWITCH project (FP6 programme of European Union No. 018530).

1.5. Research Methodology

1.5.1. Approach

This MSc research was carried out as a desktop study, which consisted of 3 phases:

Phase1: Describe in detail existing situation (and related issues) for Accra and Lima
The following information was collected and analysed (not all the desired data was available):

- Existing sanitation systems (handling and disposal) for different areas within the city
- Existing situation of water supply
- Income of the people/their living conditions
- Land utilization (population density, open spaces in the city level)
- Details about urban agriculture including wastewater reuse and use of excreta and urine as fertilizer (or commercial organic or inorganic fertilizer use)
- Population data in the urban and peri-urban areas
- Cost for existing sanitation options
- Institutional arrangement, policies, and strategies available

Phase 2: Continue literature review from MSc proposal phase
In this phase I expanded the literature review on

- Urban agriculture
- Methods for comparing sanitation systems

Phase 3: Data processing and analysis (for Accra only)[1]
In this phase, the following steps were carried out:

- Describe briefly the possible sanitation systems for Accra Metropolitan Assembly (AMA)
- Short-list two possible sanitation systems for AMA
- Develop a concept design (including cost estimate) for two sanitation systems (one conventional and one ecosan)
- Apply multi-criteria analysis to select most suitable (best) option (five experts were used, for details see Section 5.5)
- Analyse MDGs achievement status for two cities (current and projected future)

1.5.2. Sources of information

The following sources of information have been used:

- Reports/papers published by SWITCH project and the project partners
- Reports published by relevant organizations (for example: WHO, IWMI, UNICEF, SEI etc.)
- Library (IHE / TU) books
- Internet web sites (for example: SWITCH, Sandec, Ecosanres etc.)
- References found via database searches such as Science Direct and Google scholar
- Ecosanres discussion forum (ecosanres@yahoogroups.com, archive and postings)

[1] Originally, I wanted to include both cities, but in the end, I focussed on Accra only because of the lack of available data for Lima.

- E-mail contacts with SWITCH researchers and resource persons from Accra and Lima - namely: Adriaan Mels from Wageningen University (Adriaan.Mels@wur.nl), O. Cofie from IWMI (olufunkec@gh.iwmi.org) for Accra and Juan Carlos Calizaya from CENCA (jcarloscenca@terra.com.pe) for Lima

It was difficult for me to collect data in Lima because of the language barrier (Spanish). A colleague (Jaime Vergas) carried out some translations for me.

2. Literature Review

2.1. Methods for comparing sanitation systems

2.1.1. Sustainability criteria for selection of sanitation systems

"The sanitation approach should be resources minded not waste minded and also should provide needs of present generation without hindering that of future generation" (Winblad and Simpson-Hebert, 2004).

(Kvarnström and Petersens, 2004) describes two main functions to be considered while selecting sustainability criteria. Primary functions include hygiene, environmental protection, and resource conservation. Secondary functions include user friendliness, reliability, and affordability. Indicators are used to measure the sustainability of the aspects selected.

The main comparing criteria are:
- Social-cultural aspects
- Technical and performance aspects
- Economic and financial aspects
- Physical environment aspects
- Health aspects
- Institutional, policy, and legal aspects

Refer Appendix 2 and MCA sheets in Appendix 10 for further details.

2.1.2. Multi-criteria Analysis (MCA)

2.1.2.1.General overview

"Multi-Criteria Analysis is a decision-making tool developed for complex multi-criteria problems that include qualitative and/or quantitative aspects of the problem in the decision-making process" (Mendoza *et al.*, 1999).

The authors further describes that the MCA tool can help to evaluate the relative importance of all criteria involved, and reflect their importance in the final decision-making process. When using MCA, the involved members do not have to agree on the relative importance of the criteria or the rankings of the alternatives. Each member enters his or her own judgments, and makes a distinct, identifiable contribution to a jointly reached conclusion.

The advantages of MCA, according to (NERA, 2006) are as follows:
- Internal consistency and logical soundness
- Transparency
- Ease of use
- Ability to provide audit trail for used scores and weights
- Performance measurements can be subcontracted to experts
- Software availability

The identified disadvantages in MCA are not totally objective and reproducible.

2.1.2.2.Theory behind MCA

According to (Mensah *et al.*, 2001), the main criteria in the MCA technique are ranking and rating. The ranking involves and reflects the degree of importance relative to the decision being made. The decision elements can be ordered according to their ranks, for example, first, second etc. Rating is somewhat similar to ranking, but decision elements are assigned scores between 0 and 100. The scores of all elements (criteria) being compared should add up to 100.
The ranking can be assessed as follows:

- **0**- Not applicable criteria or indicator
- **1-** Extremely weak performance; strongly unfavourable
- **2-** Poor performance; unfavourable
- **3**- Acceptable; good operations in the region
- **4**- Favourable performance
- **5**- Very favourable performance

2.1.2.3. Assessment requirements

The assessment requirements according to (Mensah et *al*., 2001) are:

- The criteria and indicators used must cover the full range of study cases
- The information used to assess sustainability includes both qualitative and quantitative data.
- The assessment of sustainability must involve the participation of multiple interest groups, stakeholders and experts.
- Decision-making requires agreement amongst the various interest groups

2.1.2.4. Analysis procedure

The analysis procedure for one expert is indicated below according to (WasteNet, 2005):

- Identify the alternatives to be compared
- Identify the set of criteria for comparing the alternatives
- Identify the relative importance of each criterion (weighting)
- Score the alternatives against each criterion
- Multiply the score by the weighting for the criterion
- Add all the scores for a given alternative and rank the alternatives by their total score.

For combination of results from several experts:

- Enter all data into one spreadsheet
- Calculate the sum of experts vote for each criterion for both ranking and rating
- Combine the results of ranking and rating
- Calculate the final combined weight for each criterion
- Average the calculated weights for both ranking and rating

In this MSc thesis, five experts have carried out the scoring of alternatives and the calculations for the combined MCA are explained in Section 5.5.

2.1.3. Analytical Hierarchy Process (AHP)

2.1.3.1. General overview

As described by (Bailey, 2004) AHP is a scientific decision making tool, which is applied through computer software Expert Choice (EC) and it identifies twenty main criteria/parameters before establish the wastewater treatment and sludge treatment plants. They consist of flow, influent/effluent, size of site, nature of site, land cost, local money for construction, foreign money for construction, local skills for construction, community support, power source, availability of local materials, cost for operation and maintenance, professional skills available for operation and maintenance, local technical skills available for operation and maintenance, administration set up, training, professional ethics, climate, local waterborne diseases, and endemic vector-borne diseases.

2.1.3.2. Theory behind AHP

According to (Bailey, 2004) in AHP analysis, the parameters/criteria are compared in a pair-wise fashion to rate each alternative. Firstly, it determines relative importance of each criterion compared to all other criteria. Then each alternative is compared to each alternative concerning each criterion. This procedure makes the weight matrix and a rating matrix for each criterion. Finally, eigenvectors are used to determine the contents of each matrix ratings and eigenvalues are used to test the inconsistencies of the judgments.

2.1.3.3. Assessment requirements

AHP is a decision making tool suitable for identifying a single preferred alternative although the mathematics behind it are complex. It is easy to compare the criteria and alternatives pair-wise. AHP requires a very large number of judgments. Therefore, it is difficult to apply in many alternatives and criteria and to achieve sufficient consistency of input.

2.2. Definitions for urban, peri-urban, slum area, and metropolitan areas

2.2.1. Definition of urban areas

An urban area is an area with an increased density of human-created structures in comparison to the areas surrounding it (Wikipedia, 2006c). It further explains that an urban area is normally called a city or town and that the definition is different from nation to nation. (Wikipedia, 2006c) defines the minimum density requirement for urban area to be generally 400 people/km^2. Table 2-1 shows the different definitions given by different countries or organizations for the term “urban area”.

Table 2-1: Definitions for urban areas

Country/ Organization	Population density		Minimum population	Reference/ comments
	People/km[2]	people/ha[2]		
US Census Bureau: • Core census block groups • Surrounding census block groups	 386 193	 35,800 19,300		Wikipedia, 2006c
Canada	400	40,000	1,000 or more	Canada, 2006
Japan	4,000	400,000		Wikipedia, 2006c
ODPM			10,000 or more	(ODPM, 2004) all settlements above 20 ha
UN: • Zambia/Botswana in Africa • Ethiopia/Liberia in Africa • Senegal in Africa • Peru in North America • Venezuela • Bolivia and Argentina			 5,000 or more 2,000 or more 10,000 or more 100 or more dwellings 1,000 or more 2,000 or more	UNStats, 2001 75 % of economic activates are non-agricultural
European countries	• area based on urban-type land use, not allowing any gaps • use satellite photos instead of census blocks to determine the boundaries of the urban area - Wikipedia, 2006c			

2.2.2. Definition of peri-urban areas

The term "peri-urban area" cannot be easily defined or delimited through unambiguous criteria. It is a name given to the grey area which is neither entirely urban nor purely rural in the traditional sense; it is at most the partly urbanized rural area (Iaquinta and Drescher, 2000).

(FAO, 2006) states that the territory included within official city boundaries varies enormously across countries and the distinction between "urban" and "peri-urban" depends on the population density, types of inhabitants, and patterns of land uses.

The peri-urban area is characterized by strong urban influences and demand, easy access to markets, services, and other outputs, but a relative shortage of land and risks of

[2] 1 ha = 10,000 m^2 = 0.01 km^2

pollution and urban growth (Drechsel *et al.*, 2006b). The report further describes the characteristics of peri-urban area as:

- Dynamic in space and time moving from rural to urban
- Increasing competition for land and water between agricultural and non-agricultural uses, and rural and urban dwellers
- Increasing opportunities and competition for farm and off-farm jobs
- Increasing dependence on the urban centre (market and jobs)
- Increasing number of female-headed households when males assume urban jobs
- Increasing water pollution and waste disposal problems
- Changing economic and social balance between indigenous and immigrant inhabitants

The impacts of economic growth and physical expansion of the urban area are not confined within urban boundaries; they reach into much wider areas surrounding urban centres, creating so-called "urban areas", "urban fringe areas", or "peri-urban areas". While the peri-urban area retains the characteristics of the rural area, these are subject to major modifications. These changes take place with respect to physical configuration, economic activities, and social relationships.The characteristics of peri-urban areas described in (Iaquinta and Drescher, 2000) are:

- The movement of people from rural to urban places where they engage primarily in non-rural functions or occupations - the important variables due to this movement: population density and economic functions,
- The change in life style from rural to urban with its associated values, attitudes and behaviours - the important variables due to this change depend on social, psychological and behavioural factors.

(Drechsel *et al.*, 2006) report that in Kumasi (Ghana) a 40 km radius from the city centre was used to define the peri-urban zone. The report further explains that in Ghana the rural-urban interface (peri-urban area) is to be 30 – 40 km from urban centers with larger distances along major roads and much shorter distances[3] from where the road network is limited.

Peri-urban areas can be low-income and or slums (see Section 2.2.3 for definition of slums) but they can also be an area where wealthy people live. The definition of “peri-urban” does not include a statement on poverty levels.

2.2.3. Definition of slum areas

According to (UN-Habitat, 2003) a “slum” includes informal or squatter settlements which are illegal or unsanctioned subdivision of land at the periphery by squatters. Housing units are constructed usually without formal permission of landowners and materials used are not compatible with the local building codes. These dwellings vary from the simplest shack to permanent structures. Most slums in developing countries fall in to this category. The main features identified in slums are insufficient living area, undurable housing conditions, lack of access to improved water and sanitation systems, and lack of access to their tenure.

According to (Shoju, 2004), a slum area can be described as an unsafe area to live for human beings. Living in a slum often means being an illegal resident. Therefore, slum dwellers are not eligible to access basic public services such as water supply and

[3] Does not define how much distance

electricity. Most of the time, sanitation, sewage disposal and garbage collection systems are not organized or managed. Poor people living in slum areas moved there searching for economic opportunities, or because they are refugees.

(Shoju, 2004) also describes the characteristic of locations of slums – the poorest dwellings – as follows:

- On public land along streets, railroads or water ways
- In the lowest parts of settlements, along rivers and canals, situated in flood prone areas
- Isolated from access to public basic services networks including roads, water and power supply, street lighting, sewerage and drainage
- Some areas with very high health hazards such as above sewerage outlets, near or on dump sites
- Areas with no access such as alleys and corridors of buildings or on rooftops

Slum areas can exist in urban areas as well as in peri-urban areas. "In sub-Saharan Africa, 70% or more of city populations are living in slums. The Kibera area in a suburb of Nairobi, Kenya, is the largest of many slums surrounding the capital city centre. Its population is said to be over 800,000 (Shoju, 2004)".

2.2.4. Definition of metropolitan areas

(UNHSP, 2004) states that a metropolitan area is defined as a politically defined urban area for planning or administrative purposes which combines all local jurisdictions normally regarded as part of the greater urban area.
(Wikipedia, 2006a) defines that a metropolitan area is a large population center consisting of a large city and its adjacent zone of influence, or of several neighboring cities or towns and adjoining areas, with one or more large cities serving as hubs. A metropolitan area usually combines an agglomeration [4] with peripheral zones not themselves necessarily urban in character, but closely bound to the centre by employment or commerce.

2.3. Technology options for low cost sanitation in urban and peri-urban area

Sanitation consist of four elements:

- Excreta management
- Greywater management
- Solid waste management
- Rainwater drainage

This thesis focuses only on excreta management. Greywater management is only described as a side issue in Chapter 3 and 4 but not included in the remaining chapters.

In centralised sanitation systems, wastewater including faeces is transported through sewers to treatment plants or any other places where they are disposed. Centralised systems are not considered further in this thesis because they are not considered as a low cost solution for urban and peri-urban areas, some of which extend over large areas with

[4] the contiguous built-up area

relatively low population densities. Refer Appendix 3 for disadvantages of centralised (off site) sanitation systems.

2.3.1. Conventional on-site sanitation systems for excreta management

As summarised in (Münch, 2006), several types of conventional on-site sanitation systems for excreta management can be distinguished[5] (these are approximately in ascending order of cost of toilets):

- **Open defecation:** If there is no access to any type of toilet, this is the only possible way for excretion. When rain occurs, water flushes faecal matter into receiving water bodies which leads to severe public health risk. This type of sanitation does not qualify as basic sanitation and is not included in MDG achievement calculations.
- **Bucket latrines:** This system also does not qualify as basic sanitation. This system is a dry toilet, because the system requires no water to flush wastes. It consists of a simple collection system such as a bucket, shallow pit or chamber (Franceys et al., 1992). This container is generally placed on the floor either indoors, or in a small vault under the base of a latrine superstructure. The vessel must be periodically emptied with proper handling techniques to minimize contact with faecal waste. Often these collection systems are associated with health hazards and considered as physically, socially and culturally unacceptable.
- **Simple pit latrines:** This type of toilet is common in rural and low income areas because of a low population density. This toilet is not an appropriate system if the area is prone to flooding, has a rocky ground, or bad soil condition (sandy soils). More details are shown in Table 2-2. Open pit latrines or public toilets do not count as basic sanitation, but pit latrines with a slab do count.

Table 2-2: Advantages and disadvantages of simple pit latrine (Nadkarni, 2004)

Advantages	Disadvantages
Less chance for transmission of excreta-related diseases than open defecation	There is some risk of infection during adverse condition like high ground water or heavy rains. A big problem is flies which may transmit pathogens from faecal matter to food etc.
Affordable, can be as cheap or expense, as the owner wants it to be. Appropriate for low income families	Odour
Simple technology	Risk and fear of falling into pit, especially for children.
The pit can be cleaned out after a while and the content can be used as fertilizer after composting (not usually practised)	Risk of groundwater and surface water contamination
Aesthetically better than open defection	Will need some space outside the dwelling which may be difficult to find
Construction materials are mainly local materials	If not emptied, once pit is full the latrine has to be moved to another location

[5] Greywater management systems need to be designed separately except for the pour flush latrine.

- **Ventilated improved pit latrines (VIP):** This is very similar to the simple pit latrine except of a special vent pipe. The main problems (odour and fly breeding) of the ordinary pit latrine are reduced by the VIP design. This type of toilet can be constructed as double pit or single pit. The main advantages and disadvantages are shown in Table 2-3.

Table 2-3: Advantages and disadvantages of VIP latrine compared to pit latrine

Advantages	**Disadvantages**
Encourages air circulation to reduce odour and fly breeding problems	Slightly more complicated construction, especially if double pit is used
Better reuse option if double pit design is used	

- **Pour flush latrines (with pit or septic tank and soak away):** A few litres of water are poured into the toilet to flush the excreta into the pit or septic tank. The water seal in the bowl is useful to avoid odour and flies entering. The typical problems with the septic tank and soakaway pit are sludge overflowing, undersized tank, leaking tank, need for regular emptying, and need for faecal sludge management. Refer Table 2-4 for advantages and disadvantages.

Table 2-4: Advantages and disadvantages of pour flush latrine {(Mack, 2006) and (Nadkarni, 2004)}

Advantages	**Disadvantages**
Suitable for communities where anal washing is the common practice	Requires sufficient water supply for proper operation and maintenance
Highly convenient for user	Tendency for blockages
Design reduces the need to handle excreta	Requires appropriate infrastructure to manage wastewater (treatment plants)
Familiar to the community, thus likely to be maintained, and requires less education about operation and maintenance.	Below ground pits increase the risk of groundwater contamination
Minimal odour and no fly problems when maintained correctly	Pathogens mix with water spread over a large volume
Can be used indoors	Technical support required during installation.
	High initial cost

- **Aqua-privy:** An aqua-privy has a watertight tank immediately under the latrine floor. Excreta drop directly into the tank through a pipe. The bottom of the pipe is submerged in the liquid in the tank, forming a water seal to prevent escape of flies, mosquitoes and odour. Effluent usually infiltrates into the ground through a soakpit. Enough water must be added to compensate for evaporation and leakage losses. Refer Table 2-5 for more details.

Table 2-5: Advantages and disadvantages of aqua-privy latrine (Franceys et al., 1992)

Advantages	Disadvantages
Does not need piped water on site	More expensive than VIP or pour-flush latrine
Water must be available nearby less expensive than a septic tank	Fly mosquito and smell nuisance if seal is lost because insufficient water is added
	Regular desludging required and sludge needs careful handling
	Permeable soil required to dispose of effluent

2.3.2. Ecosan systems for excreta management

Ecosan stands for "ecological sanitation" and means sustainable sanitation systems (in all aspects). It may include urine diversion or it may be without urine diversion. It is a paradigm, not a specific technology.

The main piers of the ecosan approach are: recycle and reuse the urine and faeces which contain valuable nutrients for agriculture, and prevention of pollution of water bodies. "This approach is a sustainable closed loop system" (Winblad and Simpson-Hebert, 2004). The composition and volume of urine, faeces, and greywater expressed per adult per day are given in Table 2-6.

Table 2-6: Composition and volume of urine, faeces, and greywater per capita per day (Gumbo, 2005)

Parameter	Unit	Urine		Faeces[6]		Greywater	
		Value	Range	Value	Range	Value	Range
Volume	l/cap/d	1.2	0.6-1.5	0.15	0.07-0.4	150	50-300
Weight[7]	g/cap/d	1200	600-1500	150	70-400	15000	5000-30000
Total solids	g/cap/d	60	20-150	45	30-60	80	40-150
Total nitrogen	g/cap/d	11	4-16	2	1-4	1	0.2-1.5
Total phosphorus	g/cap/d	1	0.5-2.5	0.5	0.1-1.5	0.2	0.1-0.4
Potassium	g/cap/d	2.5	1-5	0.5	0.2-1.2	2	1-4
BOD_5	g/cap/d	7.5	2-14	14	6-18	28	10-40
COD	g/cap/d	15	4-28	35	20-55	60	30-90

According to (Ecosanres, 2005), excreta output varies by size of the person (adults vs. child), type of diet (vegetarian vs. meat), climate, and life style, but the proportion of nutrients and water excreted remains roughly the same regardless of the total output. 80% of total nitrogen is excreted in urine and there is 5-7 times more nitrogen in urine than in faeces. Urine contains 2/3 of excreted phosphorus and up to 80% of excreted potassium. Other nutrients, such as calcium and magnesium, are excreted in nearly equal amounts in urine and faeces. Faeces have nearly four times as much carbon than urine.

[6] Values exclude flush water. Flush water volume ranges from 15 to 80 l/p/d with an average value of 30 l/p/d
[7] Density assumed to be 1.0 kg/L

2.3.2.1. Benefits of ecosan systems

According to (Esrey *et al.*, 2001), ecosan can be defined as a closed loop system that:

- Prevents disease and promotes health
- Protects the environment and conserves water sources
- Recovers and recycle nutrients and organic matter

Prevents disease and promote health:

Linear sanitation systems with inadequate wastewater treatment (as it is common in developing countries) can cause many health problems (Figure 2-1). Those most affected are poor people - children, women, men living on marginal urban, peri-urban, rural areas and slums – in an environment contaminated with pathogens. People who use contaminated water and who live at risk of exposure to pathogens, have an increased risk of dying and malnutrition.

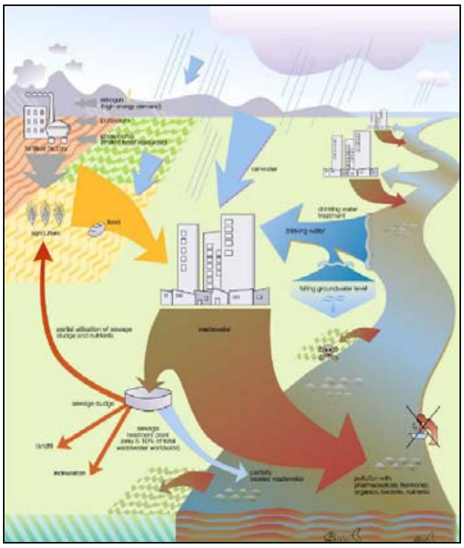


Figure 2-1: Linear sanitation (conventional) system can cause problems (UNESCO-IHP, 2006)

There can be a vicious cycle of infection (See Figure 2-2). Safe excreta management and quick destruction of pathogens before excreta enter the environment is achieved by ecosan systems.

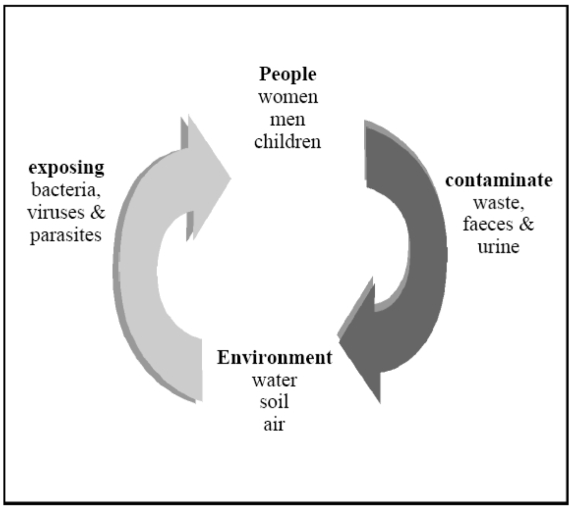


Figure 2-2: Vicious cycle of infection (Esrey et al., 2001)

Protects the environment and conserves water sources:
The disposal of human excreta to water bodies can cause severe pollution. This can destruct the marine life, cause declining fish populations, and reduce a major source of protein for human consumption. In addition, losses of biodiversity on land and in water are some possible consequences (Esrey *et al.*, 2001).

But in closed loop systems of ecological sanitation, excreta are not added to the water bodies. They are first sanitised and then reused on soil. Therefore, ecosan systems conserve the water sources.

Recovers and recycle nutrients and organic matter:

Ecological sanitation can recover and recycle the nutrients in excreta to grow crop. This system helps to reduce the risk of contaminated pathogens by sanitising excreta prior to reuse. It recycles nutrients back into land for productive purposes (see Figure 2-3).

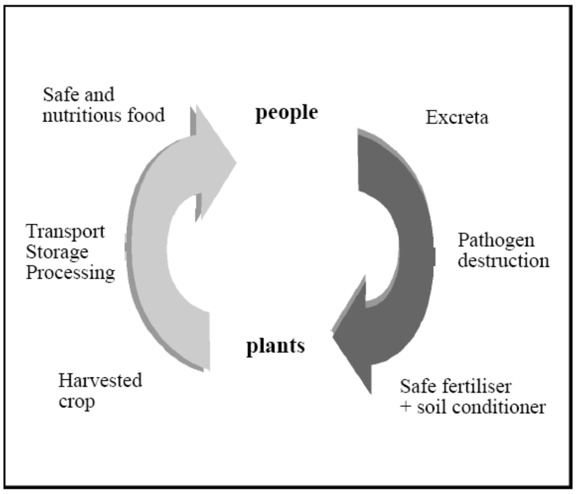


Figure 2-3: Recycling of excreta for food production (Esrey et al., 2001)

2.3.2.2. Types of toilets used in ecosan systems

(Winblad and Simpson-Hebert, 2004) describes what types of urine diversion (UD) toilets can be used in homesteads and municipal areas.
Homesteads[8]:

- **Dehydrating UD double vault toilets:** The toilet consists of two chambers: people excrete in only one chamber until it fills. Before first use of the toilet, the vault is covered with powdered earth to prevent excreta sticking to the floor and after each use people use ash to cover the faeces. One vault (0.3 m^3) can be used for about 4-5 months by a household of 4-6 people. Vietnamese people use this type of toilets for more than 25 years by now. Urine is collected in a jar behind the toilet. They use sanitised excreta and urine as a fertilizer.
- **Adaptations for "washers":** The Vietnamese toilet has been redesigned to suit "washers" (who use water for anal cleaning) in India and Sri Lanka. In this type of toilet, urine and water used for anal cleaning is diverted together and stored so that they can be used as fertilizer.
- **Composting toilets:** Mostly used in Sweden, Norway, and Mexico. It may be a single-vault or double-vault type composting toilet.

[8] "Homestead" means the house with surrounding land and buildings.

Municipal area:

- **Double-vault dehydrating UD toilets:** Mostly used in Mexico, Central America, Sweden, and China in urban and peri-urban areas.
- **Long-drop dehydrating UD toilets:** Used in Yemen, Sweden, and China (urban areas in multi-storey apartments).
- **Small flush – composting/biogas toilets:** Used in Sweden and Germany in multi-storey apartments in urban areas. Faeces are collected separately from flush water and urine. Later both faeces and urine are used as fertilizer.

The advantages of UDD toilets according to (Winblad and Simpson-Hebert, 2004) are:
In general

- Destroy the pathogens by adding lime, ash, and drying at the point of source
- Soil structure rebuilding by adding valuable nutrients from excreta and urine
- Suitable for emergency situations (Mwase, 2006)
- Save money and generate income by using sanitised excreta and urine as a natural fertiliser in agriculture

Compared to pit latrines

- Suitable for waterlogged and high water table areas
- Suitable for ground too rocky to dig holes
- Much less or no smell compared to pit latrines
- Suitable for areas prone to flooding
- Pollution prevention of ground water
- Prevention of fly and mosquito breeding

Compared to water flush toilets

- Enhance the water security
- Water saving because no water usage for toilet flushing
- No need for sewers to transport black water[9]
- Pollution prevention of surface water bodies

"Eco-toilets are just one component in the ecological approach to sanitation" (Calvert, 2004). According to his view there are two main types of "eco-toilets": desiccating/ dehydrating (due to use of dry ash, soil, lime or similar product just after defecation) and composting which is aerobic decomposition.

Double or single vault type toilets are available at low cost or as luxurious types to suit poor and rich as well as urban and rural areas (refer Figure 2-4 and Figure 2-5).

The term "eco-toilet" used by (Calvert, 2004) is not used in this thesis. What he calls "eco-toilet" is called by other authors a "dry toilet". "Dry toilet" is also misleading because urine is not dry and water may be needed for anal cleaning. In this thesis, I use the term "dehydrating toilet" instead.

[9] But a separate system for greywater treatment has to be installed.

Figure 2-4 Urine diversion water flush toilet by Roediger, Germany (left) and waterless urinal by Keramag, Germany (right) –"luxurious types" of UD toilets (UNESCO-IHP and GTZ, 2006)

Figure 2-5: Dehydrating chamber with two faeces containers and urine collection – low cost version (UNESCO-IHP and GTZ, 2006)

(Morgan, 2004) explains the simple types of "ecological toilets" used in Africa as summarised below.

Arborloo toilet: This is the simplest type of toilet without urine diversion. The toilet pit is shallow and the tree is planted there later. The pit consists of humus formed by the excreta and wood ash or leaves added by the users. But this type of toilet is only suitable for rural areas since it needs a lot of space (Figure 2-6). It could be used in peri-urban areas if space is available.

Figure 2-6: Arborloo - leave the contents, move the "loo"[10] and plant a tree (Esrey et al., 2001)

[10] Super structure of the toilet

Fossa Alterna: This is also a simple type of "ecological toilet" used in Africa. The Fossa alterna type is built with two permanent pits which can be used alternatively (no urine diversion), see Figure 2-7.

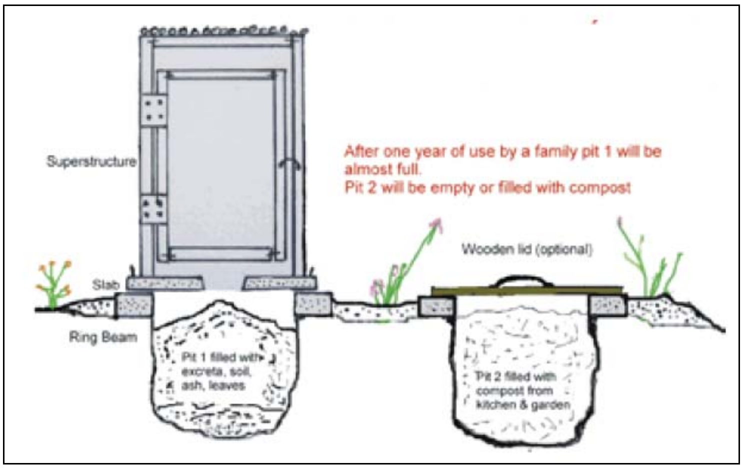


Figure 2-7: The Fossa Alterna after one year of use (SEI, 2005)

This type of toilet is suitable for higher density areas than the Arborloo because it occupies a relative small space (2.5 m x 1.5 m). The contents in the chamber can be easily removed without offensive smells, and put to productive use, stored in bags and sold, or mixed with top soil and added to tree pits, trenches or buckets for growing vegetables (Esrey *et al*., 2001). Figure 2-8 shows planting spinach with using processed excreta from one family using a Fossa Alterna toilet in Zimbabwe.

The main disadvantages in this type of toilet according to (Esrey *et al.*, 2001) is that the pits should be lined to avoid rain entering or excessive moisture to the pit, chamber contents should be stored for at least 4 months and should not be allowed to overflow (necessary empting each pit periodically).

Also, the nitrogen in the urine is lost and could reach the groundwater. Since this toilet can not be built indoors, it is not suitable for urban applications.

Figure 2-8: Planting spinach with using processed excreta from one family using Fossa Alterna toilet in Zimbabwe (SEI, 2005)

The range of available toilet types which can be used within an ecosan project is shown in Table 2-7.

Table 2-7: Range of available toilet types that can be used in ecosan projects in ascending order of water use per day (Münch, 2006)

Toilet type (F-faeces, U-urine)	UD [11] or not	Description	Example
Dry mixed	No	Faeces + Urine mixed, No flush	Conventional pit latrine, VIP latrine, composting toilet
Dry F / dry U[12]	Yes	Faeces without flush, Urine without flush	Urine diversion dry toilet, waterless urinals
Dry F / wet U	Yes	Faeces without flush, Urine with flush (mini flush)	Wost-Man, Sweden (urine diversion toilet)
Wet mixed (Vacuum)	No	Faeces + urine mixed, vacuum system (very low flush)	Roediger, Germany, vacuum toilet need about 1 litre per flush
Wet F / dry U	Yes	Faeces with flush, Urine collected without flush	Roediger, Germany, urine diversion water-flush toilet
Wet F / wet U	Yes	Faeces with flush, Urine with flush	Dubletten, Sweden, urine diversion water-flush toilet
Wet mixed (conventional)	No	Faeces + urine mixed, big flush	Standard flush toilet, about 10 litre per flush

After reviewing all the different toilet classifications described in the literature, I prefer the classification shown in Table 2-7.

To overcome the water and sanitation problems in urban and peri-urban areas in developing countries, ecosan systems can be a suitable option. On the other hand to recycle the nutrients to the soil will be helpful for improvement of urban agriculture yields in a sustainable manner.

2.3.2.3. Processing of human excreta in ecosan approach

(Esrey *et al.*, 2001) states that the urine, faeces, and a combination of urine and faeces can be processed (for pathogens destruction) in a number of different ways. It may be useful to categorise the processes according to urine diversion and non-urine diversion. In urine diversion toilets, faeces are kept separate from urine. Urine can be diluted and applied directly to soil, or stored underground in storage tanks prior to applying it to soil. Either way, it is desirable to preserve the nitrogen in urine, keeping it in a form that is usable by microorganisms and not letting it escape as a gas into the atmosphere.

The urine fraction is normally free from pathogens when leaving the body. Urine collected from different households should be stored for between one and six months, depending on the crop to be fertilised and the storage temperature, before application to the soil (Ecosanres, 2005). When single households use their own urine as a fertiliser, there is no need to store prior to apply.

[11] With urine diversion or not
[12] Often wrongly called “ecosan toilet”

According to (Ecosanres, 2005), urine should be stored in a sealed tank or container to prevent human and animals being exposed to the urine and to hinder evaporation of ammonia in order to decrease the risk of odour and loss of nitrogen. Concentrated urine provides a harsher environment for microorganisms and increases pathogen die-off. Table 2-8 shows more details about storage of urine and recommended crops according to the storing time and temperature.

Table 2-8: Recommended storage time of urine for different temperatures and recommended crops (Schönning and Stenström, 2004)

Storage temperature	**Storage time**	**Possible pathogens in urine after storage**	**Recommended crops**
4°C	>= 1 month	Virus, Protozoa	Food and fodder crops that are to be processed
4°C	>= 6 month	Virus	Food crops that are to be processed, fodder crops
20°C	>= 1 month	Virus	Food crops that are to be processed, fodder crops
20°C	>= 6 month	None (probably)	All food crops that are consumed raw

(Esrey *et al.*, 2001) further states that in non-urine diversion toilets, urine and faeces are mixed. They can remain mixed, in which case they can be composted. However, the carbon to nitrogen ratio in human excreta is not desirable for composting (the mix contains too much nitrogen in relation to carbon). If urine is first mixed with faeces and then separated, the urine may need to be treated prior to soil application. Faeces that have been mixed and then separated from urine will be moist and contain live microorganisms, some of which may be pathogens.

Faeces may contain high concentrations of pathogens (viruses, bacteria, parasitic protozoa, hookworms, helminth eggs etc.). Therefore, faeces should be treated before application to crops. The treatments can be categorized as primary and secondary (Esrey *et al.*, 2001).

- **Primary treatment of faeces:** The purpose of primary processing is to reduce the volume and weight of faecal material to facilitate storage, transport and secondary treatment, and to make further handling safer. During this phase, pathogen levels will be reduced as a result of storage time, decomposition, dehydration, increased pH, and the presence of other organisms and competition for nutrients. Urine is directed away from the faeces to keep the processing chambers dry and the volume small. Ash or lime is added after defecation to lower the moisture content and to raise the pH level, thus creating unfavorable conditions for pathogens, reduce odour, and risk of attracting flies. The material is usually kept for 6- 12 months before secondary treatment.

- **Secondary treatment of faeces:** The purpose of this treatment is to make human faeces safe to return to the soil. Secondary processing can consist of high temperature composting, chemical addition of urea and longer storage times.

Incineration can be used if a completely sterile product is needed. Details for these processes are provided in the Appendix 4.

2.3.3. Fertiliser and soil conditioner values of human excreta

Accoring to (Ecosanres, 2005) the products of ecological sanitation, sanitised faeces and urine, are well suited as a fertiliser because they contain all nutrients essential for crops. The fertilising effect of urine is greater if the soil contains at least some organic matter. Urine is nutrient-rich and faeces are high in organic matter content. They should be used in combination with each other, but not at the same time.

(Esrey *et al.*, 2001) reveals that the three major nutrients used in chemical fertilisers are found in human excreta (i.e. nitrogen, phosphorus, and potassium). In addition, faeces contains valuable organic matter which will act as a soil conditioner (see Figure 2-9).

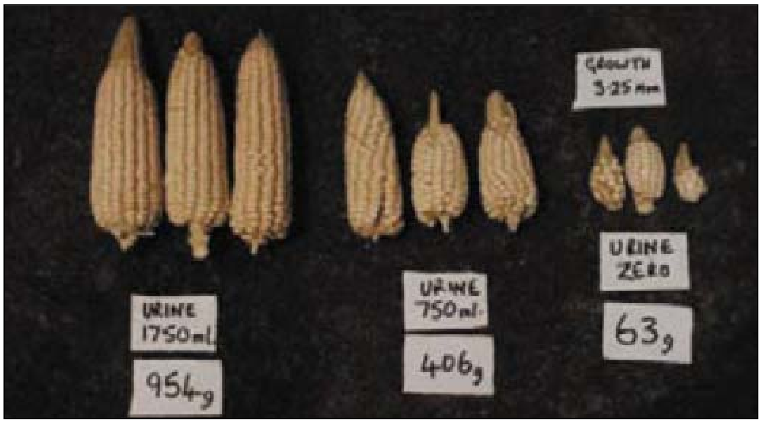


Figure 2-9: Yield of maize increased by using ecosan fertilisers in Zimbabwe (Ecosanres, 2005)

(Asante and Cofie, 2006) explain that fertiliser produced by human excreta contains trace elements [13](copper, boron, iron, chloride, manganese, molybdenum, and zinc) which help to pretect the plants from parasites and diseases. It also promotes the development of small microbes, which converts the minerals to forms that plants can use and improves soil structure. This type of fertilisers increases the crop yield and it helps to alleviate poverty and malnutrition with the advantage of being available "for free" to the farmers. . Table 2-9 shows the comparable fertiliser capacity of urine and faces for production of cereal. Table 2-10 shows comparison of fertiliser value with other types of natural manures. The values are very similar.

Table 2-9: Comparable fertiliser capacity of urine and faeces for production of cereal (Ecosanres, 2005)

Fertilizer	**500 L of urine (urine per capita per year)**	**50 L of faeces (faeces per capita per year)**	**Total**	**Fertiliser needs to produce 250 kg of cereal[14]**
Nitrogen	5.6 kg	0.09 kg	5.7 kg	5.6 kg
Phosphorus	0.4 kg	0.19 kg	0.6 kg	0.7 kg
Potassium	1.0 kg	0.17 kg	1.2 kg	1.2 kg

[13] Which are not always included in chemical fertilisers.
[14] Requirement of one person per year

Table 2-10: Comparison of human excreta fertiliser with other natural manure (% of dry solids) (Nadkarni, 2004)

Type	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Human excreta	9-12	3.8	2.7
Plant matter	1-11	0.5-2.8	1.1-11
Pig manure	4-6	3-4	2.5-3
Cow manure	2.5	1.8	1.4

2.3.3.1. Usage of urine as a fertiliser

(WHO, 2006) states that urine is a quick-acting nitrogen rich complete fertiliser and the fertilising effect is rapid and the nutrients are best utilized if the urine is applied prior to sowing and up until two-thirds of the period between sowing and harvest. It can be applied pure or diluted and this should be done once or twice per growing season. To avoid odour, and the loss of ammonia, the urine should be applied close to the soil and incorporated into the soil as soon as possible.

Figure 2-10 shows the household application of urine as a fertiliser.

Figure 2-10: Household application of urine as a fertiliser (Ecosanres, 2005)

As a general rule of thumb, (Ecosanres, 2005) states that one can apply the urine produced by one person during 24 hours to one square meter of land per growing season (crop). The urine from one person will be enough to fertilize 300-400 m^2 of crop per year and even up to 600 m^2. Urine application before sowing on a large scale is shown in Figure 2-11.

Figure 2-11: Urine application before sowing on a large scale in Sweden (Kvarnström et al., 2006)

2.3.3.2. Usage of faeces as a fertiliser

(Ecosanres, 2005) describes that the total amount of nutrients excreted with faeces is lower than with urine; however, faeces are concentrated and rich in phosphorus, potassium and organic matter. Sanitized faeces should be applied prior to planting or sowing because high phosphorus content is beneficial for root formation of plants. The faeces should be thoroughly mixed in and covered by soil before cultivation starts. In the case of limited amount of faeces fertiliser, it can be applied in holes or furrows close to the plants to capitalise on this valuable asset.

(Esrey *et al*., 2001) states that compost (e.g. by secondary treatment of faeces) improves soil and its fertility. Compost improves soil structure, increases the water holding capacity of soil, moderates soil temperature, breaks up organic matter into basic elements that plants need, releases nutrients at the rate plants need them, neutralises soil toxins and heavy metals, and reduces pests and diseases. It makes soil easier to cultivate, reduces the need for chemical fertilisers and pesticides. Figure 2-12 shows human faeces usage in urban agriculture as a soil conditioner/compost.

Figure 2-12: Trial with human faeces as a soil conditioner used in urban agriculture (Esrey et al., 2001)

(Ecosanres, 2005) also describes that applying sanitised faeces can greatly improve the structure and water-holding capacity of the soil. Additions of ash during primary processing of faeces will improve the buffering capacity and the pH of the soil. The production of faeces from an average person per year (around 50 liters) will fertilize 1.5 – 3.0 m^2 of crop if the application is made according to organic content. If application is instead based on phosphorus content, it will be enough to fertilise 200-300 m^2.

2.3.4. Low – cost greywater management options

Greywater is water from baths, showers, hand basins, washing machines and dishwashers, laundries and kitchen sinks. According to (Morel and Diener, 2006) in urban and peri-urban areas of low and middle-income countries, greywater is currently discharged into stormwater drains or sewers or the ground. This inadequate greywater management is linked to public health risk and environmental degradation such as oxygen depletion, increased turbidity, eutrophication as well as microbial and chemical contamination of receiving water bodies.

Greywater reuse in agriculture can reduce agricultural use of drinking water and can increase food security. Therefore, greywater management is very essential. However because of the time constraints I was not able to expand this section.

3. Review of existing sanitation situation in Accra and Lima

3.1. Accra, Ghana

3.1.1. Introduction

The total estimated population and population density of Ghana in 2006 according to (CIA, 2007) are 22.4 million and 0.94 people/ha respectively. The estimated population growth rate in 2006 is 2.07% per annum. The total area of Ghana is 239,460 km^2 and 3.5% of it is water. Arable land area in Ghana is 17.54% of the total area (42,000 km^2). Accra is the capital city of Ghana, which is a West African (English speaking) country (see Figure 3-1). AMA covers an area of about 200 km^2 and is the most urbanized city in Ghana. It has a population of 1.6 million and a population density of 83 people/ha (RUAF, 2006). The urbanization has been mainly due to the rapid increase in population as a result of the concentration of industry, manufacturing, commerce, business, education, and administrative functions (see Figure 3-2 and Figure 3-3).

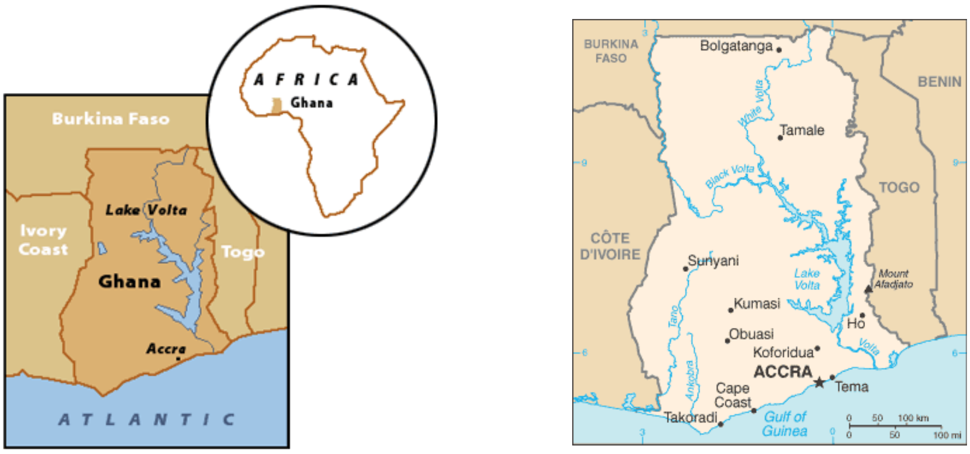


Figure 3-1: Ghana map (Source: http://www.cia.gov/cia/publications/)

According to (GSS, 2002), the Greater Accra region occupies a total area of 3,245 km^2 or 1.4% of the total area of Ghana. The location of Accra Metropolitan Assembly (AMA)[15] has a population density of 82.9 people/ha, and its location. AMA includes the CBD (Central Business District) of Accra is shown in Figure 3-5 (Map drawn by Sampson Oduro-Kwarten[16]). The total area of AMA is 200 km^2. All the towns outside of AMA can be called peri-urban towns of Accra. The population of greater Accra is 2.9 million in 2000 and it comprises of five areas/districts: They are Accra Metropolitan area (AMA), Tema municipal area, Ga district, Dangme West district, and Dangme East district (GSS, 2002) (more details are shown in Appendix 9). The population of the greater Accra region by religion and sex is shown in Table 3-1.

[15] I describe AMA in more detail here because the conceptual design of sanitation systems was carried out for AMA (Chapter 5).

[16] Sampson is currently doing his PhD at UNESCO-IHE (sokwarteng@yahoo.com)

Table 3-1: Population by religion and sex in greater Accra region (GSS, 2002)

Religion	Both sex	Male	Female
Christian	83.0	81.6	84.4
Islam	10.2	10.7	9.7
Traditional	1.4	1.4	1.4
No religion	4.6	5.6	3.6
Other religion	0.9	0.9	0.8
Total population	2,905,726	1,436,135	1,469,591

Figure 3-2: Accra urban area – part of AMA (www.geocities.com/renjoh/wedding.html)

For my research work in Accra, I call the administrative city boundary "urban", and land outside the immediate city boundary within a radius of up to 40 km from the city center "peri-urban".

Figure 3-3: Peri-urban area in Accra in Ghana (www.galenfrysinger.com/ghana_accra.htm)

Accra urban, peri-urban, and rural geographical area is shown in Figure 3-4 , and Figure 3-5 shows map (map drawn by Sampson Oduro-Kwarten[17]) of greater Accra region and Accra Metropolitan Assembly (AMA).

[17] Sampson Oduro-Kwarten

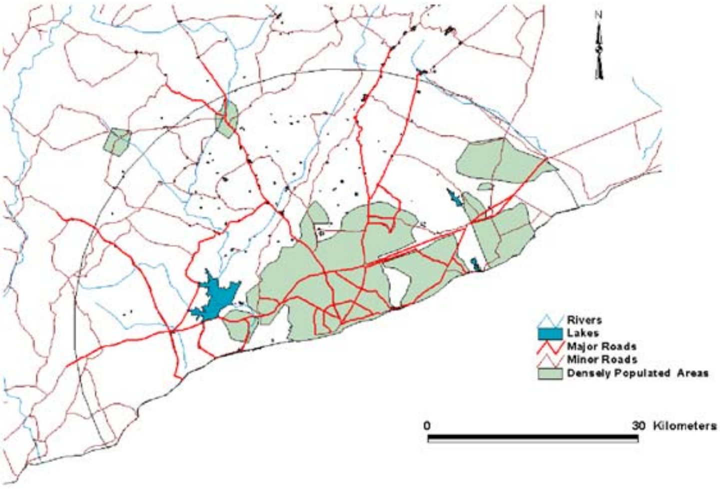


Figure 3-4: Approximate boundary between rural and peri-urban areas in Greater Accra (http://homepage.mac.com/cityfarmer/Ghana/Chap%202-Description.pdf)

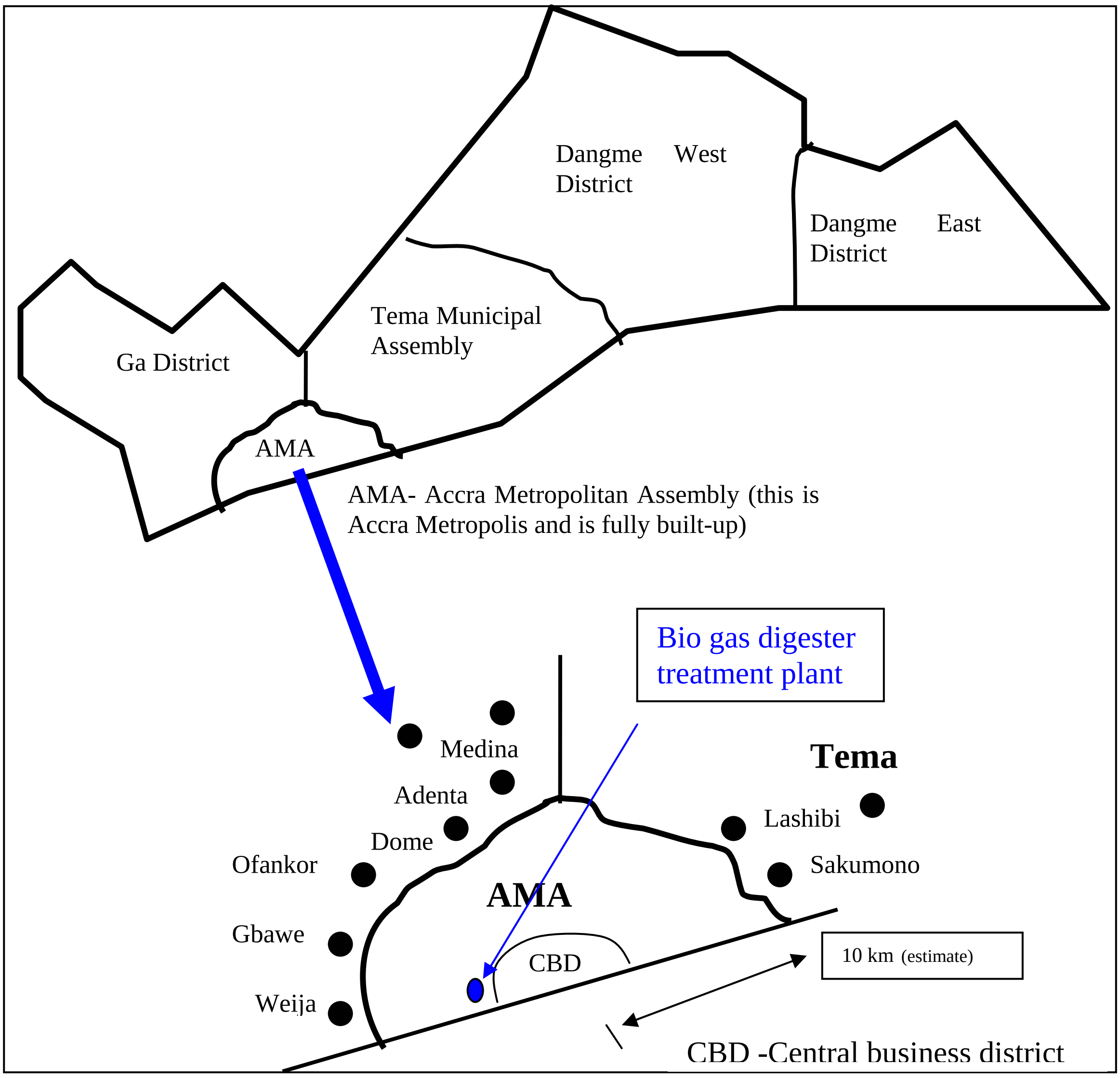


Figure 3-5: Greater Accra region of Ghana and location of (AMA)

3.1.2. Accra soil types and climate

Ghana's geology is dominated by the Dahomeyan (lower precambrian) and Birrimian (middle precambrian) (Agodzo *et al.*, 2003). (FAO, 2005) found that in Ghana there are 43 different types of soil. Generally, the soil is light-textured with relatively low organic matter content and water holding capacity. The levels of organic carbon, nitrogen, and phosphorus are relatively very low whereas potassium is mostly not present in the soils (see Table 3-2).

Table 3-2: Average soil fertility status of some regions in Ghana (FAO, 2005)

Region	Soil pH	Organic matter %	Total nitrogen %	Phosphorus mg/kg soil	Calcium mg/kg soil
Asanti	4.3-7.8	1.5-3.0	0.1-0.3	0.1-12.0	50-100
Brong Ahafo	3.5-6.7	0.3-1.7	-	0.1-64.3	16-140
Greater Accra	**5.4-8.2**	**0.1-1.7**	**0.05-0.9**	**0.8-144.0**	**14-470**
Northern	4.5-6.7	0.6-2.0	0.02-0.05	2.5-10.0	45-90
Upper East	5.1-6.8	1.1-2.5	0.06-0.14	1.8-14.8	44-152
Upper West	6.0-6.8	0.5-1.3	0.01-0.07	2.0-7.4	52-152
Western	3.8-7.1	1.0-5.7	0.06-5.4	0.4-11.3	28-420

Accra lies within the coastal zone with low annual rainfall averaging 810 mm distributed over less than 80 days (RUAF, 2006). The details about climate data for several main cities in Ghana are shown in Table 3-3. More details about Accra climate are shown in Appendix 5.

Table 3-3: Climate data for Accra (in the South of Ghana), Kumasi (in the centre of Ghana), and Tamale (in the North of Ghana)(Agodzo et al., 2003)

Yearly Average	Unit	Accra	Kumasi	Tamale
Rainfall period	-	**May-June and October**	-	5-6 months
Drought period	-	**-**	-	6-7 months
Rainfall	mm	**810**	1,420	1,033
Temperature	^{0}C	**27.1**	26.1	28.1
Relative Humidity	%	**81**	77	61
Wind speed	km/day	**251**	133	138
Sunshine	Hours/day	**6.5**	5.4	7.3

3.1.3. Selection of the city for this study

I chose Accra for this study because of the following reasons:

- It is one of SWITCH's nine demonstration cities.
- There are number of previous publications that deal with urban agriculture in Accra, mostly from IWMI.
- It is in dire need to improve its sanitation coverage.
- Ghana has a stable government and it is an English-speaking developing country.
- Accra is one of the rapidly growing cities in Sub-Saharan Africa.

3.1.4. Sanitation, wastewater management and water supply facilities

3.1.4.1. Sanitation and wastewater management in AMA

According to (Allan, 1997), one of the undesirable effects of the urbanisation in Ghana is the poor and inadequate sanitation. Over-crowding and congestion have led to the development of slums which worsened the sanitation and health problems in the city. The sanitation coverage in Ghana and MDG targets in 2015 are shown in Table 6-1 Appendix 11 respectively.

(Salifu and Doyen, 2000) state that the people who live in urban and peri-urban areas in Accra, have insufficient water supply and sanitation facilities. Therefore, they experience diarrhoeal diseases and other water-borne diseases which can lead to death (see Figure 3-6 for view of pollution and lack of facilities in slum areas)

According to data from AMA health services, the biggest killer is diarrhoea diseases followed by intestinal worms. Both are sanitation-related diseases. The reported diarrhoeal cases in AMA are 14,139 males and 15,919 females in 2005. (see Appendix 6 for more details).

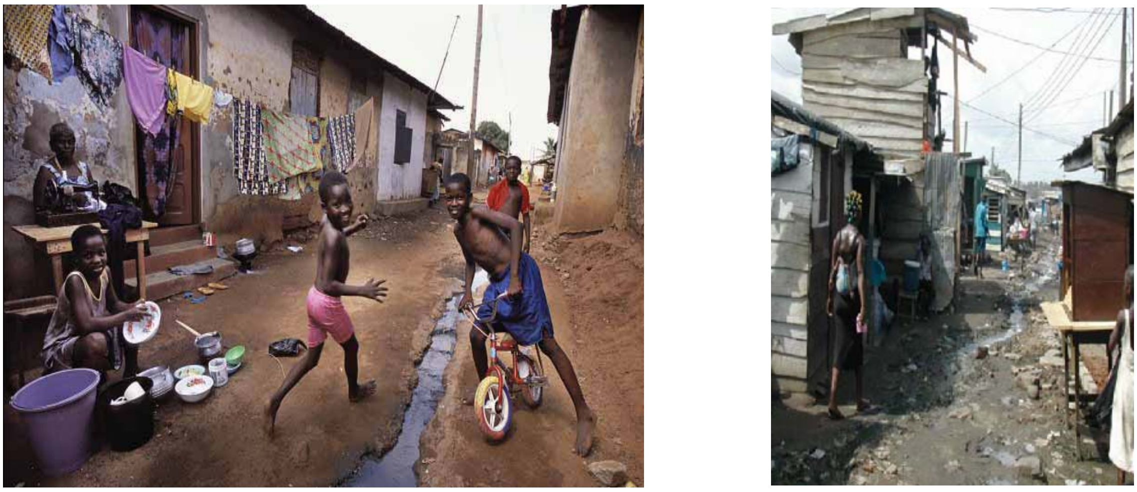


Figure 3-6: Pollution in slum areas and lack of water supply and wastewater management facilities in Accra, Ghana.

(http://www.citiesalliance.org/doc/resources/paper-pres/ssa/eng/executive_summary.pdf)

(MAC, 2006) states that in Accra there are about 22 sewerage systems and wastewater treatment plants serving institutions and hotels, but only a few are operated. Although the largest WWTP can handle about 16 ML/day, it receives only 5 ML/day due to insufficient capacity of the sewerage system.

(ADB, 2005) states that Accra is faced with severe inadequacy of urban infrastructure in the face of rapid population growth in the metropolis. Due to the limited number of treatment plants, faecal sludge from the on-site facilities is either disposed of in receiving water bodies or in nearby drains and open spaces.

According to my discussions with a Ghanian on18 February 2007, it is revealed that the main bio gas digester wastewater treatment plant, which treated the wastewater from the

[18] S. Ibrahim is a MSc student at UNESCO-IHE (ibro0072000@yahoo.com)

sewerage pipe-borne system in the AMA area, is not working at present. The untreated wastewater collected from sewerage system is directly discharged to a nearby natural lagoon which is very close to the ocean (see Figure 3-5).

(MAC, 2006) further states that Accra's major wetland, the Korle Lagoon and the Odaw stream, which is the main urban storm water drain, receive a vast amount of wastewater and solid waste due to the limited sanitation infrastructure.

According to (GSS, 2002) households in AMA use mainly public toilets[19] (32.7%), VIP, pit and bucket latrines or water closets in-house. Even though there are by-laws for all new dwellings to convert to either water closet or VIP toilets, AMA has a very high proportion of households still use bucket latrines (12.7%). In addition, still there are people who use open defecation even in the urban centres. These people defecate along the beaches or water courses, bushes, and gutters (see Figure 3-7).

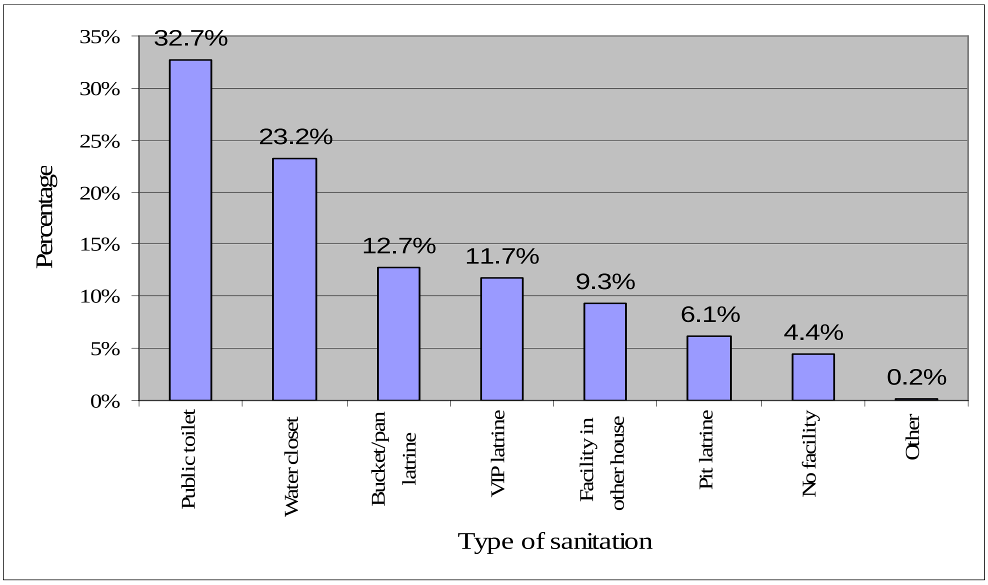


Figure 3-7: Types of sanitation systems for excreta management use in AMA (GSS, 2002)

There are no adequate facilities for collecting and treating greywater in the urban and peri-urban areas in AMA. Over half of the households in AMA use gutters (53.2%) to dispose the liquid waste/ greywater produced from kitchen and bathrooms. More details of greywater disposal in this area are shown in Figure 3-8.

[19] VIP, pit, bucket and pour flush toilets

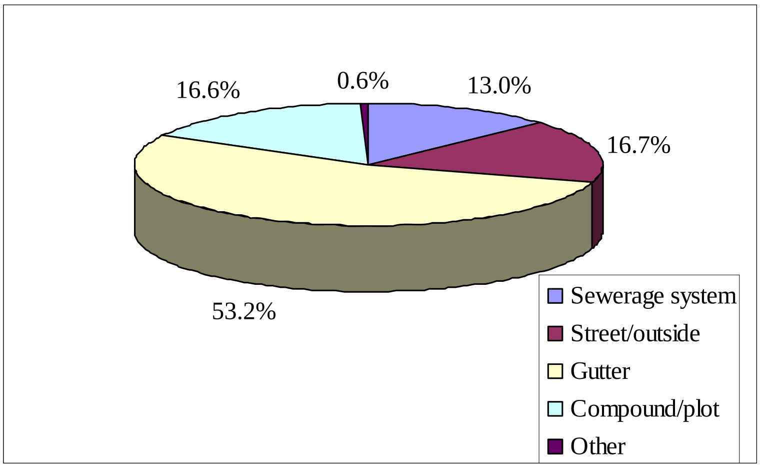


Figure 3-8: Means of greywater disposal in AMA (GSS, 2002)

3.1.4.2. Water supply coverage in AMA

The main source of drinking water in AMA for 90.5% households is water supplied in pipes either inside or outside the house (community stand post). There are about 4.7% of households in this area who utilise groundwater sources such as wells and bore holes for their drinking water (see Figure 3-9). The quality of the groundwater may be compromised by the many onsite sanitation facilities. The MDG target for water supply coverage in 2015 for Ghana is shown in Appendix 11.

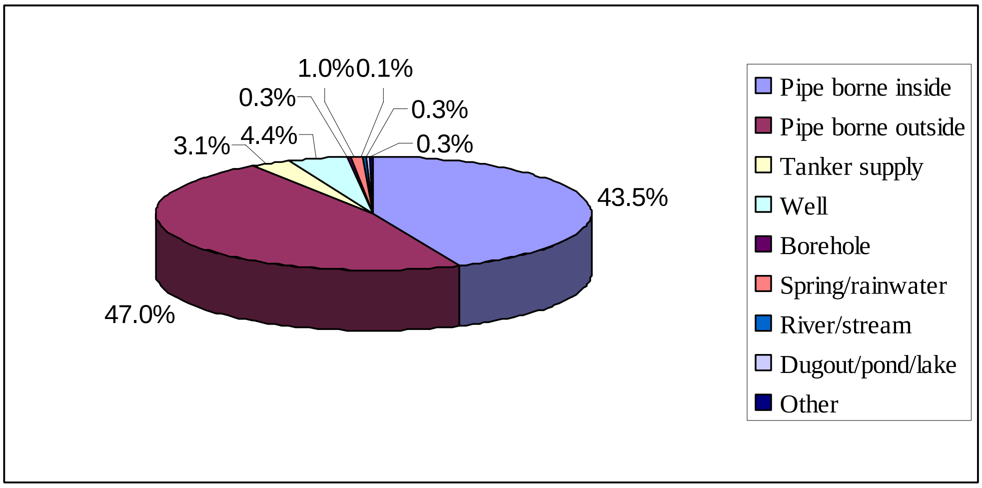


Figure 3-9: Types of sources of drinking water in AMA (GSS, 2002)

3.1.5. Acceptance of facilities by people

According to (Allan, 1997), those who use public VIP toilets, say that they are unsatisfactory in respect of cleanliness, convenience, and privacy. Households using the bucket latrines consider them inappropriate because they are more labour intensive than VIP, pit or pour flush toilets and dehumanising as a method of excreta disposal.

3.1.6. Constraints to sanitation provision in low income areas

Constraints indicated in (Allan, 1997) are:

- Financial
- Appropriate technology
- Perception of communities and public health

- Attitude of landlords, policy makers and users
- Culture

3.1.7. Existing strengths towards improvement

(Allan, 1997) explains the strengths available as following:

- Public awareness of the present situation of sanitation problems
- Willingness of user for participation and contribution to urban sanitation solutions
- Local government support
- Existence of some stakeholders
- Public willingness to pay for sanitation

Through my discussions with some Ghanians[20], I found that the constraints for sanitation improvements are still very similar as those mentioned in (Allan, 1997) even though 10 years have since passed.

3.2. Lima, Peru

3.2.1. Introduction

The total estimated population in Peru in 2005 according to (CIA, 2007) is 27.9 million and annual population growth rate is 1.36%. Peru covers a total area of 1,285,215 km² and the population density is 0.22 people/ha. By religion 81% of population is Roman Catholic, 1.4% is Seventh Day Adventist, other Christian is 0.7%, unspecified or none is 16.3 %, and 0.6% is “other religion”.

The data for Lima in the following paragraphs are taken from (Wikipedia, 2006b). Lima is the capital and largest city in Peru, which is the third largest South American country (see Figure 3-10). The city is located in an area encompassing the valleys of the Chillon, urin, and Rimac rivers. The city of Lima (urban area) covers about 800 km² and the city population is about 7.5 million in 2000 (population density 93.8 people/ha). The average family size is 3.04.

Figure 3-10: Peru map (Source: http://www.cia.gov/cia/publications/)

[20] Samson Oduro-Kwarteng and S. Ibrahim

Lima comprises of 30 densely populated central districts (see Figure 3-11). The most populous districts of Lima lie in the north and south ends of the city. Their population is comprised of immigrants from other regions of Peru. Many of them are poor people who arrived during the mid and late twentieth century after being displaced by terrorism, agrarian crises, and general economic frustration.

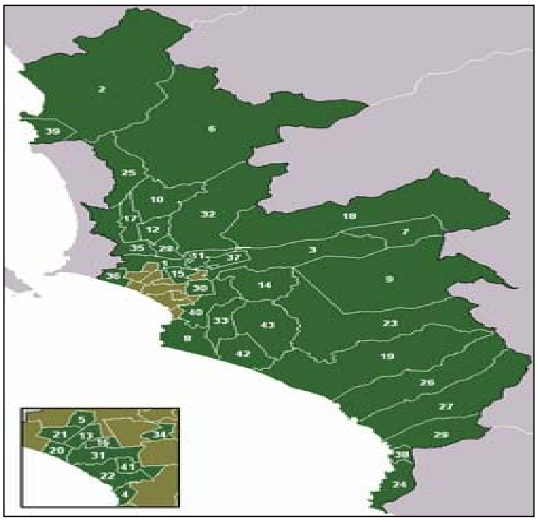


Figure 3-11: Area of greater Lima (Wikipedia, 2006b)

These urban and peri-urban areas often lack basic services such as water supply, sanitation, and electricity. The present annual population growth rate in urban areas is 1.9% per annum and 40% of the urban population is poor.

Figure 3-12 and Figure 3-13 show the situation of urban and peri-urban areas in Lima, respectively.

Figure 3-12: Urban area in Lima (www.liceoberchet.it/.../cit_imp_per.htm)

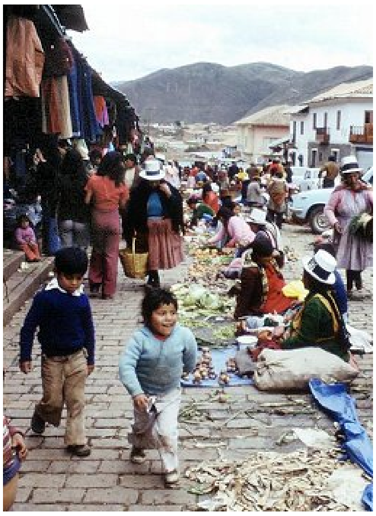


Figure 3-13: Pollution in peri-urban areas in Lima (www.livingtravel.com/samerica/peru/peru_1.htm)

3.2.2. Lima soil types and climate

The data in the following paragraphs for Lima are taken from (Wikipedia, 2006b). The city slopes gently from the shores of the Pacific Ocean into valleys and mountain slopes. As in the rest of the region, the extreme dryness of the climate means that away from the river valleys and irrigated areas the local terrain is absolutely barren of vegetation. Except in river deltas, such as the Rimac and Chillon in the case of Lima, the substratum is sand.

The average low temperatures range from 14°C to 20°C and the average maximum temperature is around 32°C considered high. Relative humidity is very high, and produces brief morning fog from December to June and persistent low clouds from May to November. Sunny, moist and warm summers (Dec-Apr) are followed by cloudy, damp and cool winters (Jun-Oct).

Rainfall is almost unknown. The yearly average of 25 mm reported at the airport is the lowest of any large metropolitan area in the world. Summer rain occurs in the form of isolated light and brief showers in the afternoon or evening. The peak of the 'rainy season,' which really does not apply, occurs during winter when late-night/morning drizzle events become frequent. Climate data for Lima is shown in Table 3-4.

Table 3-4: Climate data for Lima (WorldClimate, 2006)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Tem (^{0}C)	21.4	22.2	21.9	20.2	17.9	16.2	15.3	15.1	15.3	16.2	17.7	19.4	18.2
R/F (mm)	1.0	0.4	0.5	0.2	1.8	3.4	4.3	5.0	4.6	1.8	0.9	0.5	25.1
Wind speed (km/h)	17	15	15	15	15	13	13	13	15	15	15	17	
Humidity (%)	79.5	80.0	80.5	82.0	83.5	82.5	82.5	83.5	83.0	81.5	79.5	79.0	

3.2.3. Selection of the city for this study

I selected Lima for this study because of the following reasons:

- It is a study city in SWITCH, which should allow easier access to data[21]

[21] This expectation turned out to be not true.

- There is an active urban agriculture scene in Lima
- There is past experience with ecosan in Peru and the region
- It is a typical city in Latin America
- Lima is a rapidly urbanising city

3.2.4. Sanitation, wastewater management and water supply facilities in Lima

3.2.4.1. Sanitation and wastewater management in Lima

(WorldBank, 1997) reveals that water pollution is a major problem in Lima metropolitan area, which is increasing due to the rapid urbanisation. Due to the inadequate sanitary and solid waste disposal facilities, people discharge the waste to the waterways. Some raw sewage is used for irrigation of food crops, mainly vegetables, and in parks, and the rest is discharged to the ocean without treatment. Hence, water pollution generates an array of problems relating to health, productivity, and degradation of environment.

The data for Lima in the following paragraph is taken from (UNEP-IETC, 2005). It is estimated that in Peru 83% of the urban sewage discharges to water bodies, such as coastal areas, rivers, lakes, or even agriculture lands with no control or treatment whatsoever. For the Greater Lima[22], the sewage flow collected in the sewerage system is approximately 2,000 ML/d. Only approximately 86 ML/d is receiving treatment in secondary treatment plants (report does not explain what type of secondary treatment) and is then diverted to agriculture use. After the implementation of the Southern Lima Sewerage Project in the coming years it is expected that an additional 830 ML/d will be treated, so increasing the capital's sewage treatment to about 39%. As a result of the projects to be implemented in the interior of the country in the coming years, the national coverage for sewage treatment shall increase to a figure of 40%.

According to (WHO/UNICEF, 2006), urban sanitation facilities coverage in Peru in 2000 is shown in Figure 3-14. No separate data for Lima was found, but Figure 3-14 is probably a good indicator for the situation in Lima. The sanitation coverage in Peru and MDG targets in 2015 are shown in Table 6-1 and Appendix 11, respectively.

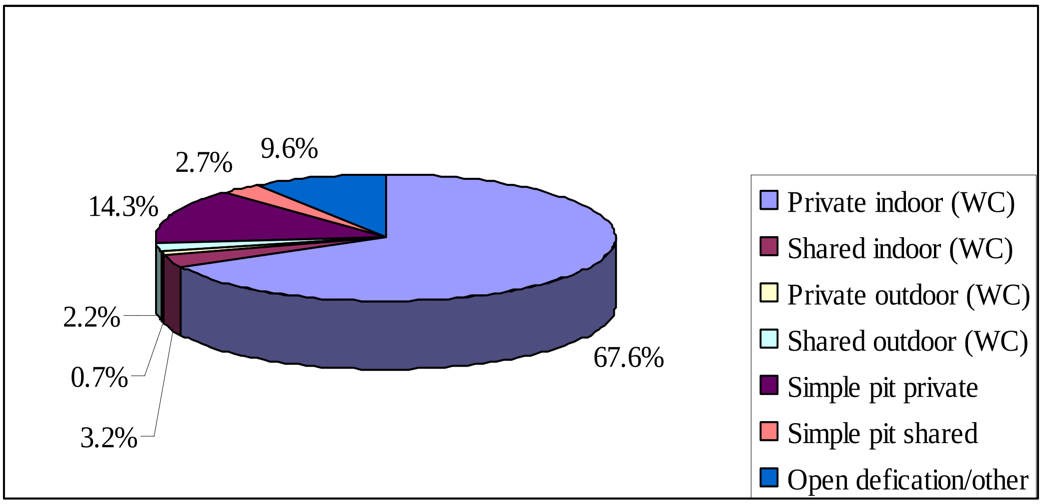


Figure 3-14: Urban sanitation coverage in Peru (WHO/UNICEF, 2006)[23]

[22] This is not clearly defined in the report.
[23] This data is not very useful because it does not indicate how toilet waste is in fact treated (septic tanks, sewer system, faecal sludge management etc.).

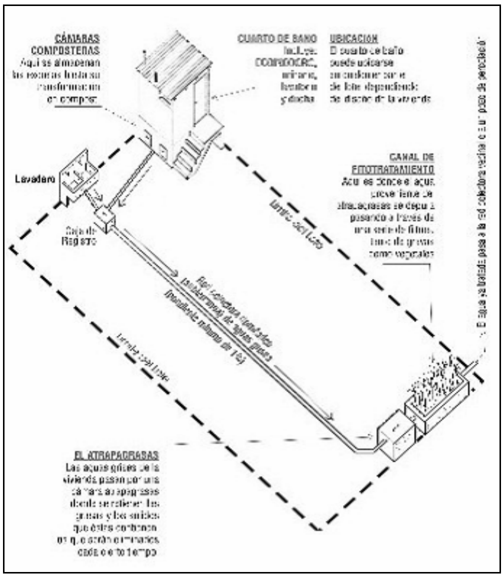
(UNEP-IETC, 2005) highlights that the small-scale water supply and sanitation service providers extend access to underserved communities – mainly poor, urban households outside the reach of public utilities in Peru.

According to (UNEP-IETC, 2005), it is revealed that Peruvian children who live in urban and peri-urban areas suffer diseases like diarrhoea due to inadequate sanitation and water facilities. In addition to that, the absence of safe water and sanitation is cause for gastrointestinal diseases in the peri-urban residents in Peru

3.2.4.2. Ecosan pilot project: ECODESS

The following paragraphs about ECODESS (ECOlogy and DEvelopment with Sustainable Sanitation) in Lima are prepared by using the data taken from(Luna, 2005). It states that people in Peru have started to implement the ecosan concept to solve their water and wastewater problems. Sedapal (the state company of services of drinking water and sewer system in Lima) and CENCA (Institute of Urban Development) have planned to do the ECODESS which is a micro integrated system. There were two pilot projects carried out in peri-urban areas in Lima, the district of Lurigancho, which is one of the poorest areas in Lima, covered approximately 118,000 inhabitants and Nieveria covered nearly 2,000 inhabitants.

There are two technical sub-divisions of the ECODESS system: domestic system and neighbourhood system. In the domestic system, the entire disposal system is included inside their premises and can be used in urban areas (see Figure 3-15 left). It includes the room of complete ecological bathroom (with eco-toilet24, urinal, lavatory, laundry for clothes, and shower, see Figure 3-16), collection and treatment of greywater, collection of urine and collection of faeces and its transformation to compost. The neighbouring/local system is a compiling network which gathers water coming from blocks of houses and leads to the wetland to leak and again reuse for irrigation (see Figure 3-15 right).



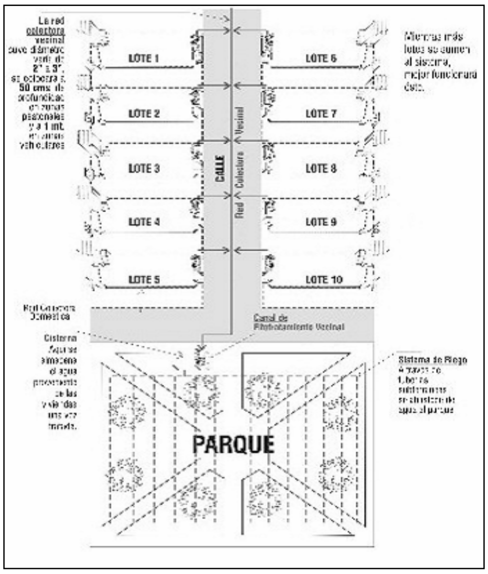


Figure 3-15:Domestic ECODESS concept (left) and neighbourhhod ECODESS concept (right) in Lima (Luna, 2005)

[24] Urine and faeces are collected separately

Ecological dry bathroom inside the house built according to the instructions by CENCA (Institute of urban development) is shown in Figure 3-16.

Figure 3-16: Ecological dry bathroom built inside the house in Lima by CENCA (Luna, 2005)

3.2.4.3. Water supply situation in Lima

According to my verbal discussion with a Peruvian[25] the following data was collected. The major source of Lima´s water supply is the Rimac River, which is polluted by heavy metals from nearby mines as well as untreated sewage from unplanned human settlements. About one third of Lima´s drinking water comes from wells. The groundwater is polluted increasingly by salinity when the water table near the ocean drops because of increased pumping of water in the dry season. Those people who do not have house water supply connections rely on standpipes, on water vendors and on other sources such as wells.

Because of supply interruptions, even people with house connections are storing water under unsanitary conditions. People without connections spend hours waiting their turn at public standpipes (a total of seven hours a day queuing during the dry season).The use of drinking water is not regulated and is an expensive water source for farmers.

3.2.5. Acceptance of facilities by people

(IPS, 2006) found that people in Lima’s urbanised poor neighbourhoods do not have sufficient drinking water and sanitation facilities. According to the people’s view, they say that the government does not interfere to find better solution for the problem. Therefore, people may need to privatise the water sector (water supply and sanitation).

3.2.6. Constraints for sanitation provision in low income areas

(Alcazar *et al.*, 2000) state that the following are the constraints to improve the water supply and sanitation facilities in Lima:

[25] Alicia Roman, MSc student at Hamburg University of Technology, Germany (alicia.roman@tu-harburg.de)

- Insufficient land for people in urban, peri-urban areas
- Lack of finance for people as well as municipalities (government)
- Lack of political will
- Lack of policies, regulations etc.

(Luna, 2006) states that it is necessary to invest approximately 3500 million US$ to overcome the sanitation deficit[26], however, the government has capacity to invest 780 million US$ only.

3.2.7. Existing initiatives towards improvement

(WUSC, 2006) states that the prevailing water laws are going to be replaced by a new Water Resources Management Law. This new law aims to improve the efficiency in the usage of water resources through the creation of water markets and establishment of private water-use rights. Yet, the new water law relies on the Environmental Code and Environmental Authority to set and enforce water quality standards. The Government uses a sectoral approach to wastewater management and coastal pollution control. This approach seems to be a major cause for the fragmentation of institutional responsibilities in the sector. Currently, the Ministries of Health, Agriculture, Industry, Mining and Energy all have responsibilities for policy formulation and enforcement in water pollution control, yet there is little coordination among these ministries. Moreover, public support for and participation in wastewater management and coastal pollution control is still very limited, but will be needed to support the successful implementation and enforcement of policies and projects.

3.3. Summary of sanitation situations and comparison of findings

The general comparison data in Ghana and in Peru is shown in Table 3-5.

Table 3-5: Comparison of general country data for Ghana and Peru (CIA, 2007)

Description	Ghana	Peru
Population density (2006 estimated)	0.94 people/ha	0.22 people/ha
Annual growth rate (2006 estimated)	2.07 %	1.32 %
GDP/capita (2006 estimated)	2,600 $	6,400 $
Fertility rate (2006 est.)	3.99/woman	2.51/woman
Infant mortality rate-deaths/1,000 live births (2006 estimated)	55	31
HIV/AIDS – Adults prevalence rate (2004 estimated)	3.1 %	0.5 %
Literacy rate (2004)	74.8 %	87.7 %
Life expectancy at birth (2006 estimated)	58.8 years	69.8 years

The key characteristics for AMA and Lima are summarised in Table 3-6 and sanitation coverage is summarised in Figure 3-17.

[26] It is nor clear deficit is on conventional sewer-based sanitation or ecosan.

Table 3-6: Comparison of key characteristics for AMA and Lima with respect to sanitation and water supply (summary of Section 3.1 and 3.2)

Description	AMA	Lima
Annual rainfall	810 mm (tropical wet and dry climate[27])	25 mm (arid)
Average temperature	27.1 ^{0}C	18.2 ^{0}C
Population	1,658,937	7,500,000
Area covered	200 km^2	800 km^2
Population density	83 people/ha	93.8 people/ha
Average household size	4.5	3.04
Major religious group	Christian – 83 %	Roman Catholic – 81 %
Existing greywater disposal options	About 53 % dispose to gutter, only 13 % dispose to sewer	Not available
Constraints against sanitation improvement	Lack of finance, lack of appropriate technology, perception of communities, culture, attitudes of landlords, users and policy makers	Lack of finance, lack of political will, lack of policies
Existing strength towards improvement of sanitation systems	Public awareness about sanitation problem, willingness of user participation, payment and contribution, local government support	Some water laws available
Water supply methods	47 % houses connected to pipe water, others: stand pipe, tanker, river, stream, lake, groundwater	Main source: piped connections to households, others: stand pipe, vendor, groundwater

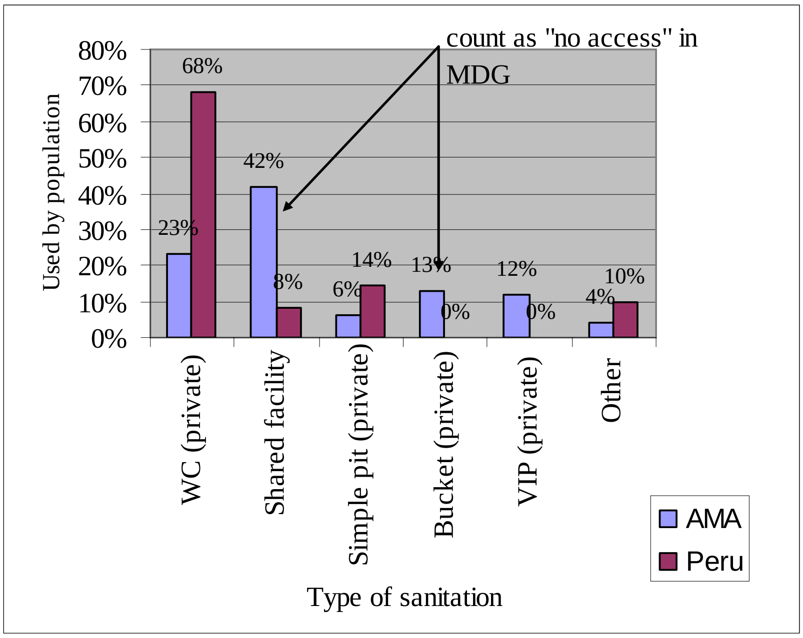


Figure 3-17: Comparison of sanitation coverage in AMA and Peru

[27] According to Wikipedia classification (http://en.wikipedia.org)

From the above Table 3-5, Table 3-6 and Figure 3-17, the following observations can be made:

- Lima has very low rainfall
- Considerable percentage of population has no sanitation facility in both cities
- Considerable percentage of population use “unimproved” sanitation systems in AMA
- There are some common constraints against sanitation improvement

4. Review of urban agriculture in developing countries

4.1. Overview of urban agriculture

The purpose of this chapter is to show the relevance of sanitation provision for urban agriculture regarding the water content in wastewater, and fertiliser value of human excreta.

The agricultural activities in and around the city are generally called "urban agriculture". Urban agriculture offers many advantages to cities from both ecological and technical perspectives, especially if the green spaces that result are an integral part of the urban fabric. Apart from the functioning of the city, it has social advantages in that it enables vulnerable groups in the urban community to improve their conditions (Sachs and Silk, 2006).

Urban and peri-urban agriculture is defined in (Mougeot, 2000) as the production, processing, and distribution of foodstuff from crop and animal production, fish, ornamentals, and flowers within and around urban areas. It further says that the term "urban" and "peri-urban" agriculture are often used synonymously.

Another definition for urban agriculture is: "urban agriculture is food production occurring within the confines of cities. This production takes place in backyards, rooftops, community vegetable and fruit gardens, and unused or public spaces. It includes commercial operations producing food in greenhouses and other spaces, but is more often small-scale and scattered around the city" (NugentRachel, 1997)

(IWMI, 2006) states that the urban agriculture is a dynamic concept that consists of a variety of farming systems, ranging from subsistence production and processing at household level to fully commercialized agriculture. Urban farming systems can be classified according to different criteria such as location, crops cultivated, tenure modality, scale of the production, seasonality, and product destination (Mougeot, 2000).

The report from (Zeeuw, 2002) explains clearly the above classification:

- **Types of products:** Types of products include plant production (grains, vegetables, mushrooms, fruits, flowers, ornamental plants, herbs, spices, and medicine plants etc.), live stock production (cattle, goat and sheep rearing for milk and meat, poultry production for eggs and meat, bird keeping, rabbits for meat, bees for honey etc.), and aqua culture (fish for consumption and ornaments). Often the more perishable and relatively highly valued vegetables and animal products and by-products are favored.

- **Types of economic activities:** Urban agriculture includes production activities as well as related processing and marketing activities, input production and services delivery (e.g. animal health services).

- **Types of location:** Urban agriculture may take place in locations inside the cities (intra-urban) or in the peri-urban areas. The activities may take place on the homestead (on-plot) or on land away from the residence (off-plot), on private land (owned, leased) or on public land (parks, conservation areas, along roads, streams and railways), or semi-public land (schoolyards, grounds of schools and hospitals).

- **Scales of production and technology used:** In the city, it may encounter individual or family farms, group or cooperative farms and enterprises, micro-, small- and medium-sized enterprises, as well as large-scale undertakings.

- **Types of people involved:** In many cities, one will often also find lower and mid-level government officials, school teachers and the like involved in agriculture, as well as richer people who are seeking a good investment for their capital. Women play an important part of the urban farming.

(UNDP, 1996) reports that urban agriculture is widely practised in developing countries and more than 800 million people worldwide are actively involved. The report describes that most of these urban dwellers engage in subsistence gardening and more than 200 million practise market-oriented farming on undeveloped urban spaces. There are about 150 million people who are full-time employees of urban agriculture.

(Mougeot, 2000) states that most urban farmers have some experience in farming because they have a rural background.

Urban agriculture is becoming a very visible economic activity in urban and fringe areas of cities worldwide (Smit *et al.*, 1996). This is because urban agriculture plays an important role in enhancing urban (and peri-urban also) food security and nutrition, local economic development, poverty alleviation, and sustainable environmental management in the cities.

(FAO, 2006) describes more how urban agriculture affects the urban community:

- The quantity of food available is increased through both urban and peri-urban agriculture. Poor urban dwellers often lack the purchasing capacity to acquire adequate amounts of food. Urban agriculture appears to reduce food insecurity by providing direct access to home-produced food to households and to the informal market.

- It enhances the freshness of perishable foods reaching urban consumers, increasing overall variety and the nutritional value of food available, especially for children, when poor urban families farm. An important reason appears to be that food produced by consumers or in close proximity to them is often fresher than food that travels a long distance to markets.

- Urban agriculture offers opportunities for productive employment in a sector with low barriers to entry. It is estimated that one-quarter to two-thirds of urban and peri-urban households are involved in agriculture. Urban agriculture is often carried out on a part-time basis by women, who can combine food production activities with child care and other household responsibilities.

- Wastewater effluent from domestic uses (greywater) is used for backyard farming and sometimes treated domestic wastewater or untreated wastewater[28] is reused for large scale agriculture. It provides all of the nitrogen and much of the

[28] Untreated wastewater use for agriculture carries high risks.

phosphorus and potassium that are normally required for agricultural crop production.

- Urban agriculture can reduce the costly and problematic transportation of food from rural areas because it produces food locally. This means saving on roadways, trucks, fuels, and warehouse as well as storage and refrigeration installations. The transportation of food products is often subject to considerable losses due to spoilage and pests. This problem can be reduced by more decentralized food production.

4.2. Urban agriculture in Accra

4.2.1. Features of urban / peri-urban agriculture in Accra

According to (RUAF, 2006), in general there are two major categories of urban agriculture in Ghana: household gardening and open space farming. Household gardening takes place in and around homes, and the open space farming takes place on lands some distance away from human dwellings along drains, road sides, abandoned waste dumps, around public buildings, wetlands etc. Most of the open space farmers do not own lands and do not pay any fee. These open lands are owned by government or private developers. Under these insecure conditions, open space farmers do not invest in farm infrastructure, soil conservation, and long term fertility improvements.

In Accra, there are seven urban agriculture systems that can be identified (Danso *et al.*, 2002). They are:

- Irrigated vegetable farming
- Backyard farming
- Livestock farming
- Aquaculture farming
- Small ruminant farming
- Seasonal crop farming
- Non-traditional farming

Irrigated vegetable farming

Irrigated urban agriculture takes place on 7 larger sites, mostly along streams and drains. The open spaces and farming activities on these open spaces in AMA is shown in Figure 4-1.

According to (IWMI, 2006), there are about 600 farmers who grow exotic vegetables throughout the year and about 400 farmers who grow indigenous vegetables, for example okro and tomatoes. They normally grow these vegetables in the rainy season and occasionally use polluted streams and drain water. Figure 4-2 shows some irrigated vegetable sites in Accra.

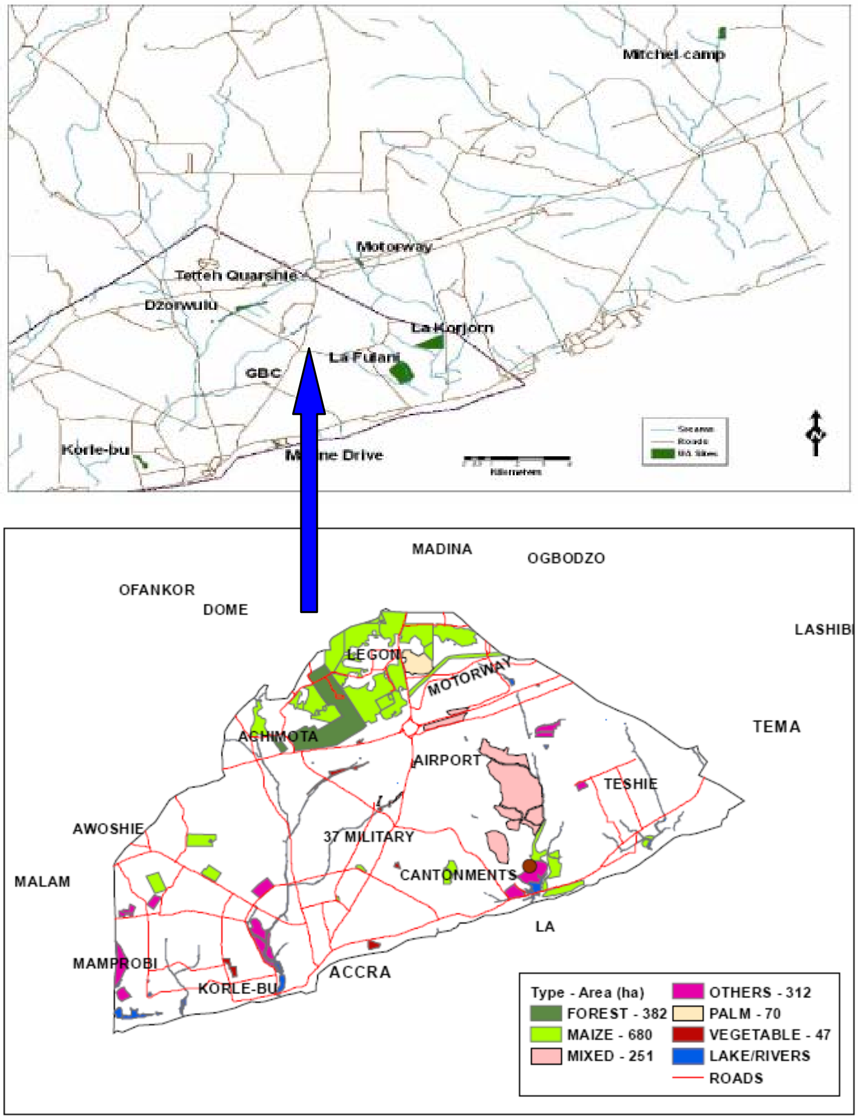


Figure 4-1: Maps of Accra; Top - Urban irrigated agricultural sites in Accra (IWMI, 2006), bottom - open spaces and farming activities on them in AMA (Kufogbe et al., 2005)

Figure 4-2: Irrigated vegetable sites in Accra (IWMI, 2006)

In Accra, about 50% of open space farmers use effluent from open drains as their main source of water for growing vegetables (Mensah *et al*., 2001). Figure 4-3 shows a farm which is cultivated using stream water in Accra.

Figure 4-3: Stream water use for vegetable farm in Accra (Drechsel et al., 2006a)

(RUAF, 2006) states that household farmers use treated pipe water and greywater for farming while open space farmers use drain water, streams/rivers which are polluted by wastewater, pipe borne water and hand-dug wells.

Farmers use watering cans and buckets and manually carry water from a water source (mostly shallow dug wells or streams), to the fields, followed by watering crops through the spout or shallower head of the can. In addition to manual methods, the farmers use motorised pumps with hosepipes and surface irrigation methods for watering.

(CWC, 2006) states that in Accra, the need for year round production of vegetables in the urban areas makes irrigation necessary. Lack of reliable and affordable irrigation water has compelled the urban farmers to use wastewater. Farmers strategically site their farms along main drains so they have easy access to irrigation water at no cost. Wastewater usage (by percentage) in urban irrigation in Accra is shown in Appendix 7.

Features of urban agriculture in some places in Accra are shown in Appendix 7. Figure 4-4 shows a typical open-space site in Accra used for vegetable cultivation. There are about 12 ha irrigated around the Dzorwulu electric power station and a storm water drain. More features of irrigated vegetable farming in Accra are shown in Appendix 7.

Figure 4-4: Vegetable open space farm near electric power station and a storm drain (Drechsel et al., 2006a)

According to the data from (Cornish and Lawrence, 2001) the plot sizes of small scale urban vegetable farms in Accra vary from 0.01-0.2 ha and on the peri- urban areas it varies from 0.1-0.8 ha.

Backyard farming

Backyard gardening is characterized as the cultivation of crops and rearing of animals around and in households (see Figure 4-5). It has been reported that every second household is engaged in some form of backyard gardening (Drechsel *et al.*, 2004) .

(IWMI, 2006) revealed that most farmers under this system are middle-aged and have good standards of education. The main occupations of the farmers are 40% private services, 42% public service, 15% are pensioners and the rest have other jobs. Many people do this farming as a hobby or necessary addition to subsistence. Occasionally, when good harvests are produced, the excess is sold to neighbours or market sellers.

However, it mainly serves to support the household and it contributes to ensuring food security in homes. Typical features of this type of urban agriculture are shown in Appendix 7.

Figure 4-5: Backyard garden with fruit trees in Accra (IWMI, 2006)

Livestock farming

In Accra, ruminant rearing is very common in densely populated areas to generate additional income. According to the laws of the Accra Metropolitan Assembly, farmers are not allowed to keep birds, sheep, goats, cattle as well as other animals outside of their premises.

The number of animals owned by the individual farmers ranged from 4 to 200. Mature individual animals owned by farmers range from 2-150 whereas young individuals range from 2-50 (IWMI, 2006). Wastes from livestock are disposed of at the refuse dump, and some keepers sell this waste to crop farmers for use as fertiliser. Mixed farmers use it as input for their crops. Figure 4-6 shows livestock farming in-house in Accra, and more features of livestock farming are shown in Appendix 7.

Figure 4-6: Cattle, sheep, and goats farming in Accra (IWMI, 2006)

Aquaculture farming

The farmers who engage in this farming have background knowledge about basic ecological principles. There were more women (80%) involved than men (20%) (IWMI, 2006). They are doing aquaculture as a hobby as well as a business. Mudfish and tilapia are the main types of fish kept by the farmers. Typical feature are shown in Appendix 7.

Poultry farming

Many of the people in poultry farming are well educated, implying that with the requisite knowledge and assistance they could expand their farms, employ more people and help reduce poverty. The Ghana Poultry Farmers Association exists to help the poultry farmers in terms of providing feed at reduced prices. The Veterinary Services Department help farmers to diagnosis and treat for diseases of birds (IWMI, 2006).

Some farmers engage in poultry and vegetable farming together. It is more beneficial because manure from poultry can be used for vegetable farming. For example, farmers in Kumasi apply poultry manure to cabbage (see Figure 4-7).

Figure 4-7: Farmers in Kumasi apply poultry manure to cabbage (Danso *et al.*, 2006)

Seasonal farming

(IWMI, 2006) shows that the "seasonal farming" system is very common at the outskirts of AMA, and is undertaken for sales and home consumption. In AMA, this system is mostly carried out during the rainy cropping season (March-September). It is found all over the city, but predominates in the low-density areas with open spaces (for more features see Appendix 7. These farmers are involved in other income generating activities like cane basket weaving, office security services and carpentry. The seasonal farming income enables them to meet their basic needs.

(Agodzo *et al.*, 2003) state that even the seasonal crop farming also sometimes requires irrigation water according to the effectiveness of rainfall in the respective location of Ghana (see Appendix7).

Non-traditional farming (grasscutter and snail farming)

Grasscutter farming is one of the very lucrative farming systems in the city. It is the most expensive meat sold at the restaurants, canteens, hotels, and chop bars in the city. Most of the farmers (74%) were of the view that keeping grasscutter is sustainable because of its profitability, low mortality of animals, abundance of feed (grass) and the occurrence of two cycles in a year.

4.2.2. Profiles of urban / peri-urban farmers

(Maxwell *et al.*, 2000) report that the mean household size (persons) in Greater Accra of female-headed households is 5.2, male-headed households is 4.8, and all households is 5.1. The average household size in AMA is 4.5. More details of household size of farmers in Accra are shown in Table 4-1. In Accra between 13 – 16% of the urban and peri-urban dwellers engage in some form of agricultural activity including livestock and poultry production.

Household size is important in this thesis because in the conceptual design, one toilet is designed for one household with an assumed size of 4.5 people (see Section 5.3).

Table 4-1:Household size of farmers in Accra, Kumasi[29] and Tamale (Obuobie et al., 2006)

Family size	Accra %[30]	Kumasi %	Tamale %
Alone	20	35	15
1-5	49	59	50
6-10	26	6	30
Above 10	5	0	5

Most of open space farmers are Muslims who migrated to the city searching for job opportunities. The religious status of urban farmers is shown in Table 4-2 (Obuobie *et al*., 2006). This is important for this research because there are some religious impacts for selection of toilet types (washers and non-washers) and usage of faeces and urine for urban agriculture.

Table 4-2: Religious status of urban farmers in Accra, Kumasi, and Tamale (Obuobie et al., 2006)

Religious affiliation	Farmers in Accra %	Farmers in Kumasi %	Farmers in Tamale %
Christian	30	61	13
Muslims	67	37	86
Other	3	2	1

The gender ratio in open-space farming in various cities of West Africa is shown in Table 4-3 (Obuobie *et al*., 2006). The authors further state that the gender ratio can be varied in backyard farming.

Typically, females of the households are engaging in backyard farming whereas males are engaging the other types of farming. Females involve more directly in sanitation issues, so the gender ratio in urban agriculture is important if we want to link sanitation to urban agriculture.

Table 4-3: The gender ratio in open-space farming in various cities of West Africa (Obuobie et al., 2006)

Country	City	Female %	Male %
Benin	Cotonou	25	75
Burkina Faso	Ouagadougou	38 (0-72)	62
Ghana	**Accra, Kumasi, Tamale**	**10-20**	**80-90**
Nigeria	Lagos, Ibadan	5-25	75-95
Senegal	Dakar	5-30	70-95
Sierra Leone	Freetown	80-90	10-20

There is a wide variation in literacy level, and in many open space farmers are illiterate. Farmers in Accra and Kumasi have a higher literacy level compared to farmers in Tamale (Table 4-4).

[29] Kumasi and Tamale are other two main cities in Ghana
[30] Preferably Greater Accar

It is important to know the education level of farmers for this research because farmers should be educated regarding usage of natural fertilisers (sanitised faeces and urine) in urban farming.

Table 4-4: Education status of farmers in Accra, Kumasi, and Tamale (Obuobie et al., 2006)

Education attainment	Accra %	Kumasi %	Tamale %
Illiterate	48	35	79
Primary	4	51	17
Secondary	44	12	3
Tertiary	4	2	1

4.2.3. Financial conditions in Accra related to urban peri-urban agriculture

Specialisation in high-value crops enables farmers to earn a significant income and provide the city with a reliable supply of perishable crops (Drechsel *et al.*, 2006b). The authors further state that the irrigated vegetable production is financially attractive in providing income and livelihood. The data from (Danso *et al.*, 2003), for individual profits from mixed vegetable production in open-space urban agriculture shows a wide range of monthly incomes, which depends on the farm size (refer Appendix 7).

Comparing different farming systems in Kumasi, urban farmers with access to irrigation water are able to cultivate all year round and can obtain annual income levels of US$ 400 to 800 (Cornish and Lawrence, 2001). However, to reach this income level needs careful observation of market demand. Revenue generated in different farming systems in Kumasi is shown in Appendix 7.

4.2.4. Constraints associated with urban, peri-urban agriculture in Accra

Constraints identified in urban peri-urban farming in Accra, Kumasi, and Tamale are as follows (Obuobie *et al.*, 2006):

- Marketing of production: vegetable market sellers dictate produce prices at harvest
- <u>High cost for fertiliser</u>, pesticides, farm tools etc.
- Pest and disease threats to crops
- Lack of available land and tenure insecurity due to increasing rate of urban development
- Dry-season <u>access to water for irrigation</u>
- High labour cost (personal or paid) for watering of vegetables
- Poor seeds viability (lettuce, cauliflower, cabbage)
- Lack of capital funding sources: farmers have to fund themselves or make an arrangement with the market seller to provide them with some advance payments for more production
- Limited support by extension service, for example government, municipality or NGOs

Underlined constrains are those for which ecosan can play a role in reducing these constraints. It is easy to find natural fertilisers and soil conditioners such as urine and sanitised faeces from the farmers' own residential areas. These fertilisers are cheaper than chemical fertilisers.

In ecosan type of toilets water is not used for toilet flushing and greywater is reused which automatically leads to reduce the household water demand. This saved water can be used for agricultural purposes.

Table 4-5 shows the percentage of farmers who identified each constraint as important. According to the values in the table, it is clear that input (that represents the fertilisers) and water are the most important constraints for urban agriculture in Accra.

Table 4-5: Key constraints identified by farmers in Accra and Kumasi (Obuobie et al., 2006)

Constraint	**Accra %**	**Kumasi %**
Marketing	42	35
Input (fertiliser/manure, tools, seeds)	**82**	69
Water	**75**	53
Crop disease	48	55

More details of nature of important constraints identified by farmers in Accra and Kumasi are shown in Table 4-6.

Table 4-6: Nature of important constrains in urban farming in Accra and Kumasi (Obuobie et al., 2006)

Nature of constrains	**Water (%)**		**Input (%) (Fertiliser, tools, seeds)**		**Marketing (%)**		**Crop disease (%)**	
	Accra	Kumasi	Accra	Kumasi	Accra	Kumasi	Accra	Kumasi
Lack of adequate supply	2	45						
Public criticism	11	0						
Conveyance	2	31						
Quality	22	0	20	26				
Cost	24	8	**47**	68				
Shortage	**56**	42	6	0				
Viability of seeds/expired chemicals			27	20				
Lack of tools and equipment			12	0				
Seasonal low demand					28	59		
No direct market access/cheaper pricing for production					32	29		
Yield reduction							31	22
Crop damage					12	18	69	78

4.2.5. Usage of fertiliser and soil conditioner on urban peri-urban agriculture in Accra

According to (Asante and Cofie, 2006), the main challenge in usage of sanitised human excreta in Accra would be the perception of people. This depends on factors such as culture, economy, urban/rural population pattern and gender influencing how people perceive human excreta, and arrangements and devices for managing faeces and urine. The general view is that the odour and appearance of faeces is more repulsive than that of urine. However, over time the odour of urine can become worse when the urea in urine is converted to ammonia gas[31].

Muslim communities[32] in Accra consider urine as unclean and usually wash it off after urinating because of their religious belief. Therefore, according to (Asante and Cofie, 2006) it would be highly impossible for Islamic faith farmers to associate with use of urine in agriculture[33]. They would prefer to use urine rather than faeces. The view of Muslims is that faeces should not be seen. However, non-Muslim communities' view is different.

The farmers in Accra prefer to buy chemical fertilisers rather than human excreta and animal waste (Asante and Cofie, 2006). However, ecosan systems can provide the fertilizer needed in both urban and rural areas. Human urine and faeces collected and sanitised in cities can be transferred to rural areas as fertiliser. This should result in higher crop yields.

(Asante and Cofie, 2006) further state that "The Valley View University (VVU) located at Oyibi in Accra has begun using urine as manure to grow crops in a pilot project. The university collects all in storage tanks, store it for between three and four months and transport it to its farmlands to fertilise maize, sorghum, plantain, pawpaw and other crops. Seven urine collection and three storage tanks have been installed on the university for processing of 10,000 liters of urine. About 40 farmers in Oyibi and other nearby communities have been exposed to the urine technology and are using urine manure in their farms".

The NGOs the "Rural Entrepreneur Development Foundation" and the "Orphange Home Ayeniah" use this technology and have commenced to educate farmers on the use of human excreta as fertiliser (Asante and Cofie, 2006).

4.2.6. Fertiliser prices in Ghana

In Ghana, 80% of the total fertilizer requirement of the country is imported. Ghana imports large amounts of ammonium sulphate (AS) and muriate of potash (MOP) and marginal amounts of urea, single super-phosphate (SSP), and triple super-phosphate (TSP), see Table 4-7 (FAO, 2005). These figures of imported fertilisers are for the whole of Ghana. It is unknown how much of this fertiliser is used for urban agriculture in AMA or Greater Accra.

Table 4-7: Fertiliser imports in Ghana ('000 tonnes product) (FAO, 2005)

Year	15-15-15[34]	Urea	MOP	AS	SSP/TSP & others	Other compounds	Total	Total [35] (kg/ha/yr)
1997	19.2	1.9	5.5	10.7	1.1	17.9	56.3	13.4
1998	13.1	0.5	3.1	13.3	3.6	8.8	42.4	10.1
1999	3.2	0.0	8.1	4.8	5.5	0.4	22.0	5.2
2000	14.1	0.1	4.5	23.2	0.8	0.8	43.5	10.4
2001	31.8	2.5	4.1	22.6	2.3	17.5	80.8	19.2

[31] This is not usually a problem since urine storage tanks are covered, hence odour is contained in the tank.
[32] Most of the farmers in urban Accra are Muslims (see Table 4-2)
[33] But note that Muslims in other parts of the world have used urine as fertiliser, e.g. Philippines (see Section 4.4.2)
[34] 15-15-15 means a fertiliser with (by weight) 15 % N, 15 % P_2O_3, 15 % K_2O
[35] These figures were calculated based on arable land area 4,200,000 ha of Ghana (see Section 3.1).

The retail prices of fertilisers in Ghana are shown in Figure 4-8. It seems that the prices of fertilisers increase drastically between 1999 and 2002. These values were calculated by using the current exchange rate Euro/Cedis equals to 1/11500. I used the current exchange rate for each year from 1990 to 2002 but the value of Cedis might have been higher in the early1990s, so it is difficult to compare. The higher the price for urea, the more attractive will it be to use urine as a nitrogen and phosphorus rich fertiliser in urban agriculture instead.

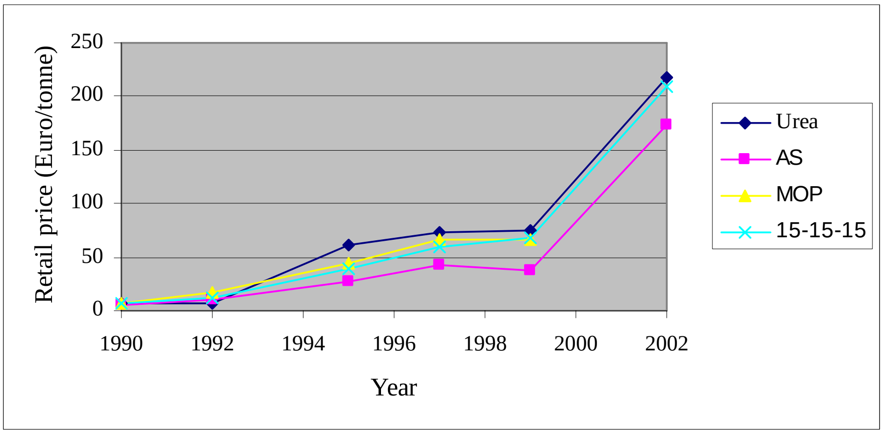


Figure 4-8:Retail prices of fertilisers in Ghana (Euro/tonnes) (FAO, 2005))

The optimum fertiliser requirements and prices, maximum crop yield and value cost ratios (VCR) are shown in Table 4-8. The VCR should be higher than 2 for secure and profitable return to the farmer (FAO, 2005).

Table 4-8: Optimum fertiliser requirements, maximum crop yield and VCRs in Ghana (FAO, 2005)

Crop	Fertilizer type	Bags/ha (1bag=50kg)	Maximum yield (Tonnes/ha)	Fertilizer total cost (Euro)	Crop value (Euro)	VCR
Maize	AS SSP MOP	5 5 1	5.0	89	239	2.7
Rice (flooded)	AS TSP	5 2.5	6.5	62	622	10.0
Cassava	AS SSP MOP	7.5 5 2.5	28.0	128	609	4.9
Groundnut	AS SSP MOP	1.5 5 0.5	2.0	57	209	3.6

4.3. Urban agriculture in Lima

4.3.1. Features of urban / peri-urban agriculture in Lima

(CIA, 2007) states that the total arable land in Peru is 2.89% of the total area and the permanent crop area is 0.4%. The total irrigated land in Peru is 11,950 km^2. Agricultural products in Peru are coffee, cotton, sugarcane, rice, potatoes, bananas, grapes, oranges, coca, poultry, beef, dairy products and fish. Maize, lettuce, spring onions, green beans, tomato, aromatic plants and ornamental plants are the main agricultural crops in Lima.

(Inkaways, 2006) states that about 35% of the Peruvian population is working in agriculture.

According to (Ninez, 2006), Peruvian governments past and present have attempted to feed the nation's 19 million people by both increasing agricultural output and expanding the land area under cultivation. Neither land reform nor large-scale colonisation, however, has produced the expected results. Agricultural production is generally marked by an increasing coastal output in urban food items (chickens, eggs, milk, horticultural field products etc.) and agro-industrial crops.

(Ninez, 2006) further describes that Lima is historically known as the "Garden City". Gardening on the Peruvian desert coast is not an easy task. Except in river deltas, such as the Rimac and Chillon in the case of Lima, all efforts at cultivation depend on the presence of (non-saline) irrigation water, something that poses a particular problem for the slums. For the slum inhabitants, poor soil is an additional impediment to the establishment of productive gardens.

(Bussink *et al.*, 2002) states that Lima metropolitan is located at the end of three river basins with long, drawn-out irrigated agricultural areas where a lot of the food[36] is grown for the city and where some export crops are produced that contribute substantially to the nation’s income. The metropolitan location has an ambiguous influence on agriculture in Lima, since expansion of urban areas competes with land area available for agriculture. But at the same time the growing demand for food gives agriculture good revenues, and influences structure and intensity of crop production.

(IWMI, 2003) describes that the treatment and use of wastewater are a challenge in Lima. It is a challenge because the use of untreated wastewater is often the only option available to peri-urban farmers. In 2003, about 80% of wastewater was discharged untreated into bodies of waters or was used for irrigation in farming. This poses potential serious health problems because of the presence of pathogens. It is an opportunity because wastewater is a valuable resource, not only from the economic viewpoint but also from an environmental perspective.

(IWMI, 2003) further describes that many households in the shantytowns have to buy water from private suppliers. This water is much more expensive than water from the public system. In older poor areas of the city, houses are linked to the public water supply network but the supply they get is so little, often just a few hours a day. Therefore, families are not keen on using it to grow vegetables.

Frequently, kitchen wastewater (part of greywater) is used for producing small numbers of plants and rearing animals. Figure 4-9 shows a home garden irrigated with treated greywater. On a limited scale, extra water is purchased for gardens where metered lines are not available (Ninez, 2006).

[36] They do not mention how much.

Figure 4-9: A home garden irrigated with treated greywater in Lima (Laura, 2005)

(Pinzas, 1994) states that the average size of the allotments in poor areas decreases. By 1994, urban specialists say that the average area of new houses in shantytowns is around 80 m^2, which does not leave much room for gardens. Some families specialise in growing vegetables for the local market, but this path is not taken by the majority and cannot be considered a significant survival strategy in urban areas. Unfortunately, vegetables do not have an important place in the traditional or present diet patterns of low-income families.

Figure 4-10 shows how urban farmers grow salad in the limited space in Lima.

(Ninez, 2006) shows data on indigenous food gardens of Lima (low-income gardens) ranging in size from a few square meters to an entire lot of 900 m^2. Beginners often start with nothing more than a few corn stalks, a young banana shoot, and some herbs and flowers, which are frequently consumed or used by the household. The family kitchen garbage pile often functions as a seedbed for planting of tomato, papaya etc.

(Ninez, 2006) further describes that while planting continues and increases; soil is improved slowly through the incidental and planned incorporation of plant refuse. Examples of excellent suppliers of organic refuse are banana, papaya, and pigeon pea. Vegetable remains can be fed to household animals, usually guinea pigs and/or rabbits and poultry, including ducks, turkeys, and chickens.

Figure 4-10: Salad production in Lima (www.cipotato.org)

According to (Laura, 2005) in the case of rabbits, farmers recognised that they get benefits from the rabbits because they reproduce very fast, so some families not only eat but also sell them (Figure 4-11).

Figure 4-11: Cages with rabbits in home garden in Lima (Laura, 2005)

(Ninez, 2006) describes that in mature gardens with water and space available, the cropping list can be quite diverse. The typical garden features tree crops (mainly banana and papaya, as well as avocado, mango, guava, guanabana, fig, pacay etc.), fruit-bearing climbers (passion fruit), vegetable staples (maize, roots, and tubers), and some leaf and fruit vegetables and beans. Herbs, medicinal plants, and flowers complete the cropping list. Vegetables not native to the region and poorly adapted to the harsh desert environment are only found in the larger plots of experienced gardeners or of people with field horticultural backgrounds who are provided with good soil and water.

According to (Ninez, 2006) the gardening skills were acquired in family agricultural field and horticultural production before coming to the capital, as a child living with parents or relatives. One of the main differences between male and female gardeners in Lima is that men are usually interested in capitalising on their backyard enterprises such as planting mostly fruit trees with a good market value, while women are aiming to produce food for family consumption.

(Rios, 2003) states that in Lima, there is a new technology, which is called hydroponics (tubeoponics). Hydroponics is a technology characterised by the absence of soil, allowing the growing of crops of better quality in small urban spaces, requiring less time, less labour, and less inputs. Figure 4-12 shows how large varieties of crops are grown on a small area. It uses containers, in some cases under direct irrigation with water enriched with nutrient-enriched solutions, and in others, with irrigation through substrata that also serves to fix roots, provide adequate humidity and meet the oxygen requirements for specific crops. Results are said to be spectacular, in terms of both yields and low-cost of inputs.

Figure 4-12: A large variety of crops are grown on a small area with hydroponics system in Lima (Rios, 2003)

Hydroponics for the poorer segment of the population is based on the following concept: "It allows the production of fresh, healthy and abundant legumes with low water consumption and less physical work, but with a lot of dedication and perseverance, in small spaces at home, in many cases taking advantage of waste elements[37]. This urban agriculture technology gives a productive use to some of the idle time of family members. The potential productivity of hydroponic crops when developed in optimal conditions is greater than the productivity generated by traditional garden cultivation systems" (Rios, 2003).

(Rios, 2003) further states that the Peruvians focus on hydroponics as it is the most suitable technology for household and commercial practices. It implies the growth of legumes, ornamental, aromatic and medicinal plants in the peripheral areas of Lima, where it is difficult to farm due to poor soil conditions and lack of water for irrigation. Hydroponics is also practised on rooftops in Bogota, Colombia.

4.3.2. Profiles of urban / peri-urban farmers in Lima

(Ratta, 1993) found that in the slums of Lima, 80% of farmers are housewives. Urban women farm to feed their families and to generate income. Growing and eating home-grown food frees up income for other necessities and improves the family's diet. Women's role in urban agriculture is not limited to food production, but includes processing food for home consumption and for the market (Figure 4-13). Urban agriculture in the hands of women is a powerful tool to improve their families' diets, incomes and food security.

[37] This is of course inline with the ecosan concept of reuse.

Figure 4-13: Harvesting with a local women producer in one city in Lima (Merzthal, 2006)

The publication of (Ninez, 2006) shows that many female heads of household have opted to start a small garden adjacent to the family dwelling. Male family members seek employment outside, whilst women with small children are usually unable or unwilling to find work away from home.

4.3.3. Financial condition of people in Lima engaged in urban peri-urban agriculture

According to (Ninez, 2006) over five months, earnings for the average family amount to an average US$ 300 from their gardens. Garden produce adds an indirect income of almost 10%, not counting the convenience of having a ready supply of basic foodstuffs and/or animal fodder. A 10% increase in earnings helps considerably in Peru's continuing struggle against increasing prices. “At the macro-level, the cumulative benefits of seemingly insignificant household gardens are staggering. Calculated on the basis of this average garden, an annual US$ 56,660,000 of food could be produced by the larger metropolis if, out of the seven million inhabitants of Lima, one million families were to plant only a small food garden” (Ninez, 2006).

4.3.4. Constraints associated with urban peri-urban agriculture in Lima

(Pinzas, 1994) states that “lack of water is a major constraint to vegetable gardening in the coastal region of Peru, where Lima and the other main cities are located. In the case of Lima, rapid urban growth has outpaced the construction of potable water-supply systems”.

Water is still the major limiting factor for urban gardening. During the warmer months, water is periodically unavailable in many lower-class Lima suburbs, and gardens suffer considerably (Ninez, 2006).

According to (Ninez, 2006) the expansion of protected garden areas occurs close to the house, either onto the family lot or onto public land, such as roadside areas or land earmarked for parks. This expansion of vegetation, especially trees, is encouraged by municipalities, who regard such efforts as free beautification projects by citizens in the absence of municipal funds. However, families who expand their food production ventures onto public land have no tenancy rights, which is of great concern to gardeners and a definite constraint to increasing urban household food production.

(Agren, 2004) found that one major problem faced by urban and peri-urban farmers is their lack of access to knowledge and technologies for safe and sustainable agricultural development. Uneducated and excessive use of pesticides by peri-urban farmers in some regions often results in dwindling profits as well as health problems. To avoid this, conventional methodologies should be adapted to the socio-economic needs of the (peri) urban farmers, and to the (peri) urban environment.

(Agren, 2004) also found that another main problem confronting the practice of urban and peri-urban agriculture in Lima is the absence of local policymaking and planning procedures for urban agriculture. Poor city farmers often farm illegally on marginal plots of land using polluted water sources. This is because city planners, so far removed from the realities of the poor urban residents, do not recognize agriculture as being a viable urban activity, and instead consider it a public nuisance.

4.3.5. Usage and prices of fertilisers and soil conditioners on urban peri-urban agriculture in Lima

I found the information in paragraphs below through verbal discussion with a Peruvian[38] and by using the translation of some details from Spanish to English from the web site given below.
(http://www.fertilizer.org/ifa/publicat/PDF/2003_rome_poster_bowen.pdf).

The use of commercial fertiliser for agriculture in Peru follows a very general pattern distinguishing smallholder and commercial production. Most of the country's crop is grown by independent farmers, usually in some mixture of subsistence and commercial sale, with very low levels of commercial fertiliser and other purchased inputs.

On the other side, commercial fertilisers are heavily used by larger scale commercial potato, asparagus, paprika, rice producers, typically in coastal valleys west of the Andes. A recent survey carried out in La Encañada, an area near Cajamarca, indicated that only thirty percent of potato farmers in the area applied fertiliser, though some applied poultry manure when it was available. When using those fertilisers, the average nitrogen application rate was approximately 30 kg/ha. By comparison, in the Carchi area of Ecuador, where more intensively commercial production has been underway for several years, farmers typically apply 140 kg nitrogen and other nutrient elements per hectare.

The average price for urea in Lima was € 40.4 per bag of 50 kg in September 2006. Normally in Peru is 90% of the fertiliser used is imported (see Figure 4-14).

According to (Laura, 2005), people use the compost produced from ecosan toilets as fertilizer for their plants and green gardens.

Refer Section 3.2.4.2 for example of human excreta usage in Lima.

[38] Alicia Roman

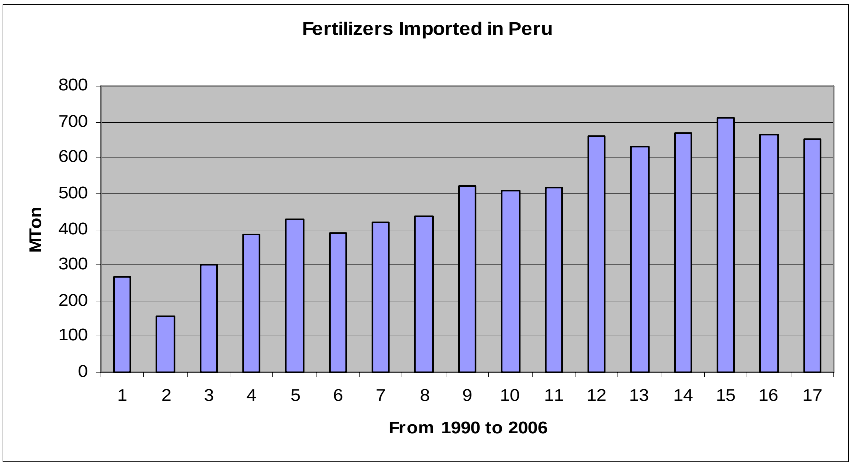


Figure 4-14: Amount of fertilisers imported in Peru (10^6 ton per year)

(Source: http://www.fertilizer.org/ifa/publicat/PDF/2003_rome_poster_bowen.pdf)

The figures of imported fertilisers as shown in Figure 4-14 are for whole of Peru. It is unknown how much of this fertiliser is used for urban agriculture in Lima.

4.4. Comparison of urban agriculture in Accra and in Lima

The Table 4-9 and Table 4-10 below summarise the urban agriculture situation in Accra and in Lima based on the information presented in Section 4.2 and 4.3.

Table 4-9: Summary of urban agriculture characteristics in Accra and in Lima

Description	Accra (or AMA)	Greater Lima
Rainfall (mm/yr)	810	70
Soil quality	Unfertile soil	Sandy unfertile soil
Type of farming	Irrigated, livestock, aquaculture, open space, backyard and seasonal crops	Irrigated, livestock, aquaculture, dairy products and hydroponics
Type of crop	Maize, lettuce, spring onions, beans, tomato, rice, cassava, cabbage, spinach, cauliflower, cucumber	Maize, lettuce, spring onions, green beans, tomato, aromatic plants, ornamental plants
Type of water supply	River, drain (ww), stream, shallow well	River, Drain (ww), kitchen ww, drinking water
Fertiliser use	Artificial inorganic (15-15-15, urea, AS, MOP), animal manure (poultry)	Artificial inorganic (urea- only known)
Main constraints	Access for water, high cost for fertiliser, lack of capital, lack of technology, market for production, lack of space, pest & disease threat	Access for water, high cost for fertiliser, lack of capital, lack of technology and knowledge, lack of policy making and planning procedures
Current cost of urea (€/ton)	218	808
Country-wide fertiliser use	19.2 kg/ha/year	While application 30 kg/ha
% of residents engaged in urban agriculture	For AMA 10-16 %	Un known

Table 4-10: Summary and possible role of ecosan of main constraints in urban agriculture in Accra and in Lima

Constraints for urban agriculture	Impact of ecosan to reduce constraint	Further approaches and solutions to lift constraints
Access for water	• Greywater treatment and reuse • Save water by not using it to flush water • Consider rainwater harvesting • Soil conditioner increases water holding capacity (less water needed for same yield)	• Introduce UDD toilets in low-income urban areas • Implement projects to safely reuse greywater even at household level
High cost for fertiliser	• Use of human urine as a fertiliser • Use of sanitised human faeces as soil conditioner • Easy to find these natural fertilisers locally at low cost	Launch awareness campaigns to educate farmers in practices to ensure sustained soil fertility
Market for production		
Lack of capital	Ecosan-derived fertilisers much cheaper than artificial fertilisers	
Lack of space	Higher yield on smaller areas; hydroponics reduces space requirement	
Lack of technology		Government-supported education campaigns; school gardens
Pest & disease threat	Urine has been used to kill some insects	
Lack of secure tenure		Need to form farming groups and negotiate with land owners

4.5. Examples of urban agriculture practices in other cities of developing countries

4.5.1. Kuala Lumpur, Malaysia

Worn rubber tyres are used in urban agriculture as a growing medium of plants: They can be used as containers (filled with soil), in which water can be efficiently used for soil composting and for storing material, and for growing a variety of plants and trees (Globnet, 2006). This is a good concept for soil preservation and water management in urban areas, which have little space for farming/gardening.

4.5.2. Philippines

According to (Holmer and Miso, 2006), there are two types of gardens in the Philippines: Allotment gardens where parcels of land are cultivated individually, and common gardens where the total area is tended to collectively by a group of people. In Cagayan de Oro, a city in the Philippines uses urine and faeces in urban gardening (collected in UDD toilets). According to the data, yield of sweetcorn increased up to 30% while applying urine compared to no fertiliser added (see Figure 4-15 and Figure 4-16). Data on monthly household income, savings of people and vegetable consumption level after introducing new allotment gardens in the city Cagayan de Oro are shown in Appendix 8.

An important point for this Philippines example is that they have overcome the lack of secure tenure by securing a long-term agreement with the land owners. Also farmers are Muslims but are still willing to reuse urine.

Figure 4-15: Transportation of urine container and application of urine through furrowing in Cagayan de Oro, Philippines (Holmer and Miso, 2006)

Figure 4-16: Maize yield increased up to 30% by applying urine in Cagayan de Oro (Holmer and Miso, 2006)

Table 4-11 shows the perception of people who are living in Cagayan de Oro, towards the usage of products prepared by using ecosan fertilisers.

Table 4-11: Perception towards reuse of ecosan products (Holmer and Miso, 2006)

Willingness to eat vegetables fertilized with urine	**Gardeners %**	**Non-Gardeners %**
Yes	92	56
No	8	44
Willingness to eat vegetables fertilized with faeces		
Yes	92	62
No	8	38

4.5.3. Kampala, Uganda

(Kiguli, 2005) states that urban agriculture is becoming a real, complex and dynamic feature of the urban landscape and socio-economic situation in Uganda. It takes place on undeveloped areas of land, dumping places, backyards, wetlands, and other common properties of urban areas. Urban agriculture includes market garden crops, small-scale livestock rearing, poultry farming, fish farming, agro-forestry and associated post harvest operations.

(Mwanga and Makumbi, 2003) found that agriculture in the capital Kampala is practised mainly in valley slums where poor people live in informal settlements. 40% of the city's population consumes crop or animal product produced in the city, while 70% of all poultry products produced are produced within the city. 28% of the city inhabitants access food produced from urban farming. The land area used for urban agriculture in Kampala is 51% of the total city area, and 83% of households who are involved in urban agriculture have backyard gardens (75% of the people involved in urban agriculture are woman). Figure 4-17 shows farming in urban area in Uganda.

(Kiguli, 2005) shows that the major source of food grown in most urban centers are bananas, maize, cocoyams, sweet potatoes, cassava, beans, sugar cane, fruits and vegetables (cocoyams and sugar canes are considered as cash crops).

There are mainly four types of farmers engaged in urban agriculture as shown in Table 4-12.

Table 4-12: Characteristics of four types of urban farmers in Uganda (Kiguli, 2005)

Type 1	Type 2	Type 3	Type 4
▪ Economically powerful ▪ Numerically small ▪ Growing mushrooms	▪ Significant amount of land ▪ Have sufficient food including cassava, beans, sweet potatoes	▪ Largest category ▪ Aim at food security ▪ Farming is secondary employment and secondary source of income ▪ Family size 4-7 ▪ Cultivating away from their localities	▪ No other means of income ▪ Farm for survival and consumption ▪ Sometimes sell to meet other needs (soap, salt, school fee etc.) ▪ Mainly comprise of widows of female headed households


Figure 4-17: Working in an urban agriculture area in Uganda (Kiguli, 2005)

According to (Kiguli, 2005), the constraints identified for urban agriculture in Uganda are as below:

- Lack of services and markets
- Gaining access to land to grow food
- Declining land fertility
- Lack of farming technology

5. Design, cost estimates and multi-criteria analysis of two sanitation systems for Accra Metropolitan Assembly (AMA)

The detailed analysis of sanitation systems was carried out for only Accra Metropolitan Assembly (AMA) because of the lack of available data for Lima.

5.1. Components of the sanitation system

All components of the sanitation system as shown in Figure 5-1 are considered during the selection process. When I use the term "latrine/toilet" in this section it implies that all components with the downsteam processing in the sanitation systems are included[39].

Each of these components is important because of the following reasons:

- **Toilet device (Part A):** This component helps to improve the hygiene of households by avoiding contact with excreta and destroying pathogens depending on the toilet type chosen.
- **Collection and transport of excreta to treatment plant/disposing place (Part B):** This provides the connection between Part A and Part C.
- **Treatment and storage of excreta (Part C):** Pathogens in faeces are destroyed due to treatment or sanitising by storage which reduces spreading of waterborne diseases.
- **Transport from treatment plant to place of reuse (Part D):** This part describes the transfer of sanitised or treated excreta to reuse site linking Part C and Part E.
- **Reuse in agriculture (Part E):** Safe reuse of sanitised excreta as nutrient-rich fertiliser and soil conditioner in urban agriculture is considered in this part.

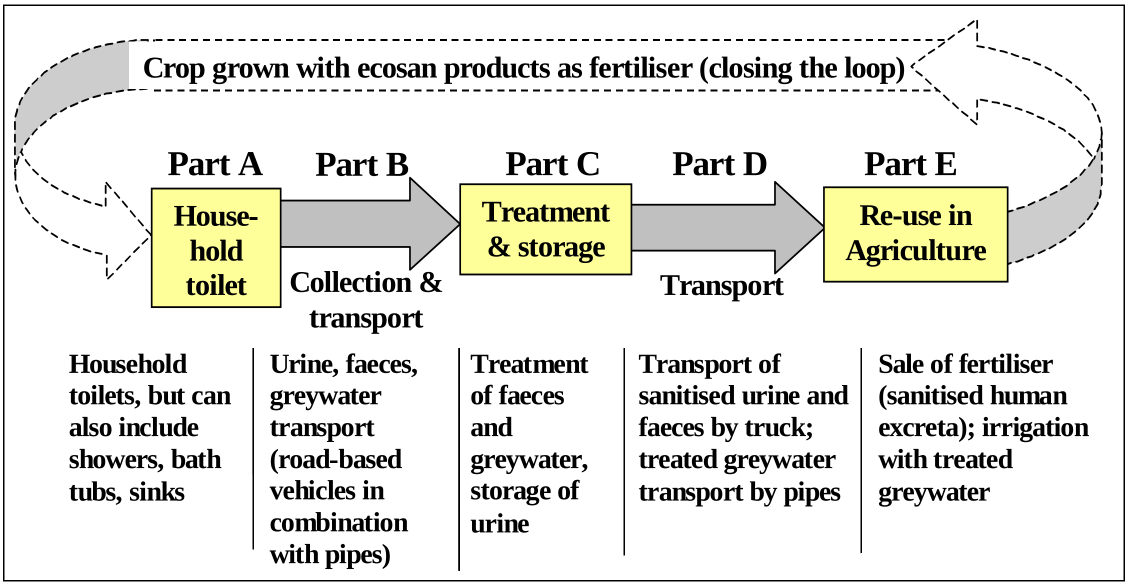


Figure 5-1: Schematic diagram of the components of the sanitation system (Münch and Mayumbelo, 2007)

[39] However, I have not included the management of the greywater because of time constraints in my thesis.

5.2. Available sanitation options in AMA and selection procedure

Although greater Accra consist of 5 main districts namely Accra Metropolitan Assembly (AMA), Tema, Ga, Dangme West, and Dangme East (more details are in Appendix 9), in this chapter I concentrated only on AMA because:

- Urban agricultural activities are mostly taking place in this district
- The area is highly urbanized with a population density of 83 people/ha.
- High inequalities exist in the distribution of income in AMA due to migrants in different income levels. Therefore, they can earn additional income, e.g. for their daily food requirements, by using low-cost natural fertilisers (sanitised faeces and urine) in urban agriculture.

5.2.1. Available low-cost sanitation options for Part A of the sanitation system

Only options that classify as "improved sanitation" from (WHO/UNICEF, 2006) are considered in the list of available sanitation options. I have considered the following four as low-cost, improved sanitation options for AMA.

Option 1:Ventilated improved pit latrines (KVIP/VIP)[40]: This type of toilet is commonly used in this area.

Option 2: Urine Diversion Dehydrated toilet (UDD): For this study, I selected the double vault UDD type and not the single vault type because it gives more complete sanitation (when one vault is full the other vault is used for collection or excreta). After one year storage time, the excreta is mostly sanitised and can be removed from the vault easily. Although in my conceptual design, I assumed that all excreta is transported to the storage site, in an actual situation the households can utilise them easily as soil conditioner after one year of storage time in their own vaults.

Option 3: Simple pit latrine (with or without lining): This type of toilet is used by a considerable percentage of households in AMA.

Option 4: Pour-flush or water closet (WC) toilet: This type of toilet can be connected to either a waterborne sewer system or a septic tank and soakaway. In the waterborne system, wastewater is collected through a centralised sewer system and treated and/or disposed. When the toilet is connected to the septic tank and soakaway sludge from septic tank has to be desludged periodically. Normally this type is used by high income families only unless the pour-flush toilet is connected to a pit.

Notes related to the available sanitation options:

- All options could be implemented as either individual household toilets or shared public toilets.
- All options require faecal sludge management because they produce wet sludge except Option 2.

5.2.2. Selection criteria for Part A of the sanitation options

Any sanitation option should be of course environmentally sustainable, reliable as well as affordable for households living in the selected area.

[40] Although Accra people say KVIP (Kumasi ventilated improved pit latrine), I use the established abbreviation VIP since there is no significance difference between them.

I used the following criteria for selection of the sanitation options (Part A) of the Accra Metropolitan Assembly (AMA):

- Groundwater and surface water sources should be protected from pollution by human excreta (pathogens and nitrate).
- Investment and operation and maintenance cost are very important criteria for sanitation technology selection for poor households in an urban area.
- Since water supply in unreliable in AMA (see Section 3.1), water should not be wasted for toilet flushing and transport of waste.
- Odour and flies should not be present.
- The possibility to use sanitised human excreta for urban agriculture would be an advantage.

5.2.3. Short listing of sanitation options

According to the selection criteria listed above the following sanitation options for Part A are disqualified.

Option 3: Simple pit latrine (with or without lining): This type of latrine infiltrates the leachate to the soil and eventually groundwater which can lead to pollution of groundwater. Groundwater is used as drinking water in AMA (see Section 3.1). When considering the whole downstream process of the pit latrine option it causes pollution of the surface water by discharging treatment plant effluents as well (if faecal sludge is treated at all). Odour and flies are also significant problems related with this type of latrine.

Option 4: Pour-flush or water closet toilet: Pour-flush latrines have a higher water use compared to the other options which results in greater pollution potential and wasting of good quality water[41]. If connected to a septic tank, the septic tank needs be emptied periodically otherwise faecal sludge might overflow. High operation costs are associated with the emptying. Investment costs are also relatively higher for this option than others. If the pour-flush toilet is connected to a pit only, then groundwater pollution can occur. This option is therefore ruled out.

The only two remaining sanitation options out of the four options listed above are Option 1 (ventilated improved pit -VIP) and Option 2 (urine diversion dehydrated -UDD – double vault type ecosan option). However, this does not imply that these short-listed two options have no disadvantages (see Table 5-1)

Note: Option 1 and 2 consist of more than just the toilet (see Table 5-3), so when I refer to option 1 as the “VIP toilet option” I mean “VIP toilet plus downstream processing” (the same for Option 2).

[41] Most of the time drinking water is used for flushing the toilet.

Table 5-1: Advantages and disadvantages of Option 1 and Option 2 (VIP and UDD toilets used) in Part A

Short-listed option for Part A	Advantages	Disadvantages
VIP latrine Option 1	• No or less odour compared to simple pit latrine • Does not require water for flushing unlike pour-flush latrine • Comparatively low construction cost and low cost for operation and maintenance compared to septic tank option	• Risk of pollution of groundwater • Needs to be emptied or abandoned when full • Needs faecal sludge management • Faecal sludge treatment plants are difficult to operate with good liquid effluent quality • No easy reuse of nutrients in excreta for urban agriculture
UDD toilet (Double valut) Option 2	• No pollution of groundwater or receiving water bodies • Can be used in high water table areas – no need for excavation • Nutrients from urine can be recycled as fertilisers in urban agriculture; faeces can be recycled as soil conditioner • No water usage for flushing • Can be constructed indoors • Easy to destroy (by drying) pathogens due to separation of urine and faeces • Low cost for construction and maintenance • No odour (if use correctly)	• Somewhat higher investment cost compared to VIP latrine • Require user awareness, cooperation and training to use correctly • Requires know-how of this technology for labourers and all staff involved in the project • Requires yearly emptying of faeces from vault • Collected urine needs to be dealt with • Odour if used incorrectly

5.2.4. Implementation level of selected options for Part A

Both VIP latrines and UDD toilets can be implemented at household level or at communal level in AMA (public toilet or community toilet).

5.3. Conceptual design for Option 1 (VIP) and Option 2 (UDD)

5.3.1. Assumptions for conceptual design

For the conceptual design below, I have made the following assumptions:

- Each household would get their own toilet rather than having to share a toilet with other households. This implementation level was used because it is comfortable and hygienically safe to use one toilet for one household. However, it costs more.

- Sufficient space outside of the house or inside of the house is available for construction of latrine/toilet for each household (for UDD toilet).
- Sufficient access roads are available to toilets for collection and transport of faecal sludge, dried faeces and urine.
- 16 % of the total urban population in AMA is used for the design. This is the total population who are engaged in urban farming in AMA (total population of AMA is 1.6 million and 16% of this is around 265,000). This population of urban farmers is selected because urban farmers can use their own sanitised faeces and urine for farms with low cost and they can buy these fertilisers[42] easily in their own areas.
- The average household size (who will have one toilet) is considered as 4.5 (see Appendix 9).
- Typical transport distance (Part B) will be approximately 10 km.
- No storage after centralised treatment of faecal sludge for Option 1 (VIP) (after treatment direct transport to the agricultural area).
- Farmers are willing to buy treated sludge/ sanitised faeces/urine and are willing to transport it at their own cost (distance for Part D approximately 10 km).
- I used the work of (Mayumbelo, 2006) as a starting point. In the following, I will highlight where I made changes to his design. He had also short-listed two options for peri-urban areas in Lusaka, Zambia, namely VIP latrines and UDD toilets (single vault).

5.3.2. Details of concept design

Figure 5-2 and Figure 5-3 show a schematic diagram for a VIP latrine and for a UDD toilet, respectively. Table 5-2 and Table 5-3 show details used for conceptual design.

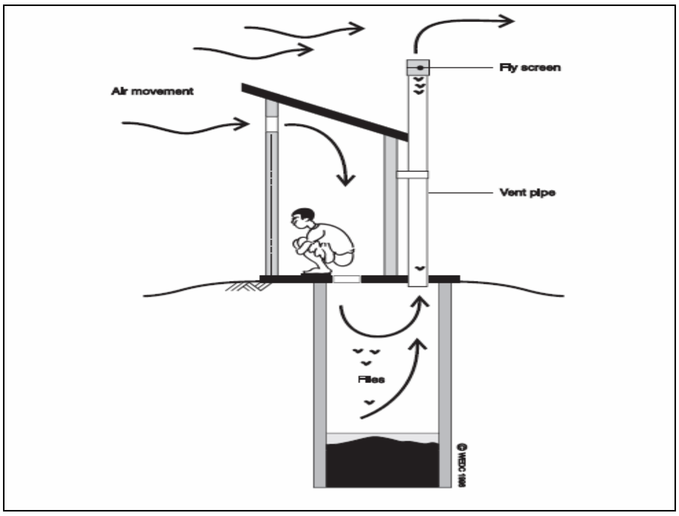


Figure 5-2: Schematic diagram of VIP latrine (source: (Harvey et al., 2004))

[42] Where exactly these 265,000 people in AMA live is unclear. They are scattered over the entire area of AMA.

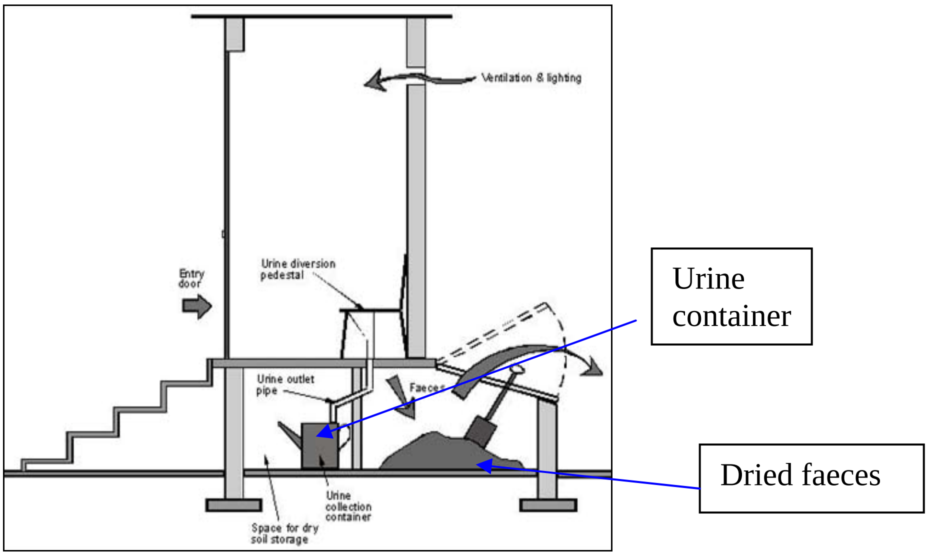


Figure 5-3: Schematic diagram of UDD toilet (www.sustainablesettlement.co.za)

Table 5-2: Input data for Option 1 and Option 2 for Part A

Input values for Part A	**Unit**	**Option 1 (VIP)**	**Option 2 (UDD)**	**Comments**
No of people sharing 1 toilet	people	**4.5**	**4.5**	Average household size of AMA
Specific sludge production	m^3/cap/yr	0.07	0.05	(Münch, 2006)
Desludging period	years	5	**2**	Alternatively use two vaults
Unused pit depth	m	0.6	0	
Substructure[43] cross sectional area (1 x 1.5)	m^2	1.5	1.5	Same for both
Superstructure maximum height	m	2	2	Same for both
Calculated values for Part A				
Minimum substructure volume	m^3	**1.58**	**0.45**	Volume of produced sludge/faeces (double vault volume for UDD) – see equation 1
Total substructure volume	m^3	**2.48**	**0.45**	Accounts for unused substructure depth)
Substructure depth	m	**1.05**	**0.3**	Calculated from volume of sludge produced & substructure
Total substructure depth	m	**1.65**	**0.3**	Substructure depth plus unused pit depth (from input values above)
Number of blocks in substructure	No	**47**	**19**	Calculated from size of substructure volume
Number of blocks in superstructure	No	93	93	Same for both options

The map in Figure 5-4 shows the location of the bio gas digester treatment plant for Option 1 (VIP) and proposed locations for storage of faeces and urine for Option 2 (UDD) in AMA. I assumed there are three centralised storage points at equal distance for easy transport for urine and faeces for Part A and Part D of Option 1 and one bio gas digester (with sludge drying beds) treatment plant for Option 1 because it is costly to construct and maintain more plants.

[43] Substructure is a pit for Option 1 (VIP) and vault for Option 2 (UDD).

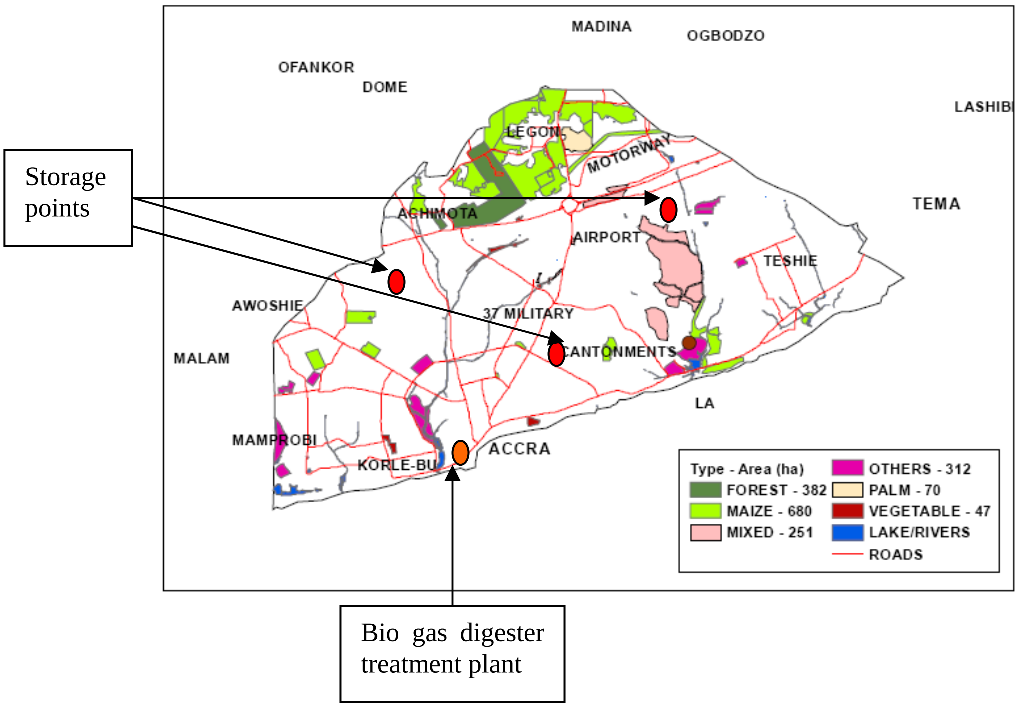


Figure 5-4: Locations of bio gas digester treatment plant (Option 1) and storage points for urine and faeces (Option 2) in AMA (area of locations are not to scale)

Table 5-3: Summary of concept design of two short-listed options[44] for AMA (population of 265,000 and average household size 4.5)

	Items which have an impact on capital cost		**Items which have an impact on O&M cost**	
	Option 1	**Option 2**	**Option 1**	**Option 2**
Part A Household toilets	VIP toilets (**59,000 toilets**)- outdoor toilets	Double vault UDD toilets (**59,000 toilets**) – indoor toilets	None	Additives to faeces chamber after defecation is assumed to be available for free
Part B Collection and transport of excreta	**Four** (Appendix 9) vacuum tankers to transport the faecal sludge to the treatment plant	• **One** (Appendix 9) open truck to transport dried faecal matter • **Seven** (Appendix 9) open trucks to transport urine barrels • Plastic barrels of **100 L** (assumed urine is collected once in every 14 days) for the urine storage at UDD toilet (2 barrels per toilet) Assume there are **three** centralised storage points at equal distance for easy transport for urine and faeces (see Figure 5-4)	Removing faecal sludge from the pit once it is full (includes fuel, maintenance on trucks, salary overheads)	Transport cost for faecal matter and urine barrels; includes fuel, maintenance on trucks, salary, overheads. Emptying of vaults (should be similar to garbage collection services).
Part C Treatment and storage of excreta	**One** (because it is costly to construct and maintain more plants) centralised faecal sludge treatment plant **(bio gas digester treatment plant with sludge drying beds**) (see Figure 5-4 for location)	No treatment required, only storage: • Dried faecal matter storage: Dried faecal matter is stored for 6 months on 2 m high piles on concrete slabs and covered with tarpaulin sheets during the rainy season to avoid leaching the nutrients • Urine storage tanks: assume urine will be stored in plastic tanks for 2 weeks to allow collection for re-use	Staff labour for operating the faecal sludge treatment plant (use figures for cost of treatment from **Accra**).	No treatment is needed, only further storage (increases pathogen die-off). Assumed five workers managing the incoming and outgoing flows of material.
Part D Transport of sanitised excreta	Open trucks could be used but are not included in cost estimate because we assume that in this case in Accra, the burden of transport would be shifted to the farmers who buy the fertiliser			
Part E Reuse in agriculture	No capital cost items (buying of land is not included)		Sale of treated sludge (compost)	Sale of ecosan products (sanitised faeces and urine)

[44] This conceptual design is principally the same as the one proposed in. Any differences are highlighted in bold.

5.4. Cost estimates for two short-listed options

It is relatively easy to quantify the cost for the toilet component itself (part A), while cost of the downstream process components (Part B to Part E) are more difficult to estimate because a detailed design would be necessary for an accurate cost estimate.

5.4.1. Cost estimates for Part A

The first cost estimations for VIP and UDD toilets in Part A are comparatively high (see Appendix 9 for details). Therefore, I used the cost from Burkina Faso[45] (see appendix 9 for details) for UDD toilet (because Ghana and Burkina Faso are neighbouring countries). I was unable to find the cost value for VIP toilet from Burkina Faso. Then, I used VIP to UDD cost ratio (see Table 5-4) from my first calculations to find out cost value for VIP toilet in Burkina Faso. Finally, I used these Burkina Faso costs to calculate the investment costs in Table 5-7 for Part A for Option 1 and 2.

Table 5-4: Investment cost for a VIP latrine and an UDD toilet in AMA based on Burkina Faso cost

Burkina Faso cost for UDD toilet	134 Euro
VIP:UDD in my case in Accra	0.79
Burkina Faso cost for VIP toilet	106 Euro

Table 5-5: Cost comparison for UDD toilets from different developing countries

Option	Minimum volume of substructure from Eqn. (1) (m^3)	Total volume of substructure (m^3)	Total depth of substructure (m)	Cost (€)
VIP toilet with first 1.0 m of pit side walls (my first estimate for Option 1)	1.58	2.48	1.65	354
Double vault UDD toilet (my first estimate for Option 2)	0.45	0.45	0.3	447
Comparison costs from others				
VIP toilet with first 1.2 m of pit side walls being lined for Lusaka, Zambia (Münch and Mayumbelo, 2007)	4.2	5.1	3.4	348
Single vault UDD toilet for Lusaka, Zambia (Münch and Mayumbelo, 2007)	0.6	1.2	0.8	371
VIP toilet in Uganda (Niwigaba *et al.*, 2006)				106 - 211
Double vault UDD toilet in Uganda (Niwigaba *et al.*, 2006)				296 - 464
Double vault UDD toilet in South Africa[46]			0.4	632
UDD toilet from Ouaga dougou in Burkina Faso				**135**
UDD toilet from Pucheng, China				72

[45] linus dagerskog (linusdagerskog@yahoo.fr)
[46] The municipality of eThekwini (Durban) in South Africa installed 37,000 double vault UDD toilets at € 632 per toilet in 2005 (personal communication: Teddy Gounden, Manager Community Education, e-Thekwini Water and Sanitation, Durban, South Africa).

By comparing the cost of the UDD toilet from different sources, I can observe wide range for a cost for one toilet (from € 72 to € 632).

5.4.2. Equations and data used for cost estimation

The minimum volume of the substructure of the VIP and UDD toilet are calculated by using Equation (1). The symbols of the equation are explained in Table 5-6.

$V_{sub,min} = p_f \times N_{Accra} \times T_d$ .... Equation (1)

The equations below are used to calculate O&M costs of Part B, C and E ((Münch and Mayumbelo, 2007)

$C_{Part\ B,\ O\&M} = F_d \times N_{Accra} / N_{P/t} \times C_{ve} + (F_{w,1} \times p_f + p_{urine}) \times N_{Accra} \times C_{t,1} / V_{tv}$ ...... Eqn (2)

$C_{Part\ C,\ O\&M} = F_{w,1} \times p_f \times N_{Accra} \times C_{tr,s} + N_w \times C_{w,a}$ .... Eqn (3)

$C_{Part\ E,\ O\&M} = - \rho \times F_{w,2} \times F_{w,1} \times p_f \times N_{Accra} \times C_{Fm} - p_{urine} \times N_{Accra} \times C_{urine}$ .... Eqn (4)

The symbols of the equations and input data used for the cost calculation are shown in Table 5-6. The tables thereafter summarise investment costs, annual operation costs, and NPV for both options.

Table 5-6: Input data for cost calculation (those values in bold are different than (Münch and Mayumbelo, 2007))

Parameter	Symbol	Unit	Option 1	Option 2	Further explanations
Cost of using a transport vehicle for transport from household to treatment site (Part B)	$C_{t,1}$	€/event	**70**	**50**	Travel distance about 10 km (current practice in Accra) - Vacuum tanker for Option 1 & open truck for Option 2
Cost of vault emptying, per event	C_{ve}	€/event	0	5	Assuming 30 minutes, and € 10 per hour salary cost
Cost of treating faecal sludge	$C_{tr,s}$	€/m^3	2.4	0	Based on current charge of AMA
Sales prices for treated faecal matter	C_{Fm}	€/ton	2	2	Current price for biosolids from AMA
Sales price for urine	C_{urine}	€/m^3	0	0.75	Personal communication Linus Dagerskog, CREPA, Burkina Faso (nutrients worth 15 cents per 20 L jerry can; able to sell at one tenth of this price)
Annual cost of a general worker	$C_{w,a}$	€/a	0	**2,000**	
Frequency of desludging or emptying	F_d	1/a	0.2	**0.5**	Desludging period 5 years for Option 1 and emptying period for Option 2 is 2 years
Factor to account for volume change	$F_{w,1}$	-	2	0.5	Option 1: Increase due to necessary water jetting.
Factor to account for water loss during treatment in Part C	$F_{w,2}$	-	**0.2**	0.5	Option 1: Own estimate for dried fraction from drying beds, Option 2: further drying ($F_{w,1}$ x $F_{w,2}$ = 0.25)
Average number of people per toilet	$N_{P/t}$	-	**4.5**	**4.5**	Equals to average household size (one toilet per household)
Number of people covered in the scheme	N_{Accra}	cap	**265,000**	**265,00**	Design value (urban population in AMA who engage in urban agriculture)
Number of workers at the storage site	N_w	-	0	5	Design value
Specific annual faecal sludge/matter production	p_f	m^3/cap/yr	0.07	0.05	Heinss *et al.* (1998) for Option 1; Jönsson *et al*. (2004) for Option 2
Specific annual urine production	p_{urine}	m^3/cap/yr	0	0.55	Source: Münch (2007)
Density of compost or dried faecal matter	ρ	ton/m^3	1.2	1.2	Estimate
Time between desludging or emptying events	T_d	years	5	**2**	Design value (inverse of F_d)
Total volume of substructure	$V_{sub,min}$	m^3	**2.475**	**0.45**	Equals sludge volume when pit or vault is full (see Table 5-2)
Volume of transport vehicle (vacuum tanker for Option 1, skip on open truck for Option 2)	V_{tv}	m^3	5	15	

Table 5-7: Investment cost for Option 1 and Option 2 for AMA (in € unless otherwise indicated)

Part		Option 1 (VIP system)	Option 2 (UDD system)	Comments
Part A	**Investment costs of latrine**	6,261,328	7,903,916	Cost of one toilet as shown in Table 5-4
Part B	**Transport cost from latrine to treatment plant**	440,000	400,000	4 vacuum trucks of € 110,000 each for Option 1; 8 (1 urine transport and 7 for faeces transport) open trucks of € 50,000 each for Option 2
Part C	Treatment plant (bio gas digester + sludge drying beds)	205,000	0	See Appendix 9
	Land requirement (value) for treatment plant	153,990	0	Land cost in AMA approximately € 29 per m^2 (Appendix 9)
	Faecal matter storage	0	29,117	See Appendix 9
	Land requirement (value) for faeces storage	0	48,140	Land cost in AMA approximately € 29 per m^2 (Appendix 9)
	Urine storage tanks	0	1,925,882	See Appendix 9
	Land requirement (value) for Urine storage	0	81,490	Land cost in AMA approximately € 29 per m^2 (Appendix 9)
	Subtotal	***358,990***	***2,084,629***	
Part D	**Trucks to transport the waste and urine**	0	0	Assume farmers have to get it
Part E	**Sale of treated sludge or faecal matter**	0	0	No capital cost item here
	Total investment costs (million €)	**7.1**	**10.4**	
	Total investment costs (€/cap)	**27**	**39**	Total investment cost divided by number of people covered in scheme (265,000)

Table 5-8: Annual Operation and maintenance cost for Option 1 (VIP system) and Option 2 (UDD system) in €/year unless otherwise indicated

Description		Option 1	Option 2	Comments
Part A	Operation & Maintenance costs for toilets	0	0	Structures are robust enough requiring only cleaning
	Material added after defecation (sand)	0	0	free
	Subtotal	0	*0*	
Part B	Cost of removing sludge or faecal matter from the pit or vault	0	147,222	First part of Equation 2
	Faecal sludge / faecal matter transport cost from plot to treatment plant / storage site	519,400	22,083	Second part of Equation 2
	Urine barrel transport costs from plot to storage site	0	485,833	Third part of Equation 2
	Subtotal	*519,400*	*655,139*	
Part C	Treatment costs (including labour)	89,040	0	First part of Equation 3
	Staff labour cost for storage facility	0	10,000	Second part of Equation 3
	Subtotal	*89,040*	*10,000*	
Part D	Transport cost of treated sludge or faecal matter from treatment plant to disposal/user	0	0	Assumed that transport costs are covered by farmers when they come to buy fertiliser
Part E	Income from sale of treated sludge or faecal matter	-17,808	-7,950	First part of Equation 4 (note negative values since it is an income)
	Income from sale of urine	0	-109,313	Second part of Equation 4
	Subtotal	*-17,808*	*-117,263*	
Total O&M cost (million €/yr)		0.59	0.55	
Total O&M cost per capita (€/cap/yr)		2.2	2.1	

5.4.3. Summary and discussion of costs

Table 5-9: Summary of cost and NPV for Option 1 (VIP system) and Option 2 (UDD system)

Parameter	Option	
	Option 1 (VIP system)	Option 2 (Double vault UDD system)
Total capital costs (million €)	7.1	10.4
Capital costs per capita (€/cap)	27	39
Total O&M cost (million €/yr)	0.6	0.5
O&M cost per capita (€/cap)	2.2	2.1
Total NPV (million €), based on 12 % discount rate and 10 year project lifetime	10.5	13.5

Observations made from costs figures:

- Option 1 has lower NPV and is therefore financially attractive
- Operation and maintenance cost for Option 2 is lower than option 1

5.4.4. Sensitivity analysis

The results of the financial model are highly sensitive for the number of people using one toilet. If more the people used one toilet then the investment cost would be lower (refer Table 5-10) whereas sale price of urine is also very sensitive for this financial model (see Table 5-11)

Table 5-10: Sensitivity of financial model for number of people sharing one toilet

Parameter	No. of people per toilet = 4.5		No. of people per toilet = 9		No. of people per toilet = 13.5	
	Option 1 (VIP)	Option 2 (UDD)	Option 1 (VIP)	Option 2 (UDD)	Option 1 (VIP)	Option 2 (UDD)
Total capital costs (million €)	7.1	10.4	3.9	6.5	2.8	5.1
Capital costs per capita (€/cap)	27	39	15	24	11	19
Total O&M cost (million €/yr)	0.6	0.5	0.6	0.5	0.6	0.4
O&M cost per capita (€/cap)	2.2	2.1	2.2	1.8	2.2	1.7
Total NPV (million €), based on 12% discount rate and 10 year project lifetime	10.5	13.5	7.3	9.5	6.2	8.1

Table 5-11: Sensitivity of financial model for sale price of urine

Parameter	Urine price 0.75 €/m³		Urine price 7.5 €/m³	
	Option 1 (VIP)	Option 2 (UDD)	Option 1 (VIP)	Option 2 (UDD
Total capital costs (million €)	7.1	10.4	12.3	16.8
Capital costs per capita (€/cap)	27	39	46	63
Total O&M cost (million €/yr)	0.6	-0.4	0.6	0.5
O&M cost per capita (€/cap)	2.2	-1.6	2.3	1.8
Total NPV (million €), based on 12% discount rate and 10 year project lifetime	10.5	12.7	3.4	3.0

Other model parameter values, which the model would be very sensitive to include:

- Sales price for treated faecal matter
- Frequency of desludging or emptying the toilet
- Cost for transport

5.5. Application of multi-criteria analysis (MCA) for short-listed Options)

Although there are many methods available to compare different options (see Section 2.1), multi-criteria analysis (MCA) is chosen here as a suitable method to assess the sanitation options. In MCA, it is possible to obtain view from many experts and the weighting and scoring against each criterion gives a detailed evaluation of options. Section 2.1.2.2 showed that either a ranking or a rating technique could be used. I used the rating technique for simplicity reasons.

In this research, the two short-listed options namely Option 1 (VIP latrine with downstream processing) and Option 2 (double vault UDD toilet with downstream processing) are compared by using MCA. All categories from Part A (toilet device) to Part E (use of the products in urban agriculture) are considered separately for each option over the entire project cycle – from construction to operation and maintenance.

I used the MCA data from 5 experts in the field for this analysis namely:

- Expert 1: Myself
- Expert 2: Dr. Elisabeth von Münch, senior lecturer in UNESCO-IHE
- Expert 3: Mariska Ronteltap, lecturer in UNESCO-IHE
- Expert 4: Oswell Katooka, Manager sewerage services in Lusaka water supply and sewerage company, Zambia
- Expert 5: Kennedy M. K. Mayumbelo, Manager peri-urban in Lusaka water supply and sewerage company, Zambia

5.5.1. Sustainability criteria

This list of criteria is based on the work of several documents (Kvarnström and Petersens, 2004) and (Wang, 2005). Each of these aspects has a number of specific indicators, which are different for the Part A to Part E (e.g. cost per person, risk assessment etc.). The entire list is shown in Appendix 10.

I used following sustainability criteria to compare the Option 1 and Option 2:

- Criterion 1: Social aspects
- Criterion 2: Technological aspects
- Criterion 3: Economic aspects
- Criterion 4: Physical environment aspects
- Criterion 5: Health aspects
- Criterion 6: Institutional aspects

All sub-criteria are not equally important and their weighting might therefore be varied according to the actual situation of the place/situation of applied. According to the sanitation component applied (Part A to E) the importance of weighting of the main criteria can be varied. For example, social aspects would be more important than technical aspects for Part A of both Options (for more details see Appendix 12).

5.5.2. Weighting and scoring procedure on criteria

The procedure used was as follows:

- First, allocated the weighting of 6 main criteria mentioned above by keeping the total weight equal to 100 for each option. For weighting factors of main criteria, I used weight multiples of 5 according to the importance for the respective sanitation component (Part A to Part E) considered at each time. For example, on the most important criteria, I put the highest weight.

- Then, each sub-criterion was given an equal fraction of the weight if expert did not weigh the sub-criterion (e.g. sub-criteria of acceptability and system complexity of social aspects in Part A have equal weight 8.3) otherwise sub-criteria also were weighted according to the importance for the relevant sanitation component.
- Scoring was done on each sub-criterion for Option 1 and Option 2 and for each sanitation component. It varies from score 5 to 1 for each sub-criterion (see Table 5-12).
- The experts did not have to judge (for scoring) the economic aspects (costs) since I fixed those from my cost calculations.
- The weighted score for each sub-criterion was then calculated by multiplication of weight and score. The maximum total weighted score for each option would be 500 (100*5).
- The weighted score for sub-criterion by group was taken as the average weighted score of 5 experts (e.g. group weight for sub-criterion acceptability in social aspect of Part A of Option 1 = (40+33+17+33+30)/5=31).

Table 5-12: Details for scoring

Score description	Score
Excellent	5
Good	4
Acceptable	3
Poor	2
Very poor	1

5.5.3. Results of analysis

According to the results of individual and group analysis of data, it is clear that Option 2 (double vault UDD toilet system) is the most suitable sanitation option for AMA. The summaries of MCA analysis are shown in Table 5-13 and Table 5-14.

The following observations are made from the analysis:

- It is noticed from individual expert analysis that the allocated weighting on the main criterion varies from 5 to 35, for example: economic aspect has weight 35 and health aspect has weight 5 for Part B from expert 3.
- All experts selected Option 2 (UDD system) as the best option for Part B and Part C with significant difference with the weighted score between both options.
- For Part A component, also it is clear that considerable difference for weighted scores can be observed from the experts, except from expert 4 who found the Option 1 as the best option.
- When consider the Part D, it is noticed that there is only a marginal variation of weighted scores from the experts. I think that is because just transportation of treated or sanitised faecal matter and urine from treatment plant or storage places to farms would not be different for the two options much.
- In the case of Part E, the views of experts are quite different. I can observe marginal and significant differences from experts weighted scores for options for Part E.
- Under the criterion "health aspect" for Part E, I have included "risk assessment" as a sub-criterion (2 sub-criteria). This can be done using the new WHO (2006) guidelines.

Table 5-13: Summary of weighted scores for MCA (maximum best value is 500 – in bold the better option)

Component	Expert 1		Expert 2		Expert 3		Expert 4		Expert 5		Group	
	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2	Op 1	Op 2
Part A	339	**372**	343	**402**	277	**372**	**328**	308	279	**353**	313	**361**
Part B	293	**381**	284	**341**	243	**262**	267	**293**	220	**301**	261	**316**
Part C	249	**403**	287	**374**	231	**311**	240	**321**	187	**324**	239	**342**
Part D	**223**	217	**320**	238	138	**148**	**194**	193	130	**223**	201	204
Part E	326	**362**	285	**358**	**318**	274	255	**257**	144	**244**	266	**299**

Table 5-14: Summary of MCA analysis to assess two short-listed options for AMA (Option 1 is VIP system, Option 2 is UDD system)

	Part A	**Part B**	**Part C**	**Part D**	**Part E**	**Best option**
Expert 1	Option 2	Option 2	Option 2	Option 1	Option 2	Option 2
Expert 2	Option 2	Option 2	Option 2	Option 1	Option 2	Option 2
Expert 3	Option 2	Option 2	Option 2	Option 2	Option 1	Option 2
Expert 4	Option 1	Option 2	Option 2	Option 1	Option 2	Option 2
Expert 5	Option 2	Option 2	Option 2	Option 2	Option 2	Option 2
Group	Option 2	Option 2	Option 2	Option 2	Option 2	Option 2

It is obvious from the individual expert analysis that the overall score for Option 2 is higher than the score for Option 1 with a significance difference.

According to group view, I noticed a significant variation for the total scores for Part A to Part C and Part E. However, in the case of Part D, Option 1 and 2 have marginal difference for the total score.

5.5.4. Assessment of analysis

I faced the following difficulties while doing the MCA analysis:

- I filled the weight column as a default for each main criterion before distributing the analysis sheets to experts. Most of the experts then just adopted these weightings as if they were fixed.
- Experts sometimes did not fill the weight column even for main criteria. Then I used my default values for analysis.
- Experts (except myself) did not weigh on sub-criteria. Therefore, I used equal weight for each sub-criterion according to the weight of main criterion.
- Time requirement for experts was high.
- I could not get all experts I wanted (e.g. staff from IRC).
- Experts had to have good knowledge of VIP and UDD systems.

This analysis results were based on mainly score values for sub-criteria. Results of analysis would be better if all experts filled the weight columns for each sanitation component than using my default values for main criteria and sub-criteria.

6. MDG achievement in Ghana and Peru

6.1. MDG targets and indicators

6.1.1. Introduction

According to (WHO/UNICEF, 2006), the Millennium Development Goals (MDGs) are quantitative targets for poverty reduction and improvements in health, education, gender equality, and environmental and other aspects of human welfare. At existing rates of progress in many developing countries will fall short of these goals. However, if developing countries take steps to improve their policies and increase financial resources, significant additional progress towards the achieving goals is possible.

The first seven goals are mutually reinforcing and are directed at reducing poverty in all its forms. The last goal - global partnership for development - is about the means to achieve the first seven. Developing countries which are heavily indebted will need help to reduce their debt burdens.

The targets and indicators which are directly connected to sanitation are listed in Table 9-28 in Appendix 11. Table 9-30 in Appendix 13 shows the potential contribution of improved drinking water and sanitation to other MDGs (WHO/UNICEF, 2006).

The aim of the MDG 7 is to provide basic improved sanitation to people in urban and rural areas. According to UN definition, “improved” and “not improved” sanitation systems can be categorized as in Appendix 11, Table 9-31.

6.1.2. Water supply and sanitation coverage in global level

“There is evidence that provision of adequate sanitation services, safe water supply, and hygiene education represents an effective health intervention that reduces the mortality caused by diarrhoeal disease by an average of 65% and the related morbidity by 26%” (WHO/UNICEF, 2006). Many children die every year from diseases associated with lack of safe drinking water, adequate sanitation and poor hygiene in developing countries. Inadequate sanitation, hygiene and water result not only in more sickness and death, but also in higher health costs, lower worker productivity, and lower school days of children.

6.1.3. Water supply and sanitation coverage in Ghana and Peru

Ghana’s and Peru’s sanitation coverage improvement from 1990 to 2004 is shown in Table 6-1. Access to improved sanitation in urban areas in Ghana and in Peru is 13% and 67% respectively in 2004. Water supply coverage in 2004 in Ghana and Peru are 46% and 74%. However, the MDG target coverage in 2015 on sanitation coverage 57% and 84% in Ghana and in Peru respectively. (see Figure 6-1, and Figure 6-2). It shows that Peru is ahead of Ghana on sanitation coverage in both urban and rural area. In addition, Ghana is lagging in improvement of coverage. The MDG indicators which directly relate to the target 10 (goal 7) and their achievement for Ghana and Peru are shown in Table 6-2.

Table 6-1: Sanitation coverage in Ghana and Peru for 1990 – 2004 (WHO/UNICEF, 2006)

Country		**Population**			**Sanitation Coverage%**					
	Year	Total (x1000)	% Urban	% Rural	Total		Urban		Rural	
					Total	Household connection	Total	Household connection	Total	Household connection
Ghana	1990	15479	36	64	15	3	23	7	10	0
	1995	17725	40	60	16	4	25	9	10	1
	2000	19867	44	56	18	6	26	11	11	2
	2004	21664	**46**	54	18	7	27	**13**	11	2
Peru	1990	21753	69	31	52	38	67	54	15	3
	1995	23837	71	29	57	44	69	60	22	5
	2000	25952	73	27	61	49	71	65	29	7
	2004	27562	**74**	26	63	52	72	**67**	32	7

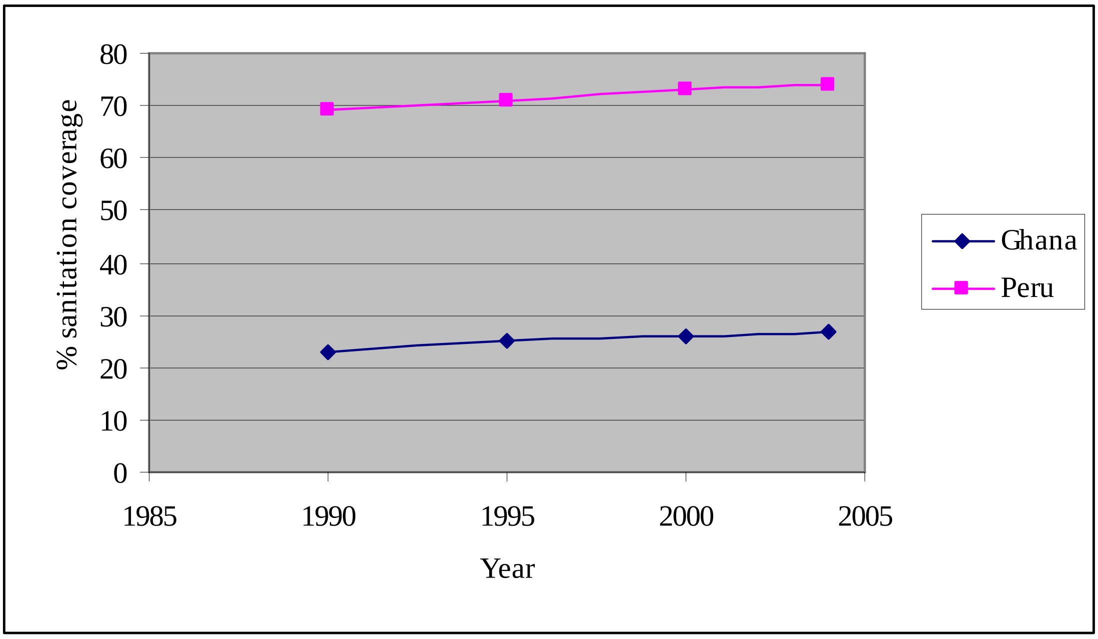


Figure 6-1: Urban sanitation coverage (in %) in Ghana and Peru from 1990 to 2004 (WHO/UNICEF, 2006)

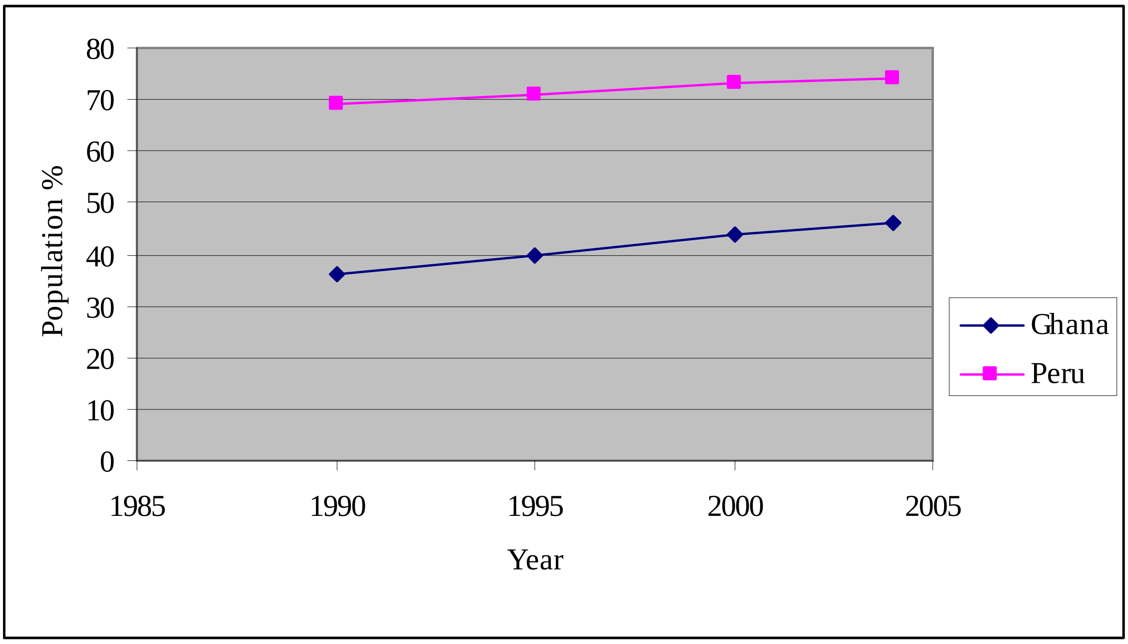


Figure 6-2: Profile of urban population percentage in Ghana and in Peru from 1990 to 2004 (WHO/UNICEF, 2006)

(GHS, 2007) states that in Ghana there are some linkages among Ministries, Departments, and Agencies in efforts to reduce child mortality and promote maternal health in line with the MDGs. Ghana Health Services have determined to reduce the mortality rates of children under five years from 132 per 1,000 births in 1990 to 44 per 1,000 by 2015; and maternal mortality rate from 214 per 100,000 in 1990 to 54 per 100,000 within the same period.

(GHS, 2007) further states that interventions in the health sector alone can not solve the problem because about 60% of deaths of children under-five years in the region were through malnutrition (see Appendix 6). Therefore, food, nutrition and sanitation should form key components of the interventions.

The MDG interventions affect the population by influencing both mortality and fertility rates. On the mortality side, the MDG interference in the health, water and sanitation sectors aim directly to reduce the mortality rates. By providing the essential services such as water and sanitation and infrastructure, health and quality of human life can be increased.

Ecosan system in collaboration with urban agriculture can play an important role to achieve MDG targets. Ecosan systems ensure the environmental sustainability (MDG No.7), helps to eradicate poverty and hunger (MDG No.1), and reduce under-5 child mortality MDG no. 4) because:

- Recycling nutrients by using sanitised faeces and urine in urban agriculture
- Fresh water (drinking water) can be saved by reusing greywater and no water used for flushing toilets.
- Natural fertilisers and soil conditioners from ecosan can be found for farmers locally with less cost than chemical fertilisers.
- Improvement of agriculture will reduce mal nutrition-related diseases and improve the health of people.

- Ecosan is less costly than conventional solutions.

Table 6-2: MDG indicators, which related to sanitation, and their achievement for Ghana and Peru (WHO/UNICEF, 2006)

Indicator	Ghana							Peru						
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
4. Prevalence of underweight children under-five years of age														
Children under 5 moderately underweight %	24.9	22.1								7.1				
Children under 5 severely underweight %	5.2	4.7								0.8				
5.Proportion of population below minimum level of dietary energy consumption														
Population undernourished %					12							12		
Population undernourished number of people					2E+06							3E+06		
13.Under five mortality rate														
Children under five mortality rate per 1000 live births			112				112			42				29
14.Infant mortality rate														
Infant mortality rate (0-1) per 1000 live birth			68				68			33				24
30.Proportion of population with sustainable access to improved water source, urban and rural														
Total %							75							83
Urban %							88							89
Rural %							64							65
32.Proportion of households with access to secure tenure														
Slum population as % of urban %				69.6							68.1			
Slum population				5E+06							1E+07			

6.2. Constrains for achievement of sanitation targets

According to (WHO/UNICEF, 2000) sanitation coverage worldwide is, at present, lower than water supply coverage. Rural coverage shows, generally, lower value than urban coverage.
Constraints to progress in sanitation are:

- Lack of political will
- Low prestige and recognition
- Poor policy at all levels
- Weak institutional framework
- Inadequate and poorly used resources
- Inappropriate approaches
- Failure to recognize defects of current excreta management systems
- Neglect of consumer preferences
- Ineffective promotion and low public awareness
- Lack of finance
- Lack of technical means
- Non-availability of human resources

In addition to above mentioned constraints, I observed below also as a constraint:

- One-sided focus on sewer-based sanitation systems

7. Conclusions and recommendations

7.1. Conclusions

Freshwater resources are becoming increasingly scarce and or polluted, due to factors such as population growth and urbanisation. Rapid population growth, especially in urban areas, increases the production of faecal sludge and wastewater. Wastewaters (black water and greywater) are often discharged into surface water bodies, untreated or partially treated, potentially impacting the health of all downstream users of the water. Poor sanitation leads to increase disease transmission through drinking water, contaminated food and recreational/occupational contact with contaminated surface waters. Sanitation is the primary barrier for preventing the entry of many human pathogens into the environment.

At present access to sanitation services is remarkably less than access to water supply in developing counties (in both urban and rural areas), and there is a need to focus attention on sanitation provision. The problems related with sanitation and water supply systems are illustrated by consideration of the MDGs and their associated targets for water supply and sanitation.

Access to improved sanitation in urban areas in Ghana and Peru are 13% and 67% respectively in 2004. However, the MDG target coverage in 2015 on sanitation is 57% and 84% for Ghana and Peru, correspondingly. Water supply coverage in 2004 in Ghana and Peru are 46% and 74%.

In this thesis, two cities were investigated in depth: Accra (Ghana) and Lima (Peru). They are part of the SWITCH project (Accra demonstration city and Lima study city). Both cities have inadequate sanitation and water supply facilities. The population in Greater Accra is 2.9 million and of Greater Lima is 7.5 million. The central district of Greater Accra is called Accra Metropolitan Assembly (AMA) and has a population of 1.6 million.

The main sanitation facilities identified in AMA are public toilets (32.7%) and other facilities such as water closet, VIP, pit and bucket latrines or water closets in-house. There are about 4.4% of households who have no sanitation facility at all. There are no adequate facilities for disposing greywater in the urban and peri-urban areas in AMA. Over half of the households in AMA use gutters (53.2%) to dispose the liquid waste/ greywater produced from kitchen and bathrooms.

Although the main source of drinking water source in AMA is pipe borne water (90.5% households) either inside or outside of the house (community stand post), there are about 4.7% of households who use groundwater.

In Peru, about 67% of households use private indoor toilets which comprise of pit latrines and WC's and yet about 9.6% of households do not have any sanitation facility. Peruvians have started to implement the ecosan concept to solve their water and wastewater problems. They use the ECODESS which is a micro integrated ecosan system which includes UDD toilets and greywater management.
The people in Lima are mainly depending on the pipe borne system for drinking water and about one third depend on groundwater.

It is clear that Accra and Lima are not on the track to meet the MDG target for sanitation coverage. The common constraints found for achievement of MDG targets are lack of finance (for people and government), lack of technology, lack of political will, and insufficient land.

To minimise the pollution of surface and groundwater sources due to human excreta in urban areas at low cost, we can consider ecosan options which can directly be linked to urban agriculture. Conventional approaches to sanitation tend to misplace the nutrients, dispose of them and break the link between sanitation and agriculture. Recycling sanitized human urine and faeces by returning them to the soil serves to restore the natural nutrient and organic matter cycle. Human excreta have sufficient plant nutrients in the forms of nitrogen, phosphorus and potassium to grow crops, and add organic matter to the soil for long-term soil fertility.

Ecosan is a closed-loop system, which treats human excreta as a resource. In this system, excreta are processed normally on site until they are free of pathogenic (disease-causing) organisms. Thereafter, the sanitized excreta can be recycled by using them for agricultural purposes. Ecosan is a new way of thinking and can use a number of different technologies and toilet types (with or without water; with or without urine diversion). Key features of ecosan are:

- Prevention of pollution and disease caused by human excreta
- Treatment of human excreta as a resource rather than as a waste product
- Recovery and recycling of the nutrients

“Urban agriculture” is food production taking place in backyards, rooftops, community vegetable and fruit gardens, and unused or public spaces within the confined of cities. The advantages of urban agriculture to the cities are ecological and technical perspectives, especially due to green spaces. On the other side, it has social advantages in that it enables urban community to improve their conditions due to income from urban agriculture.

The people in AMA are engaged in urban agriculture such as open space farming, irrigated farming, backyard farming, aquaculture, and seasonal farming. Accra has annual rainfall averaging 810 mm distributed over less than 80 days. The farmers in Ghana currently use ammonium sulphate, muriate of potash, urea, single super-phosphate and triple super-phosphate as fertilisers. Large amount of these fertilisers are imported.

The people in Lima practise irrigated farming, live stock, aquaculture and diary farming. Lima's climate is quite mild and yearly average rainfall of 25 mm. The Peru farmers use urea, poultry manure and other commercial fertilisers for agriculture.

When considering local conditions in AMA and Lima, both cities urban farmers suffer mainly due to water problems and high prices for fertilisers for agriculture. Therefore, ecosan can play a great role on urban agriculture in both cities.

The in-depth analysis to find better sanitation option was carried out only for AMA due to lack of data for Lima (Spanish language barrier also caused difficulties for me).

The available low-cost sanitation options for AMA were short-listed by using following selection criteria: protect groundwater and surface water sources from human excreta, low investment and operation and maintenance cost, minimise water wastage for flushing and transport of waste, odour and flies problem, and allow possibility of usage of sanitised human excreta for urban agriculture. According to these criteria, two options were short-listed: Option 1 (VIP system) and Option 2 (UDD double vault system). Option 1 does not fulfil the criterion of no potential for groundwater pollution but was included anyway because it fulfils the other criteria. Both options include downstream processing.

In the conceptual design and cost estmation process, the main components of sanitation systems were considered. They are: Part A – toilet device, Part B – collection and transport of excreta to treatment plant or storage place, Part C – treatment or storage of excreta, Part D - transport of sanitised faeces, faecal matter or urine to farm, and Part E – reuse of faecal matter and urine in urban agriculture. Greywater management was not included in the design and cost estimate due to time constraints.

The design and cost estimation were based on a population of 265,000 who are engaged in urban agriculture (approximately 16% of total population in AMA), and average household size of 4.5 considering one toilet for each household. The methodology used for cost estimating was based on similar work carried out by (Mayumbelo, 2006) and published in (Münch and Mayumbelo, 2007).

For Option 1 (VIP system), it was assumed that vacuum tankers are used for empting the VIP toilets once in every 5 years period and one bio gas digester treatment plant with sludge drying beds is used to treat the faecal sludge. In the case of Option 2 (UDD system), the faecal matter is collected every 2 years and the urine is collected every 2 weeks (stored in 100 L plastic barrels). No treatment facility for faeces was considered for this option except just storage for 6 months in 3 locations spread over the area of AMA. Urine is stored for 2 weeks in a centralised storage facility and is then collected by urban agriculture farmers. Transport distances (for Part B and Part D) are approximately 10 km.

The cost estimate for Part A of Option 1 is € 354 and of Option 2 is € 447 (which is based on approximate costs from AMA). The revised cost for Part A according to Burkina Faso costs of Option 1 is € 107 and of Option 2 is € 135.

According to cost estimation, investment cost per capita is € 27 for Option 1 and € 39 for Option 2. The O & M cost per capita per year is € 2.2 and € 2.1 for Option 1 and Option 2 respectively. In the case of Option 2, a major cost item is for urine storage tanks. If the costs for the urine tanks can be reduced, then Option 2 could become cheaper than Option 1. Land value is considerably higher than other areas of the country because AMA is the part of the capital city of Ghana.

Net present value was calculated for both options by considering 12% discount rate and 10 year project life time (MDG target in 2015). Option 1 had the lower NPV of € 10.5 million compared to Option 2 € 13.5 million. Furthermore, the sensitivity analysis showed that if the number of people per toilet was increased most cost components would be reducing (the cost of Part A is the main cost factor).

Multi-criteria analysis (MCA) was carried out to find out the most suitable sanitation option for AMA by collecting the views from 5 experts in the field of sanitation. The main 6 important sustainability criteria used for the MCA were social aspects, technical aspects, economic aspects, physical environment aspects, health aspects and institutional aspects. Specific indicators were listed separately for each part of the sanitation system. The weighting of the aspects was different for each part, as decided by experts. In accordance with the group result of MCA, Option 2 was chosen as the best option for Part A, B, C, and E. Part D component has almost equal marks for both options. It implies that there is no significant difference in the two options with respect to transportation to farms.

Although the costs for Option 2 (UDD system - ecosan) are higher than for Option 1 (VIP - conventional), it scores higher in the MCA, where economic aspects are included as one of six aspects. Therefore, Option 2 would be more desirable for AMA.

If ecosan could be adopted on a large scale, it would protect groundwater, rivers, streams, lakes and seas from faecal and urine contamination at a lower cost than water-borne, sewer-based sanitation. Less water would be consumed. Urban farmers would also require less commercial fertilisers, the cost of which they can often not afford.

Ecosan system in collaboration with urban agriculture can play an important role to achieve MDG targets. Ecosan systems directly connected to MDG No.7 (environmental sustainability).

7.2. Recommendations

Recommendations for future work based on the results of this research are as follows:

- Conceptual design should be carried with more specific detail for every part of the satiation components (Part A to E).
- Cost estimation should be done with accurate quantities and cost, especially for the toilet itself and the urine storage tanks since they are a major cost items.
- Stakeholders such as users, farmers, and Municipal council staff should be interviewed in relation to ecosan and reuse of sanitised faeces and urine.
- Views from more experts should be used for MCA.
- Greywater management systems should be designed and included in the cost estimate.
- Solid waste management should be studied (consider linkage between solid waste collection and urine barrel collection; private sector involvement).
- The results of this study should be disseminated within the SWITCH project (e.g. as part of the Learning Alliance system).
- Fertiliser requirements in urban agriculture of AMA and Lima should be investigated further.
- The water holding capacity improvements for soils treated with sanitised faeces should be quantified, since it would be allow “more crops per drop” which is important given the water scarcity.
- The areas where the 265,000 urban farmers are living within AMA should be further specified (identifying any clusters of urban farmers, which should first be targeted by an ecosan pilot project).
- It is necessary to research on attitudes of Muslim people who are engaged in urban agriculture to reuse of faeces.

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9. Appendices

9.1. Appendix 1: SWITCH definitions

The following definitions are specific for the SWITCH project and were taken from the project website (SWITCH, 2006).

- **Demonstration city:** The purpose of including these demonstration cities is to translate the results of the SWITCH research activities into tangible, socially-relevant demonstration activities. During the project feedback from the Learning Alliance is used to determine the scope of the demonstration activities. These cities are: Hamburg, Birmingham, Lodz, Zaragossa, Tel Aviv, Alexandria, Accra, Beijing and Belo Horizonte.

- **Study city:** Study sites may or may not be located within cities and address specific research questions via field work under real life field conditions. In this context, the work planned within study sites fits under the research programme (not demonstration). The identified study sites are the Ruhr area in Germany, Bogota and Cali in Colombia and Lima in Peru.

Objectives of sub-theme 4.1 of SWITCH project

This work package has the objective to develop, demonstrate and disseminate pollution prevention based approaches for wastewater handling in urban areas based on Ecological Sanitation (ecosan).

Expected results of Work Package (WP) 4.1

- Global assessment of the adoption, operational functioning and performance of urban ecosan systems
- Development of treatment processes for removal of organic micro pollutants (pharmaceuticals, hormones)
- Development of strategies and guidelines for agricultural use of nutrients recovered by ecosan systems
- Guidelines / technical standards for the technology components of urban ecosan systems
- Dissemination of the results through the Learning Alliance, e-learning, various trainings and stakeholder seminars

9.2. Appendix 2: Sustainability criteria for selection of sanitation systems

The comparing criteria are (Kvarnström and Petersens, 2004):

- **Social-cultural aspects:** The system should be aesthetically sound, inoffensive, and culturally as well as socially compatible for the different kind of people

- **Technical and performance aspects:** How to store, transport and treat of faeces and urine and grey water and as well as simplicity, reliability, and robustness of the system is considered

- **Financial and economic aspects:** Affordability of every kind of people (rich, poor, urban, rural etc.) is considered. The cost-benefit analysis is the important parameter to be considered.

- **Environmental aspects:** Pollution prevention of ground water, surface water resources, and nutrients recycle and reuse from urine and faecal to be considered.

- **Health aspects:** Consider how affects to the prevention of water-born disease (like diarrhoea, cholera) and reduction of child mortality rate.

- **Institutional, policy, and legal aspects:** How to provide and develop the services should be considered. The decision makers, planners, users and other stakeholders are the key players. Development of guidelines and policies as suitable for situation are also important factors to be considered

9.3. Appendix 3: Disadvantages of conventional off site systems

[Reference (Nadkarni, 2004)]

- Conventional treatment system wastes a huge amount of drinkable water. In centralised sewage systems, valuable drinking water is used as a carrier. Approximately 15,000 L of water treated to drinking standards is used every year per person to flush only 35 kilograms of faeces and 500 L of urine. Flush toilets can consume 20-40% of the domestic water resources used in a sewered city. This may be an obvious problem in the developing world especially in places, which have some water scarcity, like large urban centers in arid regions.

- It leads to the aforementioned pollution of rivers, seas and groundwater. Approximately 90% of wastewater worldwide is introduced into receiving water bodies without further treatment. In any case, sewage treatment plants are not infallible, not all pathogens are rarely retained or destroyed in conventional sewage treatment plants.

- The process of treating water is energy dependent; it wastes a lot of energy. Pathogens and nutrients contained in human excrement and in wastewater are "eliminated" with high technical and energy inputs. The energy needed is in most countries supplied from fossil fuels.

- The by-products and waste products of sewage treatment itself need to dispose of in some safe way. The sludge resulting from the common treatment of households (and occasionally mixed in with industrial effluents) are so polluted with pathogens, toxic organics and heavy metals that they are actually dangerous. Normally it is disposed off as landfills or used in agriculture. In countries where supervision and monitoring does not exist, it is dangerous and has been known to contaminate ground water. Another solution consists of burning them in big incinerators. It is also a very costly solution.

- Building and maintenance are really cost intensive. The enormous investment, operating and maintenance costs of conventional treatment plants make them unsuitable. This is clearly prohibitive for developing nations, especially those with rapid rates of urbanization.

9.4. Appendix 4: Details of secondary processing of faeces

(Source:(Esrey *et al.*, 2001))

- **Thermal composting:** Pathogens are destroyed if the compost is kept at an operational level of at least 50°C for 7 days. Addition of bulking material to the faeces is necessary to reach thermophilic temperatures and co-composting with organic household waste is an option.
- **Alkaline treatment:** Addition of urea, ash or lime to the faeces will help eliminate the pathogens by elevating both the pH and the level of ammonia. A pH of over 9 for at least 6 months will kill most pathogenic organisms. At a higher pH, shorter time periods could be recommended.
- **Storage:** The number of pathogens in faecal material during storage will be reduced with time due to natural die off, without further treatment. The type of micro organism and storage conditions governs the time for reduction or elimination. The ambient temperature, pH and moisture etc. will affect the inactivation as well as biological competition in areas where ambient temperatures reach up to 20°C, a total storage time of 1.5 to 2 years will eliminate most bacterial pathogens and will substantially reduce viruses and parasites. At higher ambient temperatures, storage times could be shortened to around 1 year.
- **Incineration:** This can be an option as it will ensure that all pathogens and parasites are destroyed, but some nutrients will be lost during the incineration.

Table 9-1: Physiochemical and biological factors affect the survival of micro-organisms in faeces (Ecosanres, 2005)

Temperature	Most micro-organisms survive well at low temperatures (below 5°C) and die off rapidly at high temperatures (above 40° C). This is the case in water, soil and sewage and on crops. At temperatures of 55–65°C all types of pathogens (except bacterial spores) die within hours.
pH	Highly alkaline conditions will inactivate micro-organisms. Inactivation is rapid at pH 12 but takes longer at pH 9.
Ammonia	Pathogens in excreta can be inactivated by the addition of ammonia.
Dryness	Moist soil favours the survival of micro-organisms. Dehydration of faeces in an eco-toilet processing chamber will decrease the number of pathogens.
Solar radiation	The survival time of pathogens on soil and crop surfaces will be reduced by UV radiation.
Presence of other organisms	The survival time of micro-organisms may be shortened by the presence of other organisms. Different types of organisms affect each other by predation, release of antagonistic substances or competition for nutrients.
Nutrients	Bacteria adapted to living in the gut are not always capable of competing with other organisms in the general environment for scarce nutrients. This may limit the ability of faecal bacteria to reproduce and survive in the environment.
Oxygen	Most enteric bacteria are anaerobic and thus are likely to be out-competed by other organisms in an aerobic environment.

9.5. Appendix 5: Climate data for Accra

Table 9-2: Climate data for Station Accra (Southern belt of Ghana) (Agodzo et al., 2003)

Month	**Mean Temp 0C**	**Relative Humidity %**	**Wind speed km/day**	**Sunshine hours**	**Mean rainfall mm**	**Effective rainfall mm**
Jan	27.7	77	207	6.8	10.9	10.7
Feb	28.4	78	259	6.9	21.8	21.0
Mar	28.4	79	268	6.9	57.1	51.9
Apr	28.3	80	251	7.0	96.8	81.8
May	27.6	82	216	6.9	131.2	103.7
Jun	26.4	86	242	5.1	221.8	143.1
Jul	25.3	85	294	4.7	66.0	59.0
Aug	25.1	84	328	4.9	28.2	26.9
Sep	25.8	83	311	5.9	67.8	60.4
Oct	26.7	83	259	7.5	62.4	56.2
Nov	27.6	81	199	7.9	27.7	26.5
Dec	27.5	79	181	6.9	18.1	17.6
Annual	**27.1**	**81**	**251**	**6.5**	**810**	**659**

9.6. Appendix 6: Summary of morbidity data in AMA for 2005

Table 9-3: Morbidity for AMA in 2005 (Source: AMA health services)

Diseases	**Male**											**Female**											**Grand Total**
	Under 1Yr	1-4 Yrs	5-9 Yrs	10-14 Yrs	15-19 Yrs	20 - 24 Yrs	25-34 Yrs	35-44 Yrs	45-59 Yrs	60+ Yrs	**Total**	Under 1Yr	1-4 Yrs	5-9 Yrs	10-14 Yrs	15-19 Yrs	20 - 24 Yrs	25-34 Yrs	35-44 Yrs	45-59 Yrs	60+ Yrs	**Total**	
Typhoid Fever (Typhoid)	3	52	76	79	102	73	123	95	58	20	681	7	41	63	86	138	190	251	229	173	43	1221	1902
Cholera	16	27	41	63	71	106	149	78	28	11	590	18	27	18	62	60	90	111	62	26	20	494	1084
Diarrhoea Diseases	**2899**	**3869**	989	811	866	1022	1457	942	741	543	**14139**	**2665**	**3269**	1096	868	1210	1471	2080	1376	1052	832	**15919**	**30058**
Infectious Hepatitis	10	4	7	6	9	17	24	7	9	3	96	6	4	5	8	5	14	12	6	2	5	67	163
Other Meningitis	0	1	2	3	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	6
Schistosomiasis (Bilharzia)	0	1	10	20	27	14	9	4	1	3	89	0	2	1	12	9	20	3	3	0	1	51	140
Guinea Worm	0	0	0	0	1	1	0	0	0	0	2	0	0	0	0	1	0	1	0	0	0	2	4
Intestinal Worms	32	302	212	145	130	184	185	137	74	53	**1454**	48	255	194	146	210	298	382	230	162	126	**2051**	**3505**

9.7. Appendix 7: Additional data on urban agriculture in Accra

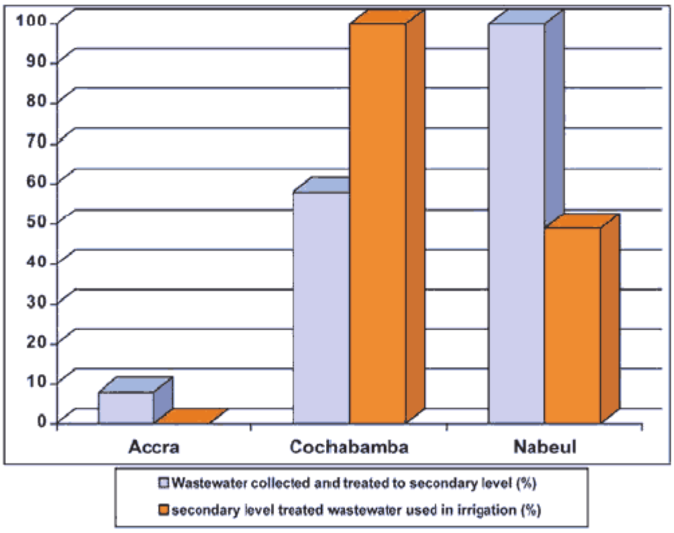

Figure 9-1:Waste water usage for irrigation in Accra (CWC, 2006)

Table 9-4: Features of urban agriculture in some open places in Accra (Agodzo et al., 2003)

Location	**No. of farmers**	**Area under Irrigation (ha)**	**Soil condition**	**Sources and quality of water**	**Crops**	**Marketing**
Marine Drive (Indep. square)	98	4	Clay, gravel	Drain water FC> $2x10^8$ Irrigation with watering cans	-Lettuce -Green pepper -Spring onion -Cucumber	Farm gate
Dzorwulu/ Plant pool	180	18	Clay, gravel	-Water from river Onyasia FC>10^6 Irrigation with watering cans, -Pipe water,	-Lettuce -Cucumber -Cabbage -Cauliflower -Onion -Chinese Cabbage -Spring onions -Radish -Spinach	Farm gate
Korle Bu Hospital	80	210	Clay, sandy	-Drain water -Shallow wells Irrigation with watering cans	-Lettuce -Cabbage -Spring onions -Beans	Farm gate
La Fulani	111	65	Sandy clay, Clay	-Water from streams FC>10^6 -Furrow irrigation	-water melon -Tomatoes -Pepper -Bean -Okra -Spring onion -Lettuce	Farm gate

Table 9-5: Features of irrigated farming (IWMI, 2006)

Name of system	Vegetable farming
Places in/around city	La Fulani, la Korjorn, Korle-bu, Dzorwulu, North Dzorwulu, Marine, Cantonments, GBC, Motorway, Mitchel Camp, Tetteh Quarshie roundabout, Haatso, Kotobabi, Abelemkpe,
Farmers #, gender, age group	There are about 1000 farmers, 90% men and 10% women. Their ages range from 18-50years.Mostly educated, 70% Muslims,
Occupation/employment	About 60% totally rely on irrigated vegetable cultivation as their only source of income, while 33% do it as a supplementary source of income; other jobs are security, Plumber, Masons, Electrician, etc
Farm sizes, beds per field, fields per farm	Total land under vegetable farming is about 160 ha with an average bed size of $20m^2$.
Main vegetables grown	Lettuce, cabbage, spring onions, cauliflower, onions, Chinese cabbage, indigenous leafy ones-(e.g. Ayoyo).Lettuce can be harvested 8-10 per years, Cabbage/cauliflower(3-4 harvest per year).Lettuce is the most profitable crop according to the farmers.
Irrigation method/ water source/ quality	Informal irrigation using watering cans is predominant. Other methods are sprinklers, water hose and furrow irrigation. The main sources of water are drains, streams, dugout wells, and limited pipe-borne water use. The water quality in most sites has higher levels of faecal contamination than recommended WHO irrigation values
Water application rate (liter/day/area) in different seasons	4-8 watering cans per bed (wet season); 6-12 cans per bed (dry season depending on crops and site. A watering can averages 15 liters.
Other inputs used	Poultry manure, mineral fertilizer, seeds, pesticides, etc
Produce use/marketing and Networking	Mostly marketing at the farm gate by women sellers.
Farmer associations	Only at three out of 7 major sites: (Dzorwulu, La, Marine drive) and need to be strengthened.
Gender	Men carry out vegetable production whilst the women are involved in marketing of the produce and occasionally help their husband or other relatives on the farm (Danso et al., 2004).
Tenure situation	Informal, mutual agreement, inheritance and few cases rental Generally weak tenure security (Obuobie et la., 2003)
Linkages with other sectors	Market women association, consumers associations, input sellers, municipalities, processing industry, input and produce transporters, households, restaurants and supper markets.

Table 9-6: Features of backyard farming (IWMI, 2006)

Name of system	Backyard gardening
Extent (%) among various UA systems	Dominates during wet season and every second household in Accra is engaged in some form of backyard gardening
Places in/around city	Cantonments, Abelemkpe and Legon whilst Dansoman had most of the backyard activities being poultry production.
Farmers #, gender, age group	Almost every open space in front, back, adjacent, all round the households during raining season. Most of the farmers middle-aged and have good standards of education and are Christians.
Occupation/ Employment	The main occupations of the farmers are 40% private services, 42% pubic service, 15% are pensioners and the rest are on other jobs. Many practitioners undertake this activity as a hobby or necessary addition to subsistence.
Farm sizes,	Any Available space in or around the household
Crops (main), others	Fruits, Millet, Maize, cassava, beans, okra, tomatoes, garden eggs, grain legumes, soybean and pepper.
Irrigation water	Usually rain-fed and wastewater from bathhouses and kitchen
Other inputs used	Cutlass, hoes, tractor, cow dung, mineral fertilizer, and seeds
Produce use /marketing and Networking	It mainly serves to supplement household income and thus contribute to ensuring food security. Occasionally, when good harvests are produced, the excess was sold to neighbours or market sellers. Some animals are given out as gifts to friends and relatives during festivals and other ceremonies.
Gender	Both male and female farmers as well as other household members are involved production for home consumption. However, this depends much on the income status of the household in question.
Tenure situation	Normally own land, caretaker's land

Table 9-7: Features of livestock farming (IWMI, 2006)

Name of system	Commercial livestock and ruminant
Extent (%) among various UA systems	Mostly in densely populated places as an investment or 'living asset' strategy
Places in/around city	La, Nima, Teshie-Nungua, Maamobi
# Farmers , Gender, age group	Quite few farmers involved aged between 18-50 years, Ga (38%), Akan (5%) or belonged to the Northern ethnic group (57%), There were 71% men and 29% female, married (76%), single (10%), divorced (9%) and widowed (5%), SSS is the highest level of education, Relatively more Christians (57%) than Muslims (43),
Occupation/ Employment	Most of them have about 10 years experience. About (52%) were into livestock as a main occupation whereas (43%) used it as a supplementary income activity. The main reason for going into livestock farming was to generate income and also because of the interest some have in it. Other income generating activities included trading and teaching.
Type of animals own	The number of animals owned by the individual farmers ranged from 4 to 200, Mature individual animals owned by farmers ranged from 2-150 whereas young individuals ranged from 2-50,
Other inputs used	Feed is obtained from the community, bush, market, chop bar, and local malt brewers. Water, grasses, hired labour, feed, salt, vaccines and drugs, pen, water troughs, and breeding stock.
Produce use/marketing Networking	The price of animals ranged from ¢175,000 –¢3,500,000 depending on the type and size of the animal. There are livestock sellers who often act as middlemen. For small ruminants, there are hardly any middlemen involved. Livestock is sold mainly to neighbours, butchers, chop bars, and the people in the open market.
Gender	Both men and women assumed responsibility for cleaning the pen, feeding, watering and general supervision of livestock. Both men and women control funds depending on who owns the livestock. Marketing is however executed by the men. Children may also be involved in feeding and cleaning of the pen
Tenure situation	Most grazing of livestock is free range, though they have a permanent sleeping place. Small ruminants are often reared next to residential houses
Association	A greater percentage of the farmers (76%) belonged to an association whereas. Members pay monthly dues of ¢10,000. The farmers at Nungua (225) had an association which was well organised. They had a brilliant idea of acquiring a cold van in the nearest future, process the product of members and have a well-planned network to supply restaurants and hotels with quality and affordable product. This would increase the income of the members and also create employment for the youth in the community.
Extension and other sector Linkages	Almost all the farmers mentioned that they have access to extension services and visits by extension officers ranged from once in a month (33%) to once in three (24%) months. The purpose of the extension officers is to offer technical advice, help in planning diets and diagnose and treat diseases. The institutions dealing with the farmers were the Veterinary Services Department of MoFA.

Table 9-8: Features of aquaculture farming (IWMI, 2006)

Name of system	Aquaculture
Places in/around city	Teshie Military Camp- Southern Command
Farmers #, gender, age group	There were more women (80%) involved than men (20%). Mainly Akans (60%) and Ewes (40%). About 60% have more than 5 years experiences. All age groups were found, Mostly married and highest level of education is up to SSS level. They were all Christians.
Occupation/ Employment	They went into aquaculture as a hobby, business and to encourage others to join. They also do other income generating activities such as dress making (20%), trading (60%) and crop farming (20%).
Farm sizes	Farmers were not knowledgeable of the dimensions of their ponds. However, from inspection they were not ponds that could serve any commercial purposes.
Type of fish	Mudfish and tilapia
Other inputs used	Fish harvester, Needle, Fingerlings, Feed, Fish pond, Labour, Wellington boot, Water hose and Water. Most of these inputs are purchased from the market.
Produce use /marketing and Networking	Sixty percent (60%) of the farmers use the fish for domestic purposes whereas 40% use it for domestic purposes as well as sell some to neighbours and some market women. The cost of a fingerling ranges between ¢2000 and ¢6000. When matured they are sold either fresh or smoked at a price range of ¢10,000 to ¢20,000.
Gender	The women do the feeding, filling of the ponds with water, weeding around the pond, marketing if any, controlling funds, etc and the men and children help in feeding, topping up water in ponds and weeding around the ponds.
Association	All the farmers do not belong to any aquaculture association
Extension and other Linkages	All the farmers have access to extension services from MoFA. This has been the main source of advice to them.

Table 9-9: Features of seasonal farming (IWMI, 2006)

Name of system	Seasonal farming
Extent (%) among various UA systems	Dominates during wet season
Places in/around city	University of Ghana lands, Tetteh Quashie, Teshie-Nungua, pockets of vacant open spaces in the city
Farmers #, gender, age group	NA, dominated by men, 30-50years, All the farmers were males and belonged to the Ewe (63%), Ga (25%) and Buzanga (13%) tribes, Both Christians and Muslims, They were all married, Education of the farmers cut across a spectrum of no formal education up to JSS. Majority of them are quite experienced in the farming activities and could be sources of knowledge transfer to fellow farmers.
Occupation/ Employment	The farmers were involved in other income generating activities, which included cane basket weaving, office security services, and carpentry. Thus the seasonal farming is a means to supplement their income to enable them meet their basic needs.
Farm sizes	Average farm holdings 1-3 acres.
Crops (main), others	Mainly maize, cassava, Okro, and pepper, beans, tomatoes, and pepper.
Irrigation water	Usually rain-fed hence high quality water
Other inputs use	Cutlass, hoes, tractor, cow dung, mineral fertilizer, seeds
Produce use/marketing and	Men carry out crop production whilst the women are involved in marketing of the

Networking	produce. About 25% of the farmers indicated that they farm on subsistence basis for home consumption. The others market their farm produce through traders
Farmer association	No farmers association but some are members of the LA Vegetable Farmers Association.
Gender	Crop production is carried out by men whilst the women are involved in marketing of the produce and occasionally helped their husband and other relatives plus children if any.
Tenure situation	Informal, mutual agreement, inheritance and few cases rent payment or sharecropping.
Extension and other sector linkages	Access to extension services was quite encouraging with 75% mentioning that they received advice from staff of MoFA once or 2-3 times in a month on farm practices. Agrimat Ltd assists farmers in their activities.

Table 9-10: Seasonal crops and water requirement for Accra, Kumasi, and Tamale (Agodzo et al., 2003)

Location	Crop	Cropping season	Crop water requirement (mm)	Irrigation water requirement (mm)
Accra	Tomato	July-Nov/Dec	527	327
	Pepper	Sept-Dec/Jan	464	325
	Okra	March-June/July	367	23
	Aubergine	Sept-Dec/Jan	508	364
	Tinda	April-June/July	274	10
Kumasi	Okra	Dec-March/April	568	504
	Aubergine	Jan-April/July	521	140
	Water melon	Dec-Feb/March	298	166
Tamale	Tomato	Oct-Jan/Feb	668	604
	Onion	Nov-Feb/March	678	581
	Okra	Nov-Feb/March	487	450
	Cabbage	Oct-Jan/Feb	590	-

Financial condition in Accra related to urban, peri urban agriculture

Table 9-11: Monthly net income from irrigated mixed vegetable farming in different countries in Africa (Danso et al., 2003).

City	Typical net monthly income per farm (US$)	GNI[47] per capita (US$ per month)
Accra	**40-50**	**27**
Cotonou	50-110	36
Dakar	40-250	46
Dar Es Salaam	60	24
Freetown	10-50	13
Kumasi	35-160	27
Ouagadougou	15-90	25

Table 9-12: Revenue generated in different farming systems in Kumasi (Cornish and Lawrence, 2001)

Location	Farming system	Typical farm size (ha)	Net revenue per actual farm size per year (US$)
Rural/peri-urban	Rain-fed maize or maize/cassava	0.5-0.9	200-450
Peri-urban	Dry season vegetable irrigation only (garden eggs, pepper, okra, cabbage)	0.4-0.6	140-170
Peri-urban	Rain-fed maize combined with dry-season irrigated vegetables	0.7-1.3	300-500
Urban	Year-round irrigated vegetable farming (lettuce, cabbage, spring onion)	0.05-0.2	400-800

[47] GNI= General Net Income (UN statistics)

9.8. Appendix 8: Usage of urine and faeces in urban agriculture in Cagayan de Oro, Philippine

Table 9-13: Monthly household income and saving of people in Cagayan de Oro, Philippine (Holmer and Miso, 2006)

Characteristics	% Gardeners	% Non-Gardeners
Monthly household income (PhP)[48]		
Below 3,000	88	12
3,001-4,000	12	75
4,001-5,000	0	13
More than 5,000	0	0
Monthly saving (Php)		
Below 200	81	19
201-400	19	19
No saving	0	62

Table 9-14: Vegetable consumption levels (Holmer and Miso, 2006)

Consumption level of vegetables after allotment garden has been established	%
Increased	94
Same level	6
Percentage of increase in consumption level	
50%	13
75%	6
100%	75
No comment	6

[48] Currency of Philippines

9.9. Appendix 9: Details for conceptual design and cost estimate

Table 9-15: Population and area data for Greater Accra by district (GSS, 2002)

District	Area (km^2)	Area (ha)	Total Population	Sex ratio: Males to 100 female	Population density per km^2	Population density per ha	District share of region's population	Proportion urban %
Accra Metropolitan Area (AMA)	**200**	**20,000**	**1,658,937**	**97.1**	**8,294.69**	**82.95**	**57.2**	**100.0**
Dangme East	909	90,900	93,112	90.4	102.43	1.02	3.2	18.1
Dangme West	1,442	144,200	96,809	92.6	67.14	0.67	3.3	23.6
Tema Municipal	565	56,500	506,400	98.7	896.28	8.96	17.4	100.0
Ga	692	69,200	550,468	100.9	795.47	7.95	18.9	72.9

	AMA	Dangme East	Dangme West	Tema Municipal	Ga
Male population of people living in area	**817,373**	44,199	46,550	251,482	276,531
Female population of people living in area	**841,564**	48,913	50,259	254,918	273,937
Average household size in the area	**4.5**	5.3	5.2	4.8	4.6
Total number of households in the area	**365,550**	17,430	18,643	105,633	119,355
Households without access (any form) to sanitation %	**4.1**	53.1	43.8	16.9	18.3
Number of households without access to sanitation	**14,988**	9,255	8,166	17,852	21,842
Residents that share pit latrines %	**9**	7.3	8.2	10.7	5.8
Average annual population growth rate	**4.4%**	4.4%	4.4%	4.4%	4.4%

Table 9-16: Predicted construction cost for VIP latrine

Item	Item Description	Unit price (Cedis) converted from ZMK[49]	Unit price (Cedis) directly from a Ghanian[50]	Unit	Qty	Cost (€) directly from a Ghanian
1	**Pit**					
	Pit Excavations (1 m x 1.5 m x 1 m deep)	273,810	200,000	Item	1.0	17.39
2	**Pit Lining**					
	concrete bricks (400 x 200 x 100 mm)	7,119	6,000	No	47	24.46
	cement (50 kg packet)	82,143	70,000	pkt	0.8	4.76
	sand	164,286	150,000	ton	0.7	9.13
	water	1,643	8,000	m^3	0.07	0.05
	Subtotal of pit and pit lining					***55.80***
3	**Cover Slab**					
	cement (50 kg packet)	82,143	70,000	pkt	1.0	6.09
	sand	164,286	150,000	ton	0.10	1.30
	Aggregate	82,143	200,000	ton	0.15	2.61
	water	1,643	8,000	m^3	0.03	0.02
	Reinforcement (10 mm diameter bars)	5,476	100,000	m^2	1.50	13.04
	Subtotal					***23.10***
4	**Superstructure**					
	hollow concrete bricks (400 x 200 x 100)	7,119	6,000	No	93	48.26
	cement (50 kg packet)	82,143	70,000	pkt	1.5	9.38
	sand	164,286	150,000	ton	0.7	9.13
	water	1,643	8,000	m^3	0.2	0.14
	Roofing Sheets	47,390	250,000	m^2	2.0	43.48
	Door including frame (wood)	328,571	400,000	No	1.0	34.78
	Subtotal					***145.20***
	Other hardware					
	Ventilation pipe	410,714	200,000	No	1.0	17.39
	Subtotal					***17.39***
5	**Total labour for building (including supervision)**	1,067,857	1,300,000	Item		**113.00**
6	**Total Investments**					**354**

The main differences of rates in Lusaka (Zambia) and Accra (Ghana):

- Aggregate, water , roofing sheets and reinforcement costs much higher in Accra
- Ventilation pipe lower cost in Accra

Note: This table is based on Kennedy Mayumbelo's work (Mayumbelo, 2006).

[49] ZMK" is the currency of Zambia.
[50]Samson Oduro-Kwarteng and S. Ibrahim

Table 9-17: Predicted construction cost for double vault UDD toilet

Item	Item Description	Unit price (Cedis) converted from ZMK	Unit price (Cedis) directly from a Ghanian	Unit	Qty	Cost (€) directly from a Ghanian
1	**Floor Slab**					
	Cement (50 kg bag)	82,143	70,000	pkt	1.0	6.09
	sand	164,286	150,000	ton	0.10	1.30
	Aggregate	82,143	100,000	ton	0.15	1.30
	water	1,643	8,000	m^3	0.03	0.02
	Reinforcement (10 mm dia bars)	5,476	100,000	m^2	1.50	13.04
	Subtotal					***21.80***
2	**Faeces Chamber**					
	concrete bricks (400 x 200 x 100)	7,119	6,000	No	19	9.78
	Cement (50 kg bag)	82,143	70,000	pkt	0.2	1.22
	sand	164,286	150,000	ton	0.8	10.43
	water	1,643	8,000	m^3	0.10	0.07
	Subtotal					***21.50***
3	**Cover Slab**					
	Cement (50 kg bag)	82,143	70,000	pkt	1.0	6.09
	sand	164,286	150,000	ton	0.10	1.30
	Aggregate	82,143	200,000	ton	0.15	2.61
	water	1,643	8,000	m^3	0.03	0.02
	Reinforcement (10 mm diameter bars)	5,476	100,000	m^2	1.50	13.04
	Subtotal					***23.10***
4	**Superstructure**					
	hollow concrete bricks (400 x 200 x 100)	7,119	6,000	No	93	48.52
	Cement (50 kg bag)	82,143	70,000	pkt	1.6	9.43
	sand	164,286	150,000	ton	0.7	9.13
	water	1,643	8,000	m^3	0.2	0.14
	Roofing Sheets	47,390	250,000	m^2	2.0	43.48
	Door including frame (wood)	328,571	400,000	No	1.0	34.78
	Subtotal					***145.50***
5	**Other Hardware**					
	Ventilation pipe	410,714	200,000	No	1.0	17.39
	Urine diversion hose	8,214	8,000	m	2.0	1.39
	Urine Tank (100 liters)	410,714	100,000	No	2.0	17.39
	UD squatting pan (GTZ datasheets)	92,000	400,000	No	1.0	34.78
	Bucket for sand or ash	41,071	20,000	No	1.0	1.74
	Subtotal					***72.70***
6	**Total labour for building including supervision (10% of direct cost)**		1,867,180	Item		**121.74**
7	**Total Investments**					**447**

Table 9-18: Mass flows and transportation details (to calculate number of transport vehicles in AMA)

Description	Unit	Option 1	Option 2	
		Faecal sludge	**Faecal matter**	**urine**
Barrels per load	number			50
Volume of one barrel	m3			0.2
Mass of full truck	ton			10
Volume on full truck	m3	5	15	10
Hours for return trip	hours	2	2	2
Working hours per day	h/day	12	12	12
Number of people	number	265,000	265,000	265,000
Excreta production per year	m3/cap/yr	0.07	0.05	0.5
Excreta production per day	m3/cap/d	0.0002	0.0001	0.0014
Total excreta production per day	m3/d	50.82	36.30	363.01
Total excreta production per year	m3/yr	18550	13250	132500
Factor F1		2	0.5	1
Actual total excreta production per year	m3/yr	37100	6625	132500
Volume that needs moving per day	m3/d	101.64	18.15	363.01
Barrels that need moving per day				1815.07
One truck can do this many m3 per day	m3/d/truck	30	90	60
one truck can do this many barrels per day				300
Number of trucks needed per day	number	3.4	0.2	6.1
Number of trucks needed per day	number	4	1	7

Table 9-19: Data for nitrogen production from urine of Option 2

Item		Qty	Unit	Comment
1	Nitrogen production - Faeces	0.55	kg/cap/yr	Source: Münch, (2007)
2	Nitrogen production - Urine	4	kg/cap/yr	Source: Münch, (2007)
3	Total N production	4.55	kg/cap/yr	
4	Total N uptake by Maize	180	kgN/ha/yr	N-uptake = 175 - 200 kgN/ha/yr (Source: Münch, (2006))
5	Urine production	0.55	m^3/cap/yr	Source: Münch, (2007)
6	Faeces production	0.05	m^3/cap/yr	Jönsson et al. (2004) for UDD
7	Duration of urine storage	2	weeks	Assume 2 weeks of storage to sanitise before re-using
8	Total faecal matter	6,625	m^3/yr	Based on total population
9	Faecal matter storage surface area	1,656	m^2	Assume height of pile is 2 m and assume 6 months storage only (area = 40 x 40 m^2)

Table 9-20: Estimation land area to use urine as a fertiliser for Option 2

Item	Population	265,430	
1	Total Nitrogen production (kg/yr)	1,208,000	
2	Land requirement (ha) (Nitrogen as limiting factor)	6,710	Design Equation: Area (ha) = N prod rate (kgN/yr)/Plant uptake rate (kgN/ha/yr); Source: Münch, (2007)
3	Total Area of AMA City (hectares)	20,000	Immediate area around AMA are all commercial farming areas
4	% of land where urine would be applied	30%	
5	Total Urine production m^3/week	2,807	Used to determine storage capacity
6	Possible urine price (€/m^3)	0.75	Personal communication data from Burkina faso
7	Possible urine income (€/yr)	109,490	Based on total urine produced per year for a population of 265,430
8	No. of urine storage tanks (57 m^3 each)	99	Total number of 57m^3 tanks required for atleast 2 weeks storage before it is used as fertiliser
9	Urine storage surface area (m^2)	2,807	Assume height of tank is 2 m, 57 m3 tanks, and 2 weeks storage only (area = 70 x 40 m^2)

Table 9-21: Land value estimation for storage of urine and faeces for Option 2(UDD system)

Item	**Item Description**	**unit Cost (€)**	**unit**	**quantity**	**Total Cost (€)**	**Comments**
1	Tarpaulin covers	129	No	7	890	1 piece of Tarpaulin = 12 x 20 m^2 (source: www.tarps-express.co.uk/prices.htm)
2	Floor Slab for faecal matter					Assume that the faecal matter will be stored in 2 m high piles or heaps that are covered by tarpaulin sheets of 12 x 20 m^2. Concrete slab = 150 mm thick
	Cement	6.09	pkt (50kg)	90	10,957	
	sand	13.04	ton	195	2,543	
	Aggregate	8.70	ton	1,770	15,391	
	water	0.70	m^3	290	202	
	Reinforcement	7.83	m^2	3	23	
	Subtotal				*29,117*	
3	Urine Storage tanks (unit cost from (Mayumbelo, 2006)	19,550.83	No	99	1,925,882	
	Total costs				1,956,000	

Item	**Description**	**Area (m^2)**	**Land value (€/m^2)**	**Cost (€)**
1	Urine storage	2,810 (Table 9-21)	29	81,490
2	Faeces storage	1,660 (Table 9-20)	29	48,140

Table 9-22: Land value estimation for Part C of Option 1 (VIP system)

Item	Description	Qty	Unit	Comment
1	Population	265,430		
2	Specific area per population equivalent[51]	0.02	m^2/PE	For UASB reactor and sludge drying beds
3	Land area required	5,309	m^2	

Item	Description	Area (m^2)	Land value (€/m2)	Cost (€)
1	Faeces treatment	5,310	29	153,990

Table 9-23: Construction cost of UDD toilet in Burkina Faso

DESIGNATION	U	Q	PU	PT	PT in €
Cement	bag	9	5,000	45,000	**69.23077**
Iron 8 mm	12m	3	2,500	7,500	**11.53846**
cut up iron bar in appropriate pieces	fee			200	**0.307692**
metal sheet for roof	u	2	3,500	7,000	**10.76923**
nails for metal sheet	u	6	20	120	**0.184615**
wood to support roof (6*8 cm)	m	1.1	800	880	**1.353846**
iron bar to attach roof to wood	u	2	200	400	**0.615385**
mosquito grid	fee			300	**0.461538**
water	barrels	8	200	1,600	**2.461538**
sable mélange pour parpaings	donkeywagon	5	500	2,500	**3.846154**
river sand for construction	donkeywagon	6	500	3,000	**4.615385**
gravel	donkeywagon	2	500	1,000	**1.538462**
jerry can	u	1	500	500	**0.769231**
pvc pipe (32 mm)	m	0.5	500	250	**0.384615**
flexible plastic pipe (32 mm)	m	0.5	700	350	**0.538462**
Metal door (170*60 cm)	u	1	7,000	7,000	**10.76923**
non qualified labour	fee			2,000	**3.076923**
brick that lets in air to the cabin	u	1	250	250	**0.384615**
local qualified labour	fee			5,000	**7.692308**
labour to make bricks	fee	4.5	500	2,250	**3.461538**
TOTAL 1 latrine				**87,100**	**134**

[51] This value taken from the design work carried out by me for bio gas digester treatment plant with sludge beds.

9.10. Appendix 10: Details of MCA

Table 9-24: Details for Part A - Toilet devices

No.	Criteria		Score		Weighted Score			Score		Weighted Score			Score		Weighted Score			Score		Weighted Score			Score		Weighted Score		Group weight		Indicator	Comments
	Part A - Toilet device	Weight	Option 1	Option 2	Option 1	Option 2	Weight	Option 1	Option 2	Option 1	Option 2	Weight	Option 1	Option 2	Option 1	Option 2	Weight	Option 1	Option 2	Option 1	Option 2	Weight	Option 1	Option 2	Option 1	Option 2	Option 1	Option 2		
		Expert 1					Expert 2					Expert3					Expert 4					Expert 5								
C_1	**Social aspects**	25					25					25					25					25								
$C_{1.1}$	Acceptability (comfort)	10	4	2	40	20	8.3	4	3	33	25	8.3	2	4	17	33	8.3	4	2	33	17	8.3	3	3	25	25	30	24	Qualitative	Very uncomfortable=1
$C_{1.2}$	Personal security (indoor versus outdoor)	7	3	5	21	35	8.3	2	5	17	42	8.3	1	5	8	42	8.3	2	3	17	25	8.3	2	4	17	33	16	35	Qualitative	Very insecure=1
$C_{1.3}$	System complexity	8	4	3	32	24	8.3	4	3	33	25	8.3	4	3	33	25	8.3	3	2	25	17	8.3	4	3	33	25	31	23	Qualitative	Very complex=1
C_2	**Technological aspects**	10					10					15					10					10								
$C_{2.1}$	System robustness (danger of pit collapsing, structural stability)	1	3	5	3	5	1.3	3	5	4	6	1.9	5	4	9	8	1.3	3	4	4	5	1.3	5	5	6	6	5	6	Qualitative	Low robustness=1
$C_{2.2}$	Robustness of use of system (effect of abuse of system)	1	5	4	5	4	1.3	5	2	6	3	1.9	5	2	9	4	1.3	3	2	4	3	1.3	3	2	4	3	6	3	Qualitative	Low robustness=1
$C_{2.3}$	Robustness against extreme conditions (flooding)	1	2	5	2	5	1.3	2	5	3	6	1.9	1	5	2	9	1.3	1	3	1	4	1.3	1	5	1	6	2	6	Qualitative	Low robustness=1
$C_{2.4}$	Use of local material for construction	2	4	3	8	6	1.3	4	3	5	4	1.9	5	3	9	6	1.3	4	3	5	4	1.3	1	1	1	1	6	4	Qualitative	Less material use=1
$C_{2.5}$	Durability/lifetime	1	4	4	4	4	1.3	4	4	5	5	1.9	3	3	6	6	1.3	2	3	3	4	1.3	3	5	4	6	4	5	years	Less durable =1
$C_{2.6}$	Flexibility/adaptability (existing ground water level, geology)	1	1	5	1	5	1.3	1	5	1	6	1.9	1	4	2	8	1.3	2	3	3	4	1.3	1	5	1	6	2	6	Qualitative	Less flexible=1
$C_{2.7}$	Potential for resource recovery (nutrients)	2	3	5	6	10	1.3	3	5	4	6	1.9	1	5	2	9	1.3	2	4	3	5	1.3	1	5	1	6	3	7	Qualitative	Less potential=1

$C_{2.8}$	Complexity for construction & O & M	1	4	3	4	3	1.3	4	3	5	4	1.9	4	2	8	4	1.3	4	3	5	4	1.3	4	3	5	4	5	4	Qualitative	Very complex=1
C_3	**Economic aspects**	**30**					**25**					**25**					**25**					**30**								
$C_{3.1}$	Capital cost	20	4	3	80	60	5	4	3	20	15	8.3	4	3	33	25	8.3	4	3	33	25	10	4	3	40	30	41	31	Cost/person	More capital cost =1
$C_{3.2}$	O & M cost	5	3	4	15	20	10	3	4	30	40	8.3	3	4	25	33	8.3	3	4	25	33	10	3	4	30	40	25	33	Cost/person/ year	More O & M cost=1
$C_{3.3}$	Capacity to pay for user	5	4	4	20	20	10	4	4	40	40	8.3	4	4	33	33	8.3	4	4	33	33	10	4	4	40	40	33	33	% of annual income	More fee=1
C_4	**Physical environment aspects**	**20**					**15**					**10**					**20**					**20**								
$C_{4.1}$	Odour	4	3	5	12	20	3.8	3	5	11	19	2.5	2	4	5	10	5.0	3	4	15	20	5.0	1	5	5	25	10	19	Qualitative	More odour=1
$C_{4.2}$	Potential of groundwater contamination	8	2	5	16	40	3.8	2	5	8	19	2.5	1	3	3	8	5.0	2	4	10	20	5.0	1	5	5	25	8	22	Qualitative	More potential=1
$C_{4.3}$	Use of natural materials for construction & O&M	6	3	3	18	18	3.8	4	4	15	15	2.5	4	2	10	5	5.0	4	2	20	10	5.0	3	1	15	5	16	11	Type and volume/person/year	Less material use=1
$C_{4.4}$	Potential to devaluation of area & inconvenience to neighbourhood	2	2	5	4	10	3.8	3	5	11	19	2.5	2	5	5	13	5.0	2	3	10	15	5.0	1	3	5	15	7	14	Qualitative	More potential=1
C_5	**Health impacts**	**10**					**20**					**20**					**15**					**10**								
$C_{5.1}$	Potential of contact with fresh excreta	6	3	5	18	30	10	5	4	50	40	10	2	4	20	40	10	3	2	30	20	5	3	5	15	25	27	31	Risk assessment	More potential=1
$C_{5.2}$	Potential to transmit pathogens through flies	4	2	5	8	20	10	2	5	20	50	10	2	4	20	40	10	3	3	30	30	5	1	3	5	15	17	31	Risk assessment	More potential=1
C_6	**Institutional aspects**	**5**					**5**					**5**					**5**					**5**								
$C_{6.1}$	Skill necessity (locally) for construction and O & M	1	4	2	4	2	1.3	4	3	5	4	1.3	3	2	4	3	1.3	4	3	5	4	1.3	4	2	5	3	5	3	Quantitative	High necessity=1
$C_{6.2}$	Training requirements for users	1	5	4	5	4	1.3	5	3	6	4	1.3	5	3	6	4	1.3	4	2	5	3	1.3	4	2	5	3	6	3	Qualitative	High need for training=1
$C_{6.3}$	Training requirements for builders	1	5	3	5	3	1.3	5	3	6	4	1.3	3	3	4	4	1.3	4	2	5	3	1.3	5	3	6	4	5	3	Qualitative	High need for training=1
$C_{6.4}$	Necessity of community awareness	2	4	2	8	4	1.3	4	2	5	3	1.3	3	2	4	3	1.3	4	2	5	3	1.3	3	2	4	3	5	3	Qualitative	More awareness need=1
	Total	100			339	372	100			343	402	100			277	372	100			328	308	100			279	353	313	361		
	Ranking				2	1				2	1				2	1				1	2				2	1	2	1		

Score description	Score
Excellent	5
Good	4
Acceptable	3
Poor	2
Very poor	1

Expert 1	My self
Expert 2	Elisabeth
Expert 3	Mariska
Expert 4	Oswell
Expert 5	Kennedy

Note: 1. The cells filled blue colour are entered values by experts.
2. The cost cells shaded with grey colour are filled according to my concept design calculations.

Table 9-25: Details for Part B – Collection and transport from household to treatment plant or storage place

No.	Criteria	Weight	Score		Weighted Score		Weight	Score		Weighted Score		Weight	Score		Weighted Score		Weight	Score		Weighted Score		Weight	Score		Weighted Score		Group weight		Indicator	Comments
	Part B - Collection and transport (Faecal sludge or urine and faeces)	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Option 1**	**Option 2**		
		Expert 1					**Expert 2**					**Expert 3**					**Expert 4**					**Expert 5**								
C_1	**Social aspects**	**5**					**10**					**10**					**10**					**5**								
$C_{1.1}$	Willingness of people to work in collection/transport business	1	2	4	2	4	5	2	3	10	15	5	1	3	5	15	5	4	2	20	10	2.5	2	3	5	8	8	10	Qualitative	Very low willingness=1
$C_{1.2}$	Reliability of collection	4	3	4	12	16	5	3	3	15	15	5	1	4	5	20	5	3	3	15	15	2.5	2	3	5	8	10	15	Qualitative	Very unreliable=1
C_2	**Technological aspects**	**20**					**15**					**15**					**15**					**20**								
$C_{2.1}$	Use of water for pumping	6	2	5	12	30	3.0	2	5	6	15	3	2	5	6	15	3	2	4	6	12	4	1	5	4	20	7	18	Qualitative	More water use=1, (Pits need to have water added for Option 1
$C_{2.2}$	Requirement for energy (operate pumps)	5	2	5	10	25	3.0	2	5	6	15	3	2	5	6	15	3	2	4	6	12	4	1	5	4	20	6	17	Cost/unit of energy	More energy need=1
$C_{2.3}$	Complexity of collection	3	2	5	6	15	3.0	2	5	6	15	3	2	3	6	9	3	2	4	6	12	4	2	5	8	20	6	14	Qualitative	Very complex=1
$C_{2.4}$	Access road width required	3	3	3	9	9	3.0	3	3	9	9	3	2	4	6	12	3	1	4	3	12	4	5	2	20	8	9	10	Quantitative	Less width need=1
$C_{2.5}$	Impact on roads and increased traffic	3	4	2	12	6	3.0	3	3	9	9	3	3	2	9	6	3	3	2	9	6	4	1	3	4	12	9	8	Quantitative	More impact=1
C_3	**Economic aspects**	**30**					**25**					**35**					**25**					**30**								
$C_{3.1}$	Capital cost	14	3	4	42	56	8.3	3	4	25	33	11.7	3	4	35	47	8.3	3	4	25	33	8.3	3	4	25	33	30	41	Cost/person	More capital cost =1
$C_{3.2}$	O & M cost	10	4	3	40	30	8.3	4	3	33	25	11.7	4	3	47	35	8.3	4	3	33	25	8.3	4	3	33	25	37	28	Cost/person /year	More O & M cost=1
$C_{3.3}$	Capacity to pay of user for collection	6	4	4	24	24	8.3	4	4	33	33	11.7	0	0	0	0	8.3	3	2	25	17	8.3	0	0	0	0	16	15	Cost/person (% of annual income)	More fee=1
C_4	**Physical environment aspects**	**15**					**20**					**10**					**20**					**15**								

$C_{4.1}$	Odour during collection	5	1	5	5	25	4	1	4	4	16	2	1	2	2	4	4	1	4	4	16	4	1	4	4	16	4	15	Qualitative	More odour=1
$C_{4.2}$	Noise during collection	4	1	4	4	16	4	1	4	4	16	2	1	4	2	8	4	1	4	4	16	4	1	5	4	20	4	15	Qualitative	More noise=1
$C_{4.3}$	Odour during transport	3	1	5	3	15	4	2	4	8	16	2	0	0	0	0	4	2	3	8	12	4	1	3	4	12	5	11	Qualitative	More odour=1
$C_{4.4}$	Noise during transport	2	4	2	8	4	4	4	1	16	4	2	0	0	0	0	4	4	3	16	12	4	2	3	8	12	10	6	Qualitative	More noise=1, Option 2 has more truck movement because of the urine barrels
$C_{4.5}$	Pollution from trucks (dust, CO_2 emission)	1	4	2	4	2	4	4	1	16	4	2	2	3	4	6	4	3	2	12	8	4	2	2	8	8	9	6	Qualitative	More pollution=1
C_5	**Health aspects**	**10**					**10**					**5**					**15**					**10**								
$C_{5.1}$	Potential health risk during collection & transport	10	2	5	20	50	10	1	4	10	40	5	2	4	10	20	15	2	3	30	45	10	1	4	10	40	16	39	Risk assessment	More risk=1
C_6	**Institutional aspects**	**20**					**20**					**25**					**15**					**20**								
$C_{6.1}$	Potential for private sector involvement	7	3	3	21	21	6.7	4	4	27	27	8.3	3	4	25	33	5	2	3	10	15	6.7	4	4	27	27	22	25	Quantitative	Low potential=1
$C_{6.2}$	Awareness amongst transport stakeholders	6	4	2	24	12	6.7	3	2	20	13	8.3	4	1	33	8	5	4	1	20	5	6.7	5	1	33	7	26	9	Quantitative	Very low existing awareness=1
$C_{6.3}$	Capacity building or training for collection & transport	7	5	3	35	21	6.7	4	3	27	20	8.3	5	1	42	8	5	3	2	15	10	6.7	2	1	13	7	26	13	Quantitative	Very high need for capacity building=1
	Total	**100**			**293**	**381**	**100**			**284**	**341**	**100**			**243**	**262**	**100**			**267**	**293**	**100**			**220**	**301**	**261**	**316**		
	Ranking				**2**	**1**				**2**	**1**				**2**	**1**				**2**	**1**				**2**	**1**	**2**	**1**		

Table 9-26: Details for Part C – Treatment and storage

No.	Criteria		Score		Weighted Score			Score		Weighted Score			Score		Weighted Score			Score		Weighted Score			Score		Weighted Score		Group weight		Indicator	Comments
	Part C - Treatment and storage (treatment for faeces and storage for urine)	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Option 1**	**Option 2**		
		Expert 1					**Expert 2**					**Expert 3**					**Expert 4**					**Expert 5**								
C_1	**Social aspects**	**5**					**5**					**5**					**5**					**5**								
$C_{1.1}$	Potential devaluation of area & inconvenience to neighbourhood	3	3	5	9	15	2.5	3	5	8	13	2.5	3	4	8	10	2.5	2	3	5	8	3	1	4	3	12	6	11	Qualitative	More potential=1
$C_{1.2}$	Willingness of workers to work at this site	2	3	4	6	8	2.5	3	3	8	8	2.5	4	4	10	10	2.5	2	3	5	8	2	2	4	4	8	7	8	Qualitative	Less willingness=1
C_2	**Technological aspects**	**30**					**25**					**25**					**25**					**30**								
$C_{2.1}$	System robustness (risk of process failure)	6	1	5	6	30	2.5	2	5	5	13	2.5	2	4	5	10	2.5	2	3	5	8	3	4	4	12	12	7	14	Qualitative	Less robustness=1
$C_{2.2}$	Use of local material for construction	2	2	4	4	8	2.5	3	5	8	13	2.5	0	0	0	0	2.5	2	3	5	8	3	3	2	9	6	5	7	Qualitative	Less material use=1=1
$C_{2.3}$	Ease of system monitoring	1	1	4	1	4	2.5	2	4	5	10	2.5	2	4	5	10	2.5	2	3	5	8	3	2	4	6	12	4	9	Qualitative	Difficult monitoring=1
$C_{2.4}$	Potential for energy generation (biogas)	3	4	1	12	3	2.5	5	1	13	3	2.5	5	1	13	3	2.5	4	1	10	3	3	2	1	6	3	11	3	Cost/one unit of energy	Less potential=1
$C_{2.5}$	Durability/lifetime	2	4	4	8	8	2.5	3	3	8	8	2.5	0	0	0	0	2.5	2	3	5	8	3	3	2	9	6	6	6	years	Less durable=1,Tarpaulin sheets for Option 2 may not last that long
$C_{2.6}$	Flexibility/adaptability (existing ground water level, geology)	4	2	5	8	20	2.5	2	5	5	13	2.5	2	5	5	13	2.5	1	3	3	8	3	2	4	6	12	5	13	Qualitative	Less flexible=1
$C_{2.7}$	Potential for resource recovery (nutrients)	5	1	5	5	25	2.5	1	5	3	13	2.5	3	5	8	13	2.5	3	4	8	10	3	1	5	3	15	5	15	Qualitative	Less potential=1
$C_{2.8}$	Complexity for construction & O & M	2	1	5	2	10	2.5	2	5	5	13	2.5	1	3	3	8	2.5	2	4	5	10	3	1	4	3	12	4	10	Qualitative	More complex=1
$C_{2.9}$	Reliability during rainy season	1	4	3	4	3	2.5	5	3	13	8	2.5	1	4	3	10	2.5	3	2	8	5	3	2	1	6	3	7	6	Qualitative	Less reliable=1, There could be leachate from faecal matter storage if not covered properly
$C_{2.10}$	Space requirement	4	3	4	12	16	2.5	3	4	8	10	2.5	3	4	8	10	2.5	3	4	8	10	3	2	2	6	6	8	10	Quantitative	More space=1
C_3	**Economic aspects**	**20**					**25**					**25**					**25**					**20**								
$C_{3.1}$	Capital cost	9	4	2	36	18	8.3	4	2	33	17	8.3	4	2	33	17	8.3	4	2	33	17	9	4	2	36	18	34	17	Cost/person	More capital cost =1

$C_{3.2}$	O & M cost	11	2	5	22	55	8.3	2	5	17	42	8.3	2	5	17	42	8.3	2	5	17	42	11	2	5	22	55	19	47	Cost/person/ year	More O & M cost=1
$C_{3.3}$	Potential for income from biogas	5	4	1	20	5	8.3	5	1	42	8	8.3	5	1	42	8	8.3	3	2	25	17	5	2	1	10	5	28	9	Cost/one unit of energy	Less income=1
C_4	**Physical environment aspects**	**25**					**20**					**20**					**15**					**25**								
$C_{4.1}$	Potential impacts on receiving water bodies	9	1	5	9	45	5	1	5	5	25	5	2	3	10	15	3.8	2	3	8	11	6.3	1	4	6	25	8	24	Qualitative	More potential=1, Liquids from sludge drying bed for Option 1
$C_{4.2}$	Potential of groundwater contamination	9	2	4	18	36	5	4	5	20	25	5	2	5	10	25	3.8	2	4	8	15	6.3	1	3	6	19	12	24	Qualitative	More potential=1
$C_{4.3}$	Odour	4	2	3	8	12	5	2	4	10	20	5	1	4	5	20	3.8	2	4	8	15	6.3	1	3	6	19	7	17	Qualitative	More odour=1
$C_{4.4}$	Noise	3	3	4	9	12	5	4	4	20	20	5	3	4	15	20	3.8	2	4	8	15	6.3	1	3	6	19	12	17	Qualitative	More Noise=1
C_5	**Health aspects**	**5**					**5**					**5**					**10**					**5**								
$C_{5.1}$	Potential for flies to transmit pathogens	2	2	4	4	8	2.5	2	3	5	8	2.5	1	4	3	10	5	2	4	10	20	2.5	1	4	3	10	5	11	Risk assessment	More risk=1
$C_{5.2}$	Potential health risks for workers	3	2	4	6	12	2.5	2	4	5	10	2.5	1	4	3	10	5	2	3	10	15	2.5	1	4	3	10	5	11	Risk assessment	More risk=1
C_6	**Institutional aspects**	**15**					**20**					**20**					**20**					**15**								
$C_{6.1}$	Resources necessity (labour, material)	6	2	4	12	24	5	2	4	10	20	5	1	3	5	15	5	2	4	10	20	3.8	1	3	4	11	8	18	Quantitative	High necessity=1
$C_{6.2}$	Capacity building needs (training labourers for treatment process)	4	4	2	16	8	5	2	5	10	25	5	1	2	5	10	5	2	3	10	15	3.8	1	3	4	11	9	14	Qualitative	Very high need for capacity building=1
$C_{6.3}$	Potential for private business	2	3	3	6	6	5	3	3	15	15	5	3	4	15	20	5	3	2	15	10	3.8	1	3	4	11	11	12	Quantitative	Low potential=1
$C_{6.4}$	Responsibility, ownership of process	3	2	4	6	12	5	2	4	10	20	5	1	1	5	5	5	2	4	10	20	3.8	1	1	4	4	7	12	Qualitative	High responsibility=1
	Total	**100**			**249**	**403**	**100**			**287**	**374**	**100**			**231**	**311**	**100**			**240**	**321**	**100**			**187**	**324**	**239**	**347**		
	Ranking				**2**	**1**				**2**	**1**				**2**	**1**				**2**	**1**				**2**	**1**	**2**	**1**		

Table 9-27: Details for Part D – Transportation of dried faces and urine from treatment plant/storage to farm

No.	Criteria	Weight (Expert 1)	Score Option 1	Score Option 2	Weighted Score Option 1	Weighted Score Option 2	Weight (Expert 2)	Score Option 1	Score Option 2	Weighted Score Option 1	Weighted Score Option 2	Weight (Expert 3)	Score Option 1	Score Option 2	Weighted Score Option 1	Weighted Score Option 2	Weight (Expert 4)	Score Option 1	Score Option 2	Weighted Score Option 1	Weighted Score Option 2	Weight (Expert 5)	Score Option 1	Score Option 2	Weighted Score Option 1	Weighted Score Option 2	Group weight Option 1	Group weight Option 2	Indicator	Comments
	Part D - Transport dried faecal sludge or sanitised faeces and urine to farms																													
		Expert 1					**Expert 2**					**Expert 3**					**Expert 4**					**Expert 5**								
C_1	**Social aspects**	**10**					**5**					**10**					**5**					**10**								
$C_{1.1}$	Reliability of collection & transport (private or Municipality)	8	4	3	32	24	2.5	5	4	13	10	5	2	2	10	10	2.5	2	3	5	8	5	1	3	5	15	13	13	Qualitative	Low reliability=1, Option 2 having to move urine barrels
$C_{1.2}$	Willingness of workers to work at this site	2	5	3	10	6	2.5	5	3	13	8	5	4	4	20	20	2.5	2	3	5	8	5	1	3	5	15	11	11	Qualitative	Less willingness=1
C_2	**Technological aspects**	**10**					**10**					**20**					**10**					**10**								
$C_{2.1}$	Complexity of transport	3	4	3	12	9	2.5	5	3	13	8	5	2	3	10	15	2.5	3	2	8	5	2.5	1	4	3	10	9	9	Qualitative	More complex=1
$C_{2.2}$	Access road width required	3	3	3	9	9	2.5	4	4	10	10	5	2	3	10	15	2.5	2	2	5	5	2.5	1	3	3	8	7	9	Quantitative	More width=1
$C_{2.3}$	Impact on roads and increase traffic	2	3	2	6	4	2.5	4	2	10	5	5	3	2	15	10	2.5	3	2	8	5	2.5	1	1	3	3	8	5	Qualitative	More impact=1
$C_{2.4}$	Requirement for specialised equipments	2	4	4	8	8	2.5	5	5	13	13	5	3	4	15	20	2.5	2	3	5	8	2.5	1	4	3	10	9	12	Quantitative	More requirement=1
C_3	**Economic aspects**	**30**					**25**					**35**					**25**					**30**								
$C_{3.1}$	Capital cost	11			0	0	8.3			0	0	11.7			0	0	8.3			0	0	10			0	0	0	0	Cost/person	More capital cost =1(not included in cost estimate)
$C_{3.2}$	O & M cost	6			0	0	8.3			0	0	11.7			0	0	8.3			0	0	10			0	0	0	0	Cost/person /year	More O & M cost=1(not included in cost estimate)
$C_{3.3}$	Capacity to pay for farmer for transport	13			0	0	8.3			0	0	11.7			0	0	8.3			0	0	10	5	1	50	10	10	2	Cost/person (income/person)	More payment need=1(not included in cost estimate)
C_4	**Physical environment aspects**	**15**					**30**					**20**					**25**					**15**								

$C_{4.1}$	Odour during transport	6	4	4	24	24	10	5	5	50	50	6.7	5	2	33	13	8.3	3	3	25	25	5	1	5	5	25	27	27	Qualitative	More odour=1, Dried faeces should not be odourous
$C_{4.2}$	Noise during transport	4	3	2	12	8	10	4	2	40	20	6.7	0	0	0	0	8.3	3	3	25	25	5	2	3	10	15	17	14	Qualitative	More noise=1, Option 2 has more truck movements because of urine barrels
$C_{4.3}$	Pollution from trucks (dust, CO_2 emission)	5	3	2	15	10	10	5	2	50	20	6.7	0	0	0	0	8.3	2	3	17	25	5	2	2	10	10	18	13	Qualitative	More pollution=1
C_5	**Health aspects**	**10**					**5**					**5**					**10**					**10**								
$C_{5.1}$	Potential health risk during transport	10	2	4	20	40	5	2	4	10	20	5	2	3	10	15	10	3	3	30	30	10	1	4	10	40	16	29	Risk assessment	More risk=1, Dried faecal sludge from Option 1 still have more pathogens than dried faecal matter due to prolonged storage for Option 2
C_6	**Institutional aspects**	**25**					**25**					**10**					**25**					**25**								
$C_{6.1}$	Capacity building required for transport	18	3	3	54	54	12.5	4	4	50	50	5	2	3	10	15	12.5	3	2	38	25	12.5	1	2	13	25	33	34	Qualitative	More capacity=1
$C_{6.2}$	Monitoring requirements for Municipality	7	3	3	21	21	12.5	4	2	50	25	5	1	3	5	15	12.5	2	2	25	25	12.5	1	3	13	38	23	25	Qualitative	Difficult to monitor=1
	Total	**100**			**223**	**217**	**100**			**320**	**238**	**100**			**138**	**148**	**100**			**194**	**193**	**100**			**130**	**223**	**201**	**204**		
	Ranking				**1**	**2**				**1**	**2**				**2**	**1**				**1**	**2**				**2**	**1**	**2**	**1**		

Table 9-28: Details for Part E – Reuse dried faeces, faecal sludge or urine in agriculture

No.	Criteria		Score		Weighted Score			Score		Weighted Score			Score		Weighted Score			Score		Weighted Score			Score		Weighted Score		Group weight		Indicator	Comments
	Part E - Reuse dried faecal sludge or sanitised faeces and urine in agriculture	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Weight**	**Option 1**	**Option 2**	**Option 1**	**Option 2**	**Option 1**	**Option 2**		
		Expert 1					**Expert 2**					**Expert 3**					**Expert 4**					**Expert 5**								
C_1	**Social aspects**	**20**					**20**					**20**					**20**					**20**								
$C_{1.1}$	Potential for cultural barriers to use products	11	3	4	33	44	10	4	3	40	30	10	4	1	40	10	10	3	1	30	10	10	1	2	10	20	31	23	Qualitative	More potential for barrier=1
$C_{1.2}$	Farmers willingness to utilise the fertiliser	9	3	4	27	36	10	3	4	30	40	10	4	3	40	30	10	3	2	30	20	10	1	1	10	10	27	27	Qualitative	Less willingness=1
C_2	**Technological aspects**	**15**					**15**					**15**					**15**					**15**								
$C_{2.1}$	Potential for impurities in final products grown with that fertiliser	2	2	5	4	10	3.8	2	5	8	19	3.8	4	2	15	8	3.8	3	3	11	11	3.8	1	3	4	11	8	12	Qualitative	More potential for impurities=1, Option 1 faecal sludge may contain more contaminants
$C_{2.2}$	Ease of storage of fertiliser (for farmers)	3	3	2	9	6	3.8	4	2	15	8	3.8	4	4	15	15	3.8	2	3	8	11	3.8	3	3	11	11	12	10	Qualitative	Difficult storage=1, Need to store urine fertiliser
$C_{2.3}$	Quality of fertiliser or soil conditioner	7	2	5	14	35	3.8	2	5	8	19	3.8			0	0	3.8	2	4	8	15	3.8	1	5	4	19	7	18	Qualitative	Low quality=1
$C_{2.4}$	Ease of application of fertiliser (need for new machinery)	3	4	2	12	6	3.8	4	3	15	11	3.8	3	4	11	15	3.8	3	4	11	15	3.8	3	3	11	11	12	12	Qualitative	Difficult to apply=1, Urine application is different
C_3	**Economic aspects**	**15**					**30**					**30**					**25**					**15**								
$C_{3.1}$	capital cost	4			0	0	10			0	0	10			0	0	8.3			0	0	5			0	0	0	0	Cost/person	Not estimated, Option 2 probably higher due to urine storage
$C_{3.2}$	Lower expenses for not having to buy chemical fertiliser	2	3	4	6	8	10	2	5	20	50	10	3	4	30	40	8.3	2	4	17	33	5	2	5	10	25	17	31	Cost/person	Higher expenses=1, Amount of fertiliser from Option 2 is much higher than for for Option 1
$C_{3.3}$	Income from higher yield by fertiliser use	9	3	5	27	45	10	2	5	20	50	10	4	3	40	30	8.3	2	3	17	25	5	2	4	10	20	23	34	income/person	Low income=1
C_4	**Physical environment aspects**	**10**					**15**					**15**					**15**					**10**								

$C_{4.1}$	Odour during storage of urine at farm	2	5	2	10	4	3	5	3	15	9	3	5	2	15	6	3	5	3	15	9	2	2	2	4	4	12	6	Qualitative	More odour-1, Option 1 no urine is applied
$C_{4.2}$	Odour during application of urine at farm	2	5	2	10	4	3	5	3	15	9	3	5	3	15	9	3	5	2	15	6	2	2	3	4	6	12	7	Qualitative	More odour-1
$C_{4.3}$	Odour during storage of solids at farm	2	4	5	8	10	3	2	5	6	15	3	5	5	15	15	3	3	3	9	9	2	3	3	6	6	9	11	Qualitative	More odour-1
$C_{4.4}$	Odour during application of solids at farm	2	4	5	8	10	3	3	5	9	15	3	3	3	9	9	3	3	3	9	9	2	3	3	6	6	8	10	Qualitative	More odour-1
$C_{4.5}$	Risk of over-fertilisation and resulting run-off	2	3	2	6	4	3	4	2	12	6	3			0	0	3	3	2	9	6	2	2	2	4	4	6	4	Qualitative	High risk=1
C_5	**Health aspects**	**20**					**15**					**15**					**15**					**20**								
$C_{5.1}$	Potential health risks for consumers of fertilised foods	12	4	4	48	48	7.5	5	5	38	38	7.5	2	4	15	30	7.5	3	4	23	30	10	1	3	10	30	27	35	Risk assessment	High risk=1
$C_{5.2}$	Potential health risk during handling of fertilisers for farmers	8	3	4	24	32	7.5	2	4	15	30	7.5	5	5	38	38	7.5	2	3	15	23	10	1	3	10	30	20	30	Risk assessment	High risk=1, Option 1 remaining pathogens
C_6	**Institutional aspects**	**20**					**5**					**5**					**10**					**20**								
$C_{6.1}$	Capacity building requirements for farmers	15	4	3	60	45	2.5	4	2	10	5	2.5	5	4	13	10	5	3	3	15	15	10	2	2	20	20	24	19	Qualitative	More capacity building require=1
$C_{6.2}$	Monitoring requirements for Municipality	5	4	3	20	15	2.5	4	2	10	5	2.5	3	4	8	10	5	3	2	15	10	10	1	1	10	10	13	10	Qualitative	Difficult to monitor=1
	Total	100			326	362	100			285	358	100			318	274	100			255	257	100			144	244	266	299		
	Ranking				2	1				2	1				1	2				2	1				2	1	2	1		

9.11. Appendix 11: MDG achievement in Ghana and Peru

Table 9-29: MDG goals, targets, and indicators directly connected to sanitation (WHO/UNICEF, 2006)

Goals and targets	Indicators
Goal 1: Eradicate extreme poverty and hunger Target 1: Halve, between 1990 and 2015 the proportion of people whose income is less than one dollar per day Target 2: Halve, between 1990 and 2015 the proportion of people who suffer from hunger	1. proportion of population below $ 1 (PPP) per day 2. Poverty gap ratio (indices x depth of poverty) 3. Share of poorest quintile in national consumption 4. Prevalence of underweight children under five years of age 5. Proportion of population below minimum level of dietary energy consumption
Goal 4: Reduce child mortality: Target 5: Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate	13. Under five mortality rate 14. Infant mortality rate
Goal 6 : Combat HIV/AIDS, Malaria and other diseases Target 8: Have halted by 2015 and begun to reverse the incidence of malaria and other diseases.	21. Prevalence and death rates associated with malaria 22. Proportion of population in malaria – risk areas using effective malaria prevention and treatment
Goal 7 : Ensure environmental sustainability Target 10: Halve, by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation Target 11: By 2020, to have achieved a significant improvement in the lives of at least 100 million slum dwellers	30. Proportion of population with sustainable access to improved water source, urban and rural 31. Proportion of population with access to improved sanitation, urban and rural 32. Proportion of households with access to secure tenure

Table 9-30: Contribution of improved drinking and sanitation for other MDGs (WHO/UNICEF, 2006)

MDG goals	**Contribution of improved drinking water and sanitation**
1. Eradicate extreme poverty and hunger	• The security of household livelihoods rests on the health of its members; adults who are ill Themselves or must care for sick children are less productive. • Illnesses caused by unsafe drinking water and inadequate sanitation generate high health cost relative to income for the poor. • Healthy people are better able to absorb nutrients in food than those suffering from water related diseases, particularly helminths, which rob their hosts of calories. • The time lost because of long-distance water collection and poor health contributes to poverty and reduced food security.
2. Achieve universal primary education	• Improved health and reduced water-carrying burdens improve school attendance, especially among girls. • Having separate sanitation facilities for girls and boys in school increases girls' attendance, especially after they enter adolescence.
3. Promote gender equity and empower women	• Reduced time, health and care-giving burdens from improved water services give women more time for productive endeavors, adult education and leisure. • Water sources and sanitation facilities closer to home put women and girls at less risk of assault while collecting water or searching for privacy.
4. Reduce child mortality	• Improved sanitation and drinking water sources reduce infant and child morbidity and mortality.
5. Improve maternal health	• Accessible sources of water reduce labour burdens and health problems resulting from water sortage, reducing maternal mortality risks. • Safe drinking water and basic sanitation are needed in health-care facilities to ensure basic hygiene practices following delivery.
7. Ensure environmental sustainability	• Adequate treatment and disposal of wastewater contributes to better ecosystem conservation and less pressure on scarce freshwater resources. Careful use of water resources prevents contamination of groundwater and helps minimize the cost of water treatment.
8. Develop a global partnership for development	• Development agendas and partnerships should recognize the fundamental role that safe drinking water and basic sanitation play in economic and social development.

Table 9-31: Categorisation of sanitation systems (WHO/UNICEF, 2006)

Improved sanitation	**Not improved sanitation**
Connection to a public sewer	Service or bucket latrine
Connection to a septic system	Public latrine
Pour flush latrine	Latrine with open pit
Simple pit latrine	Open defecation
Ventilated improved pit latrine	
Composting toilet	

Table 9-32: Global targets in 2015 in water sector (SEI, 2005)

	sanitation		**Water**	
UN region	**Urban target population (Millions)**	**Rural target population (Millions)**	**Urban target population (Millions)**	**Rural target population (Millions)**
East Asia	247.9	147.8	254.2	14.2
Eurasia	7.5	16.2	4.7	9.7
Latin America and Caribbean	114.8	25.2	97.4	7.9
North Africa	27.6	17.8	27.8	13.8
Oceania	0.8	2.7	0.8	2.9
South-East Asia	89.7	60.6	105.2	31.9
Southern Asia	189.5	380.9	171.2	132.3
Sub-Saharan Africa	158.4	199.4	146.9	147.9
West Asia	44.5	22.8	43.6	16.8
Total	**880.6**	**873.5**	**851.9**	**377.4**

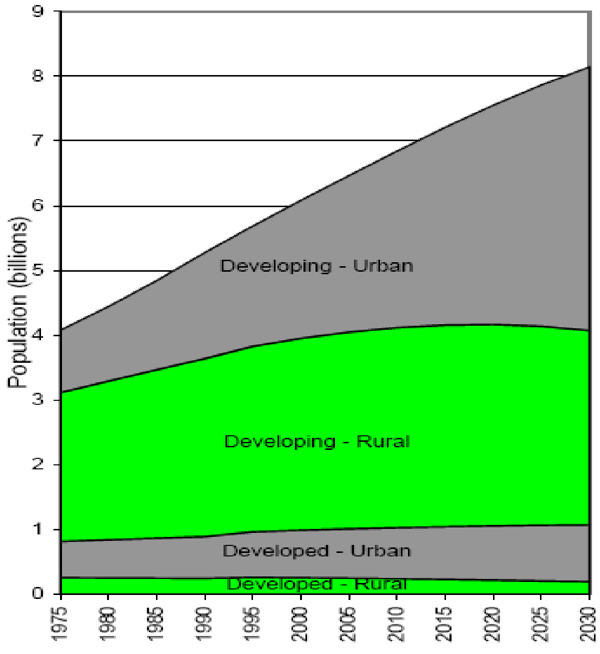

Figure 2-3: Population Dynamics 1975-2030

Figure 9-2: Global population dynamics 1975 – 2030 (SEI, 2005)

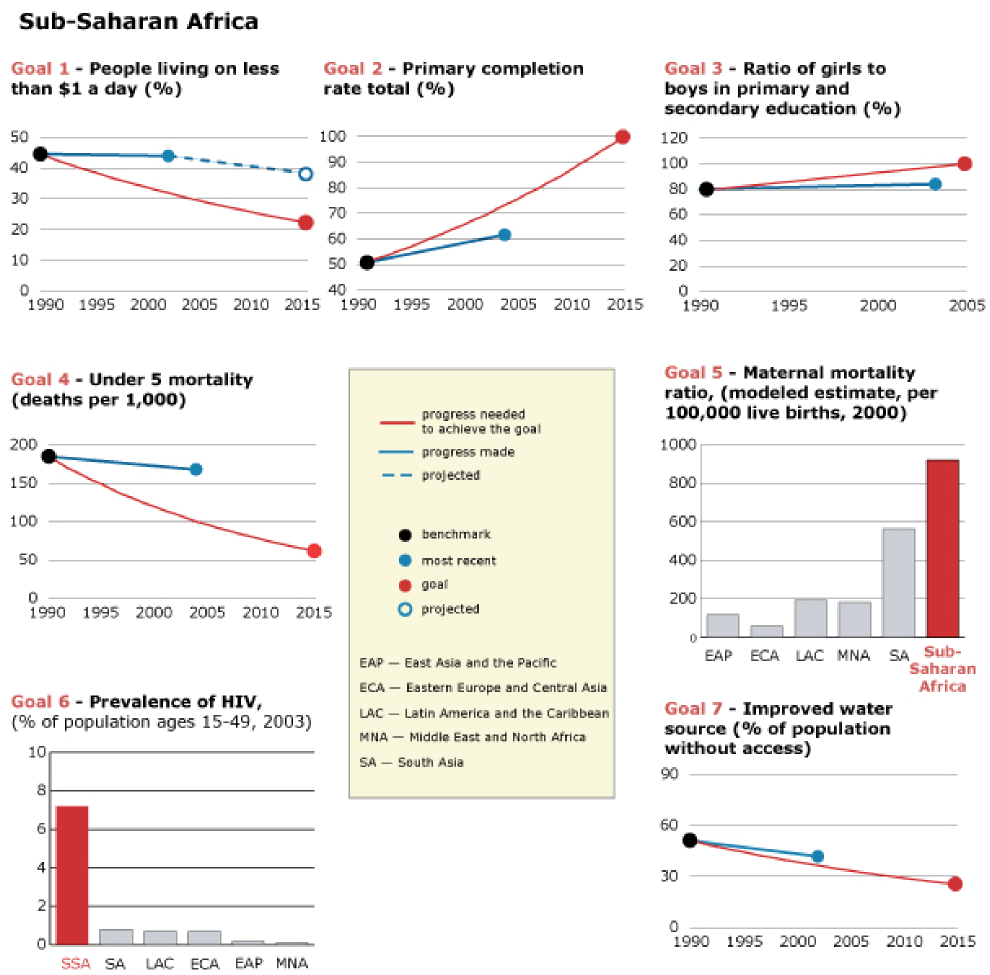

Figure 9-3: MDG achievement and 2015 targets in Sub- Saharan Africa (area in which Ghana falls) (WHO/UNICEF, 2006)

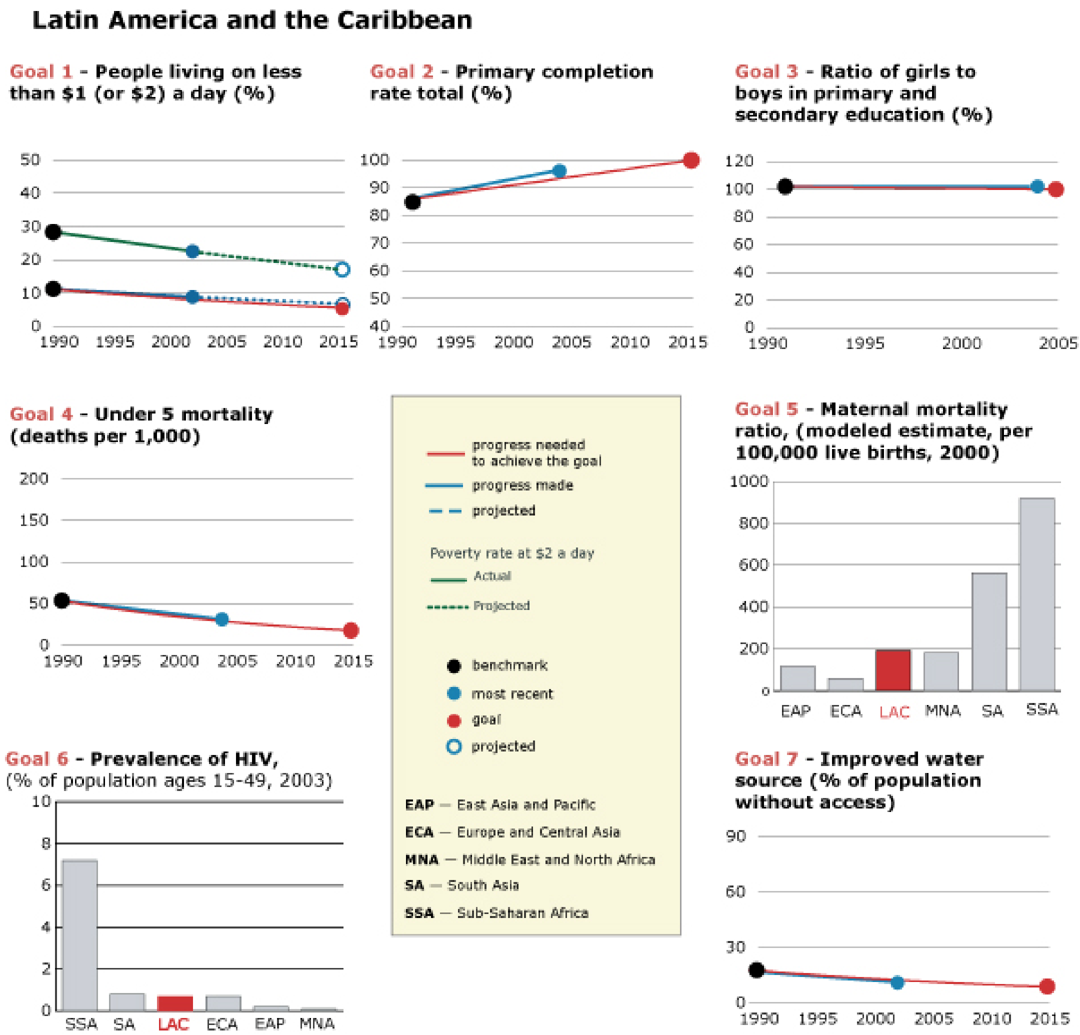

Figure 9-4: MDG achievement and 2015 targets in Latin America and Caribbean (area in which Peru falls) (WHO/UNICEF, 2006)