Technical University Hamburg Harburg
Institute of Municipal and Industrial Wastewater Management

International Master Program in Environmental Engineering (IMPEE)

Project Work

Use of Products from Ecological Sanitation Systems in Addis Ababa

-UPESSAA-

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INTRODUCTION

Addis Ababa, the capital of Ethiopia, host today around 3,5 million of people, from which more than 85% live in slums with high population density and precarious sanitation conditions. The Ministry of Capacity Building has initiated a Construction Capacity Building Program (CSCBP), in which one of the components aims to reform the University studies of Engineers and Architect, providing examples of best practices and allowing practical experiences through the implementation of urban planning projects. In his sense, a low cost building project is being carried out by the German Enterprise for Technical Cooperation (GTZ-*Deutsche Gesellschaft für Technische Zusammenarbeit*) in the inner city areas of Arat Kilo and Piazza, in order to offer a good living conditions to 50 000 inhabitants, meanwhile ensuring the extension of the capacity building of local professionals. In the frame of this great engineering project, a feasible sanitation option is needed, looking forward to a sustainable solution that could close the cycle of water and nutrients.

The aim of the present study is to propose an appropriate and sustainable human excreta management concept for the Arat Kilo and Pizza inner city areas of Addis Ababa, taking as starting point the concept of ecological sanitation. The report presents a complete description of the social, geographical, climate and economical conditions of the study area, with the objective of adapting the existing know-how to the local situation of the Ethiopian capital. Furthermore, a complete revision of the different technologies available for the recycling of nutrients is also presented, where the ecological sanitation systems are classified as dry- and low flush- systems. Examples of current and past applications of each technology are also given for urine and faeces, classifying each process in two broad categories: primary and secondary treatments. An exhaustive presentation of the health risks related to the management and re-use of human excreta is also illustrated, together with the international regulations and recommendations related to treatment and use in agricultural land.

Two different scenarios will be established for the selection of a sanitation system, using as study population 2000 persons living in eight buildings of the proposed project. Scenario A: dry toilet and scenario B: low flush toilets, both with urine separation. For each scenario, an evaluation of all the technologies available will be performed, aiming to select the process methodology that better fits in each case (with/without water). A selection criteria, taking the more relevant qualitative aspects will be implemented, after which a complete description of the sanitation system selected for each scenario will be made. Details regarding, logistics, process, capacity required, labour required, quality and quantity of products will be also included. Since in both scenarios urine will be separated, it will be handle apart, however the same criteria will be used in order to select the urine treatments that better adapts to Addis Ababa. Once the two scenarios are fully described, a cost analysis will be made, evaluating investment and operation/maintenance costs, as well as the Net Present Value, in order to decide which scenario would be more profitable. A final qualitative assessment based on ponderation of selection parameters will be performed, in order to elucidate which scenario will provide a better alternative for the existing sanitation need of the Arat Kilo and Piazza city areas of Addis Ababa.

1-Presentation of the Project

1.1- The Ethiopian context

The Federal Democratic Republic of Ethiopia is located in Eastern Africa, in a high tableland known as the Ethiopian Plateau, covering an area of 1 133 380 km^2 (Keller, E., 2005).

Ethiopia, with a population estimated in 70,678,000 inhabitants, is the third most populous country in Africa, which although having a long-standing history, diverse cultural heritage and good resource potential for development, the 44% of its population lives in absolute poverty (The World Bank Group, 2004), with an average GDP of $ 90 a year in 2002 (Keller, E., 2005).

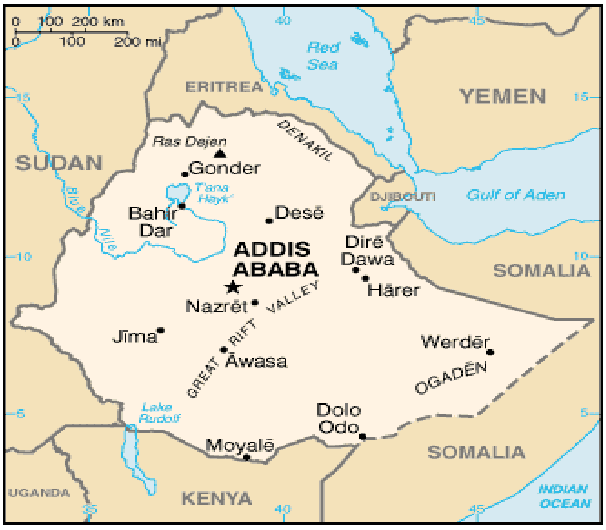


Fig.1.1- Ethiopia (http://www.climate-zone.com)

The Ethiopian poverty, paramount and widespread particularly in the 84 % of population living in rural areas, is directly linked to the prevailing degradation of the environment and natural resources (African Development Fund, 2002). The country currently faces a number of environmental challenges resulting directly or indirectly from human activities, exacerbated by rapid population growth and the consequent increase in the exploitation of natural resources (Walta Information Center, 2004).

Ethiopia's economy is based on agriculture, which accounts for 45% of the gross domestic product (GDP), 90% of exports and 80% of total employment (EARIMS, 1999). In spite of the dependency of Ethiopia on the first sector of the economy, agriculture is today plagued by periodic drought, soil degradation caused by overgrazing, deforestation, high population density and poor infrastructure (Wikipedia, 2005).

Due to the vulnerability existent in the food production sector in Ethiopia, it is regularly plagued by famine, condition which together with the high rate of infant mortality (101,29 deaths/1,000 live births) and maternal mortality (1.400/100.000) makes the living conditions far from desirable (data from AFROL, 2005). One of the largest killing factors for children aged two to five is waterborne disease (Edström G., 2000). Many die of diarrhoea during the transition from breastfeeding to contaminated drinking water, due to the scarce sanitation conditions in which most of the people live.

The most recent figures for Ethiopia (1999) indicate a water supply coverage of 26% (77% in urban areas and 13% in rural areas), and a sanitation coverage of 15% (58% in urban areas and 6% in rural areas) (World Health Organisation, 2005).

1.2- Addis Ababa

Addis Ababa, the capital of Ethiopia, was founded in 1887 by the emperor Menelik and it is today one of the fastest growing cities in Africa. Unlike other African cities of colonised countries, Addis Ababa is characterised by its spontaneous growth as an indigenous city with very little impact of external forces. The city began to develop as a political, economic and cultural centre in subsequent years. Services such as piped water, electric light and other facilities attracted migrant population from other parts of the country. In addition to this rate of rural-urban migration drained rural labour force from agricultural production created problems of unemployment, congestion and strains on existing inadequate social services in Addis Ababa (Enda Ethiopia and Preceup, 1999).

✓ GEOGRAPHY

The built up area of Addis Ababa covers 530 square kilometers in the shadows of the 3,000 meters high Entotto mountains. With an elevation ranging from 2000-2800 m it is the highest capital of Africa. Its topography is constituted by hills, valleys, rivers and streams. (Ethiopar, 2005). The city itself is divided by elevation. In the north lies the old central sector, Arada, home of the public square, several small markets, and Addis Ababa University. This area is centrally located on a hill 450 meters above the surrounding city. Connected to the Arada by Churchill Avenue, the main north-south corridor in the city, is Lower Addis Ababa. This commercial core is more characteristic of small American and European central business districts, with its mid-rise hotels and government buildings (Malacaster, 2005).

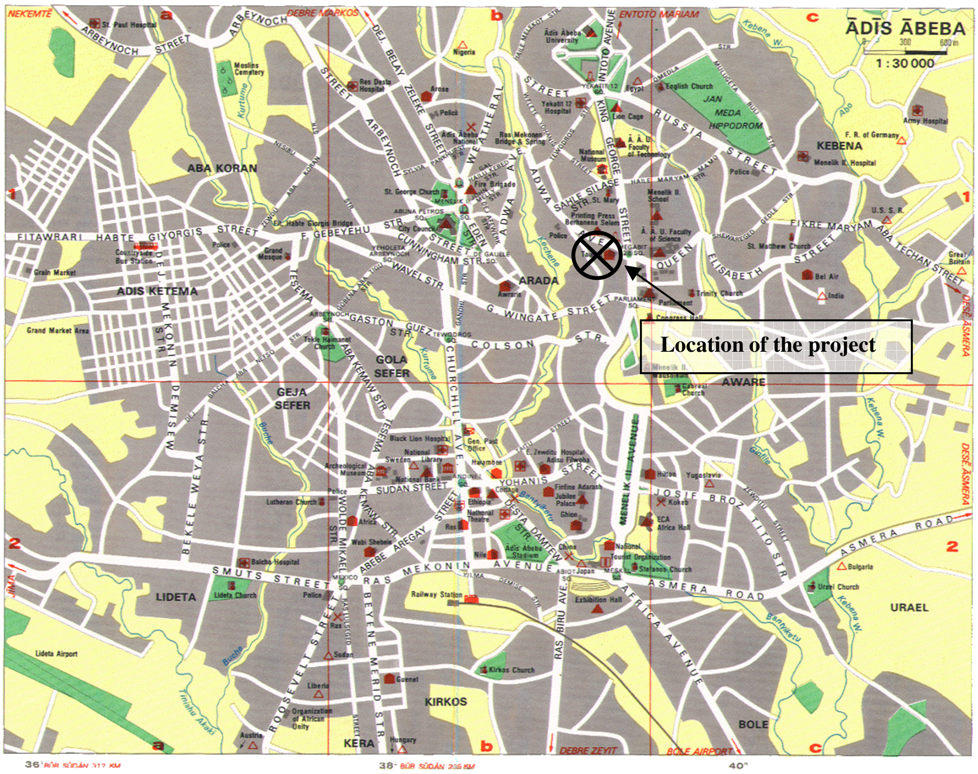


Fig 1.2- Street Map of Addis Ababa (Malacaster, 2005).

✓ **CLIMATE**

Despite its proximity to the equator, Addis Ababa enjoys a mild, Afro-Alpine temperate and warm temperate climate. The lowest and the highest annual average temperature is between 15°C and 18°C. The table below displays average monthly temperature measures in Addis Ababa based on 8 years of historical weather readings (Climate zone, 2005):

Table 1.1.- Average monthly temperature measures in Addis Ababa (Climate Zone, 2005)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature	16	17	17	18	18	16	15	15	16	16	15	15
Avg. Max Temperature	22	24	23	24	24	22	20	20	21	21	22	22
Avg. Min Temperature	7	8	11	11	11	11	11	11	10	8	7	6

Ethiopia has two major seasons: the dry season, Bega, prevails from October to May and the rainy season, Kiremt, takes place between the months of June and September. During the dry season, warm days and cold nights are expected with drastic changes of temperature. June, July, August and September are the humid months for Addis Ababa with a maximal annual rainfall of 300 mm. During those days, the solar irradiation is also low (3 hours) compared to the average hours of sunshine of the dry season (9 hours).

Table 1.2- Average monthly climate indicators in Addis Ababa (Explore, 2005)

Month	Sunshine	Relative Humidity		Average Montly precipitation
	Average hours per day	7:00 AM (%)	1:00 PM (%)	mm
Jan	9	61	33	13
Feb	9	64	39	38
Mar	8	58	37	66
Apr	7	65	44	86
May	8	63	43	86
Jun	6	76	59	147
Jul	3	86	73	279
Aug	3	86	72	300
Sep	5	79	64	191
Oct	8	56	39	20
Nov	9	59	37	15
Dec	9	62	29	5

✓ **ADMINISTRATION**

In 1991 Ethiopia was divided into 14 regions. Addis Ababa, which is located in the Oromia State was granted its own autonomous administrative status, named Region 14. Region 14 includes both an urban and a rural part, known as Addis Ababa urban and Addis Ababa rural in statistical documents. As an autonomous regional entity, the city is vested with legislative, executive and judicial powers. It is governed by a city council, known as the Addis Ababa City Council, representing the 6 zones into which Addis Ababa is divided. Each zone is divided into weredas, and weredas into kebeles, or neighbourhoods, which form the smallest administrative unit of the city. There are 28 weredas and 305 kebeles in Addis Ababa urban and 23 farmers' associations in Addis Ababa rural (Enda Ethiopia and Preceup, 1999).

✓ **URBANISM**

The Arada, the most dynamic area in Addis Ababa, is surrounded by low-income slums and shantytowns to the north, northwest and west by Addis Ketema with particularly high density low income residential areas immediately southeast of the business district. The housing situation in Addis Ababa is considered substandard, due to the lack of services, shotty construction and crowded conditions. In 2000, over 85% of the population of Addis Ababa lived in slums or informal settlements similar to the famed '*Barrios*' squatter settlements in South American cities. Though wealthier neighborhoods boast European style mansions and public buildings, the majority of Addis Ababa residents erect their own houses with whatever materials are available. Over 80% of homes have wood or mud walls and 93% are sheltered by corrugated iron roofs. Three percent of houses have thatched roofs. Only 12% of homes, mostly those of European design have cement or plastic tile floors, while 34% have wood floor boards. Over 51% of houses in Addis Ababa have only earthen floors (Malacaster, 2005).

The main streets of Addis Ababa are asphalted and spacious, but have suffered badly from lack of recent maintenance. Many side streets are still unpaved, badly-potholed especially during the rainy season, and wearing on tyres. For the vast majority of Addis Ababa's residents, transportation is a local or regional endeavor. Though cars, trucks and motorbikes clog the narrow streets, most residents do not own their own automobiles (UNDP, 2005).

Like many urban regions in developing countries, beyond its suburbs, Addis Ababa is surrounded by smaller cities on the rail line and major roads leading into the city, which rely on it as a market for products of industry. Nearby towns include Akaki on the outskirts of Addis Ababa, which is a center for light industries including textiles and food processing, and Nazareth, a sugar processing center which is southeast of the capital (Macalester, 2005). Because of its desirable central location and primate city status, all roads do indeed lead to Addis, which offers a blending of modern and traditional living patterns.

The estimated 63,000 commercial vehicles in Ethiopia operate on a network of about 17,000 km all-weather roads and about 35,000 km dry-weather roads. About one-quarter of the all-weather roads is paved, but the condition has deteriorated due to lack of maintenance in recent years. Four-wheel drive vehicles are preferable for travel to most project sites beyond the proximity of Addis Ababa and one or two towns nearby; minor roads can be quite challenging, particularly in the rainy season. An extensive country bus system exists, but schedules are irregular, and vehicles are old and very crowded (UNDP, 2005).

✓ **POPULATION**

Addis Ababa accommodates about 30% of the total urban population of Ethiopia. Its population amounted to 2.1 million in the 1994 census, estimated to reach 2.3 million in 1997. Other sources give higher estimates (3.5-4 million). The population census of 1984 gave a population at that time of 1.4 million, revealing an increase of 60% over a decade, at an annual growth rate of 3.79% (Enda Ethiopia and Preceup, 1999). Population density reaches 632 inhabitants/ha in the slum areas and 5 inhabitants/ha in Addis Ababa rural. 32% of the Addis Ababa's population is below 15 years old and 1.7% is above 64 years old. There are over 78 ethnic groups in the city, the major ones being the Amharas, Oromos, Gurages and Tigrays (Enda Ethiopia and Preceup, 1999).

An exceptional element of Addis Ababa's social system is the high proportion of women in the urban population (51,6 %). Many of the women are single and divorced, having fled to the city to find jobs after being exiled from their villages. For every 100 females in the city, there are only 95 males. These women hold one-third of all paid jobs in Addis Ababa (Macalester, 2005).

✓ **HEALTH**

Addis Ababa is fairly free of the more serious tropical diseases. Malarial mosquitoes are virtually unknown in Addis Ababa, but are found at slightly lower altitudes. Yellow fever, hepatitis A + B, typhoid fever, typhus and other tropical diseases are not uncommon. Bilharzia or snail fever is fairly widespread in the rural areas; it results from bathing in polluted water. The incidence of HIV/AIDS is increasing (UNPD, 2005).

✓ **RELIGION**

Christianity and Islam are the two major religions. Christianity was first introduced into Ethiopia in the 4th Century, and Christians are thought to constitute about half of the population. The vast majority of the Christians belong to the Orthodox Church, deeply-rooted in the highlands. Islam was introduced into Ethiopia in the 7th Century, and today more than one-third of the population is thought to be Muslim. While particularly strong in southern, eastern and southeastern regions, mosques and Muslim communities are to be found throughout the country, and there is a significant Muslim population in Addis Ababa (UNDP, 2005). Today, 82% of the population of Addis Ababa are Orthodox Christians, 12.7% Muslims, 3.9% Protestants, 0.8% Catholics, and 0.6% followers of other religions (Hindus, Jews, Bauhaus, Jehovah, Athnostics, among other) (Ethiopar, 2005)

✓ **EDUCATION**

Until the mid-1970s, the illiteracy rate of Ethiopia was among the highest in the world. Following the 1974 Revolution, an ambitious literacy programme benefited millions of Ethiopians, both children and adults; the adult literacy rate in 1990 was reported to be 66 per cent (UNPD, 2005). Today, the literacy rate in Addis Ababa is 83%. Net enrolment ratios in primary, junior and senior secondary school are 73, 35 and 36% respectively in total, with a very similar representation for both boys and girls (Enda Ethiopia and Preceup, 1999). Addis Ababa University was established in 1950 as a university college, but is now a full-fledged university, which confers its own degrees in a wide range of disciplines, and also has a graduate school. The Alemaya College of Agriculture near Harar, founded in 1954 as part of Addis Ababa University, became an independent Agricultural University in 1985. In addition, there are 16 junior colleges offering specialized training in agriculture, technology, trade and commerce, and teacher education. Seven are in Addis Ababa, and the other nine in provincial towns in various parts of the country (UNPD, 2005).

✓ **ECONOMIC ASPECTS**

The economic activity rate for Addis Ababa is 53.08%, with 65.22% for men and 41.89% for women (Enda Ethiopia and Preceup, 1999). Officially, there are 119 197 job places in trade and commerce; 113 977 in manufacturing and industry; 80 391 home makers of different variety; 71 186 in civil administration; 50 538 in transport and communication; 42 514 in education, health and social services; 32 685 in hotel and catering services; and 16 602 in agriculture.

The so-called informal sector, which is defined as not registered companies or cooperatives which are mainly engaged in marketed production with not full written book of accounts and no license, employed 166 405 people in 1996 according to the sample survey conducted by the Central Statistical Authority and the Ministry of Labour and Social Affairs. This represents 26% of economically active population in urban Addis Ababa (Enda Ethiopia and Preceup, 1999).

An estimated of 67% of Ethiopia's industries are found in Addis Ababa, but the sector accounts for only 13% of the city's economically active population. According to the UNDP (2005), the average income is below the poverty line for 60% of the households.

✓ **UNEMPLOYMENT**

Unemployment is the biggest economic challenge of Addis Ababa, with the current rate standing at 42 %, and 60 % of employment classified 'informal'. To tackle this problem by encouraging micro and small enterprises is one of the new plans of the local government, aiming to create jobs in five core areas: food processing; the textile and garment industry, metalwork, woodwork and furniture production, small construction, and municipal facilities. The local government has created the Micro & Small Enterprises Development Agency to provide credit, training and assistance to these new businesses, as well as Business Development Subsidies (BDS), Technology Improvement and marketing. The scheme has already helped create 63,000 jobs (Kervella, 2005).

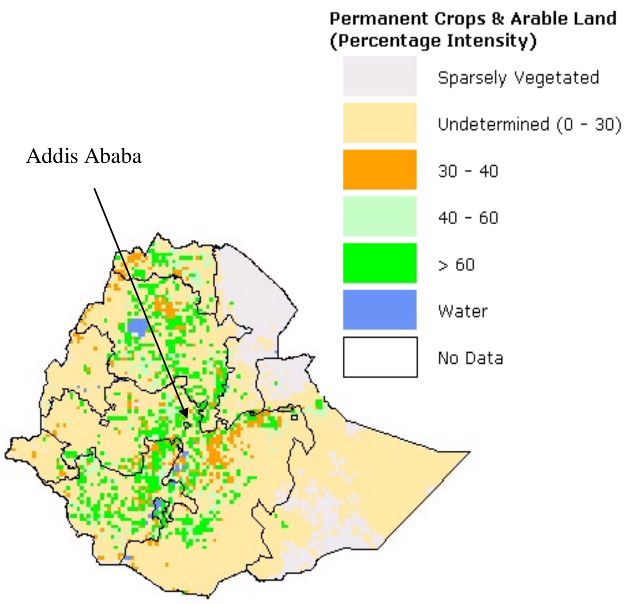
✓ **AGRICULTURAL ACTIVITY**

In Ethiopia, about 9.5 million hectares (8% of land) is under cultivation at present, with an estimation of 100,000 hectares of irrigated area. Peasant holdings still account for over 90 per cent of crops by area and production. The yield is primarily used by farmers themselves, and only a small proportion of the produce reaches the markets. Since the changes of mid-1991, the State

Farms, Production Co-operatives, parastatal marketing organizations and price-control mechanisms established following the 1974 Revolution have changed radically (UNPD, 2005).

Grain crops (the most important of which is teff, a species endemic to the Ethiopian Highlands) account for some 80 per cent of the area cultivated under major crops, and over a third of the value of total agricultural production. Although drought causes marked fluctuations from year to year, cereals production has remained around the 7.5 million metric tons mark until the exceptionally good rains of 1995 and 1996, which along with increased fertilizer use, increased production to around 11 million tons in 1996. Coffee, still accounting for about 70 per cent of exports, is mainly produced in Wollega, Kaffa, Illubabor, Gamo Gofa, Sidamo and Harerge. Other important agricultural products are cotton, sugar cane, oil seeds, vegetables and fruits. Ch'at, a mildly narcotic leaf, is an important cash-crop in Hararge (UNPD, 2005).

The following figure presents the percentage intensity of permanent crops and arable land in Ethiopia, together are also listed the production of the 20 most important food and agricultural commodities (ranked by value):



Rank	Commodity	Production (MT)
1	Roots and Tubers nes	3,700,000
2	Maize	2,800,000
3	Sugar Cane	2,235,000
4	Cereals nes	1,700,000
5	Cow Milk, Whole, Fresh	1,450,000
6	Wheat	1,400,000
7	Sorghum	1,400,000
8	Barley	850
9	Broad Beans, Dry	448
10	Vegetables Fresh nes	420
11	Potatoes	390
12	Millet	350
13	Sweet Potatoes	340
14	Indigenous Cattle Meat	304,122
15	Yams	300
16	Papayas	230
17	Coffee, Green	220
18	Chick-Peas	181
19	Peas, Dry	155
20	Cabbages	150

Figure 1.3.- Agricultural Activity in Ethiopia. (FAO, www.fao.org)

It is estimated that around 17000 inhabitants of Addis Ababa are enrolled in agricultural activities. However, the residents of rural parts of Addis Ababa, the city dwellers, also participate in animal husbandry and cultivation of gardens. About 10 400 ha of Addis Ababa surroundings were used to plant cereal and pulses in year 2003, giving a production of about 19 000 tonnes of which 56% is wheat and 30 % teff. (FAO/WFP, 2004)

Since Addis Ababa is the capital city of Ethiopia, modern economic activities, social and infrastructural services are found relatively in a better situation than other cities of Ethiopia. However the existing socio-economic and infrastructural development of Addis Ababa is too slow to meet the demands of the increasing population due to both natural growth and rural-urban migration.
Among many other urban problems, the lack of access to potable water together with the missing sanitation conditions is one of the most urgents of the city of Addis Ababa.

1.2.1- Wastewater management and Sanitation conditions in Addis Ababa

The city has a potable water supply since 1901, however the number of customers in 2001 was estimated 180,000 inhabitants (AAWSA, 2002). The current average domestic consumption amounts to about 22 l/p·d, quantity resulting from averaging 80-100 l/p·d of water consumption of people with in-house services (about 4% of the population) and the use of the remaining population with access to safe drinking water (94%) served by yard connections, which amounts to 15 and 30 l/p·d (AAWSA, 2002). According to Meinzinger and Otterpohl (2005), this low consumption is due to unreliable water supply and habits of inhabitants. According to the 1994 population census, more than 45% obtain drinking water from outside their compounds (water vendors, etc.) (Enda Ethiopia and Preceup, 1999).

In spite of multiple governmental efforts and international cooperation programs, the sanitation conditions prevailing are still inadequate. According to the Addis Ababa Water and Sewerage Authority, the majority of the population of Addis Ababa uses either septic tanks or dry pit latrines, illustrated by the fact that 49% of the population uses shared sanitation facilities of these kind; nevertheless there is a 24% of inhabitants with no sanitation facility at all (see Table 1.3) (AAWSA, 2002).

Table 1.3- Distribution of toilet facilities by housing unit Addis Ababa (AAWSA *et al*, 2002)

Type of sanitary facility	Flush Toilet Private	Flush Toilet Shared	Pit Latrine Private	Pit Latrine Shared	No sanitary facility	Not Stated
No.	30,113	14,815	67,895	169,732	89,508	3,679
Percentage	8%	4%	18%	45%	24%	1%

The existing practice of on-site sanitation is however not well monitored and present several practical problems, as the emptying of the pits is required. Due to difficulties (e.g. steep gradients, poor access and poor pumping characteristics) encountered in densely populated areas of Addis Ababa, the access to the septic tanks is complicated and irregular, posing a danger of flooding and therefore pollution of groundwater and soil with pathogens and excess of nutrients. The emptying process is carried out by vacuum trucks, which take the sludge from the dry pit latrines and the septic tanks to Kaliti and Kotebe, treatment plants operating currently nearly at capacity (AAWSA, 2002).

According to AAWSA records, there are about 1800 connections on to the existing pipe sewer system of 120km, with an infrastructure that has not improved since 1993, presenting today high infiltration rates (approx. 3,000m^3/day). The number of people connected to the existing sewer system is very low, amounting 13,000 (AAWSA, 2002). The sewage effluent is treated in a waste water treatment works at Kaliti (design capacity of 7600m^3/d), which consist of two treatment trains each with two facultative and two maturation ponds in series, discharged into the river during the rainy season.

The Authority of Water and Sewerage of Addis Ababa (AAWSA) carried out in 1993 and 2002 different Wastewater Management studies with the objective of improving the standard of living health of the citizens of Addis Ababa. The Wastewater Masterplan, as referred, addressed several issues regarding implementation and improvement of on site sanitation, collection, disposal and treatment of sludge from septic tanks and dry pit latrines, improvement of sewer connections in sewered area and provision of sewerage to un-sewered areas in Addis Ababa (AAWSA, 2002). However, due to the high costs associated and the already delay and problems faced during the implementation attempts, it is estimated that the objectives of the project will not be reached in a short nor a long term.

There is thus a need of coming up with sustainable solutions for the habitability and sanitation crisis of Addis Ababa, developed in a in holistic approach, in a way that logistic, technical, socio-economical and cultural aspects are included, allowing to propose feasible and adapted innovative wastewater management concepts.

1.3- Ethiopia Construction Sector Capacity Building Project (CSCBP)

The Ministry of Capacity Building of Ethiopia, within the context of the Ethiopia Construction Sector Capacity Building Project, initiated the reform of the university studies in Engineering and Architecture, allowing practical experience and developing of best practices through the implementation of urban planning projects (Meinzinger and Otterpohl, 2005).

The German government, through its Organisation for Technical Cooperation GTZ (*Deutsche Gesellschaft für Technische Zusammenarbeit*), currently advices the Ethiopian administration in the planning of an extensive University Capacity Building Program, involving the construction, arrangement and functioning of such activities in national Universities. As part of this broad venture, GTZ is nowadays supporting the city government of Addis Ababa in the construction of an organisation structure for the independent implementation of house construction programs, through the application of its Low-Cost Housing concept (GTZ, 2005b).

The principal objective is to promote the reduction of the construction prices through a continuous improvement, rationalisation and training of the local skilled workers, counting for instances, with the cooperation between Ethiopian and German construction industries, through private and public, as well as Universities partnerships (GTZ, 2005b).

In this sense, the Addis Ababa City Government together with GTZ have selected the quarters Arat Kilo and Piazza as areas for the implementation of a Low-cost Housing project, in which more than 10.000 new residences will be constructed in an area of 53 ha, serving a population of more than 50 000 persons (Meinzinger and Otterpohl, 2005).

Due to the existing conditions of environmental degradation and the lack of infrastructure for the urban sanitation, the implementation of the Low-cost Housing project in Addis Ababa requires the planning, according to local conditions, of an effective wastewater management, in order to contribute to the improvement of the living standard of the inhabitants of these areas.

1.4- Objectives of UPESSAA

In the frame of the GTZ low cost housing project in Addis Ababa, in the inner city areas of Arat Kilo and Piazza, a wastewater management project must be developed in order to provide sustainable sanitation for the future 50 000 inhabitants who will occupy the 10 000 housing units to be constructed.

According to the Final Report of the Preliminary investigation performed by the Institute of municipal and industrial wastewater of the TUHH (Meinzinger and Otterpohl, 2005) the most sustainable wastewater management for these areas is ecological sanitation. Due to the local characteristics of Addis Ababa, the two recommended sanitation concepts to be applied are dry toilets and pour flush toilets, both with urine separation.

The main objective to be covered by the UPESSA study (Use of products from Ecological Sanitation Systems in Addis Ababa) is the analysis of possible treatments and further uses of the human excreta proposing feasible options for the separately management and reclamation of faeces and urine.

The <u>technical objectives</u> of the project are:

- ✓ To introduce ecological sanitation as a sustainable option for the needed wastewater management in the new housing area of Arat Kilo and Piazza in Addis Ababa.

- ✓ To review the current State-of-Art of treatment of products from dry toilets and pour flush toilets with urine separation, focusing in experiences in developing countries.

- ✓ To analyse the risk associated to the handling of human excreta and to review the current international regulations and recommendations regarding the use of human excreta in agriculture and home gardening, as soil conditioning and fertilizer.

- ✓ To characterise the human faeces and urine of the Ethiopian population.

- ✓ To estimate and evaluate the quantity and quality of the products from the sanitation units (dry toilets and poor flush toilets with urine separation) that will be generated in the new housing area of Arat Kilo and Piazza in Addis Ababa.

- ✓ To propose viable options for the treatment of dry faeces resulting from the dry toilets and wet faeces resulting from the pour flush toilets, emphasising the technical aspects related to the process, logistics, economics and availability of resources.

- ✓ To propose viable options for the treatment of urine for its further use as fertilizer in agriculture, emphasising the technical aspects related to the process, logistics, economics and availability of resources.

- ✓ To compare the two sanitation options (dry toilets and pour flush toilets, both with urine separation), regarding technical, logistic and socio-economic aspects, selecting the best sanitation management option, as well as the technology for treatment of waste that better fits the needs of the inhabitants of the inner city areas Arat Kilo and Piazza in Addis Ababa.

The UPESSA project will serve as a starting point for the development of the human excreta management and treatment system of the Arat Kilo and Piazza areas, developing ideas and logistic schemes for 8 building units with a population estimated in 2000 inhabitants.

2- Understanding Ecological Sanitation

2.1- The failure of centralised options in developing countries

The conventional centralised systems, based on flush toilets and collection of bulk water by sewer systems (Fig 2.1), have been successfully applied in developed countries with high technical and economical capacity for annual investment.

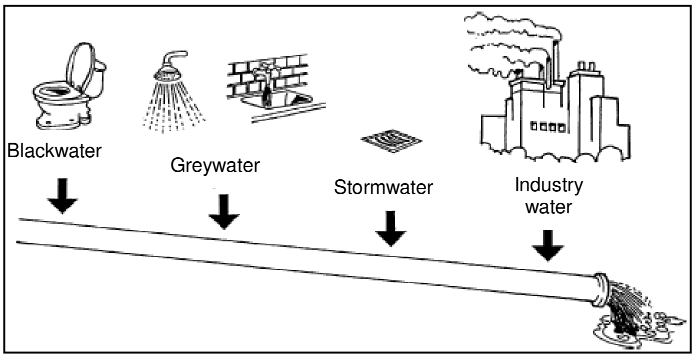


Fig 2.1- Flush-and-discharge system (Esrey, S. *et al*, 1998)

Developing countries generally do not have the financial, technical, or institutional resources to keep pace with increasing pollution and the parallel need to improve environmental sanitation services (Kalbermatten *et al.,* 1999). Therefore the application of such centralised systems in poor nations is unaffordable, presenting on the other hand the disadvantage of precious water requirement for flushing, which in water-stressed countries facing scarcity, the use of approx. 15,000 l of pure water per year for each person in order to flush 400-500 l of urine and 50 l of faeces, is considered unsustainable (water consumption data from Esrey *et al*., 1998). Furthermore, the capacity of municipalities in third world countries of providing sanitation in rural and peripheral areas is lagging far behind the progress made in water supply provisions, bringing as a consequence that over 90% of the sewage in developing countries is discharged untreated into surface waters, polluting rivers, lakes and coastal areas, and thus causing the spread of so-called "waterborne" diseases (Rose, 1999) and eutrophication of the water bodies. In addition, centralised systems need larger infrastructures and have greater energy needs and concentrates pollution at one point, increasing the probability of exceeding environmental assimilating capacities (Bertaglia, M, year not specified).

Many developing countries, in particular African nations, are suffering famine crisis due to the low accessibility to fertilizer and insufficient irrigation, making their food production inefficient and unreliable. However, worldwide prevails the misconception of the human excreta as waste with no useful purpose, idea that has led to the development of this kind of “flush and forget” sanitation solutions. Human excreta represent though a potential source of nutrients for crops, which could be used as fertilizer in a short and large scale. Farmers around the world yearly requiring 135 Mio tons of mineral fertilizer for their agricultural activities, could make use of human excrete, which is currently being dumped through conventional sanitation in the form of 50 Mio tons of fertilizer equivalents with a market value of around 15 Billion US dollar (data from Werner, 2004).

CENTRALISED SYSTEM IN ADDIS ABABA

According to the Final Report of the Preliminary investigation performed by the Institute of municipal and industrial wastewater of the TUHH (Meinzinger and Otterpohl, 2005) one option for the wastewater management of the Low-Cost Housing project in the Arat Kilo /Piazza areas in Addis Ababa would be to connect their domestics effluents to the existing sewer lines, making use of the existing wastewater treatment plant in Kaliti (described in section 1.2.1), as stated in the Wastewater Masterplan of the Addis Ababa Housing Development Project Office (AAHDPO). This option is considered unsustainable, in one hand because it is already well recognized the multiple functioning problems related to infiltration that currently presents the city sewer system and on the other side, due to the low capacity showed by the stabilisation pond system in Kaliti. Furthermore, due to the high investments required and the always-delaying condition for the realisation of projects in Ethiopia, it would be expected that the connection of these new 10 000 housing units will be concluded at a later date, in such a way that the first inhabitants moving in will not count with any wastewater treatment, circumstances that probably will remain in a long term.

2.2-Demands of a sustainable sanitation systems in developing countries

There are many reasons that explain the failure on implementing sanitation in developing countries, as illustrated in figure 2.2, however rather than the lack of knowledge or tools, the root of the problem lies at poor planning.

Why isn't sanitation happening?

- Lack of political will.
- Low prestige and recognition of the importance of sanitation.
- Poor policy, at all levels.
- Poor institutional frameworks.
- Inadequate and poorly used resources.
- Inappropriate approaches.
- Neglect of consumer preferences.
- Ineffective promotion public awareness.
- "Women and children last".

Fig 2.2- Failed sanitation (Kalbermatten, *et al.,* 1999).

The straight transfer of sanitation technologies from the developed to the developing world has failed in the sense that it has created the need for an infrastructure, which is not necessarily applicable and more important, sustainable, in all cases. The belief of flush water toilets as a sign of modernization and development, more than solving the problems it has contributed to the deterioration of the environment and living conditions. It is then a common practice in the developing countries the installation of household running water supplies through pipes without the parallel setting out of wastewater treatment plants, resulting in hundred of thousands meter cubic of domestic wastewater being discharged per day into the adjacent water body. Through many examples in Latin American, Asian and African metropolises it is notable how services are not conceived in an integrated way that takes into account all their potential impacts.

The developing of a wastewater management concept in a locality should involve all the stakeholders, in special the final users. However, there has been a tendency to develop systems that respond to problems of environmental waste management as perceived by policy makers and professionals, rather than to households' and communities' perceptions of their actual needs. This frequently results in the refusal of the supposed users of services to accept operational or financial responsibility, thereby jeopardizing the sustainability of the service. To promote user ownership of services, decisions should be taken at a level as close as possible to the source of the problem, in consultation with the people most directly affected (Kalbermatten *et al.,* 1999).

To identify the local conditions and behaviours in order to adapt the wastewater conceptions is a primal step into the sustainability of a sanitation system. Conventionally, the inhabitants of poor areas have used pit latrines located out of the household units as an alternative for disposing their excreta. This ancient practice presents several shortcomings, in particular in densely populated areas where space is limited, being also inappropriate for areas with impenetrable ground, high water tables and flooding problems (Esrey *et al*, 2001). In spite of multiple problems of pit latrines, related to contamination of groundwater and breeding of disease vectors, the pit latrines represent the most accessible solution, and in many case the chosen solution, even when flushing toilets are available, due to the irregular supply of water in poor quarters and the resulting nuisance caused by malfunctioning WC units.

Any attempt of sustainable sanitation for the developing world requires an increasing focus on source control, and hence pollution production, rather than treatment. Some possible steps towards amelioration of water and wastewater problems are (1) to reduce the volume of potable water required, (2) to reduce the volume and content of wastewater from the house and (3) to recycle the nutrients that are traditionally lost in conventional treatment processes (Craig, 2000).

With the purpose of designing a sustainable sanitation system, the recommendations made by Winblad and Simpson-Hébert (2004) should be bared on mind. In their book Ecological Sanitation, the authors stated the criteria that a system of sanitation should follow in order to contribute towards the goals of equity and a sustainable society:

- ✓ *Disease prevention:* it must be capable of destroying or isolating faecal pathogens.
- ✓ *Environment protection*: it must prevent pollution and conserve valuable water resources.
- ✓ *Affordability:* it must be accessible to the world's poorest people.
- ✓ *Acceptability:* it must be aesthetically inoffensive and consistent with social values.
- ✓ *Simplicity*: it must be robust enough to be easily maintained with the limitations of the local technical capacity, institutional framework and economic resources.

In order to ensure an adequate wastewater management in the new housing project to be developed in the Arat Kilo and Piazza localities, the remarks expressed above should be taken in to account, considering that the prevailing conditions in Addis Ababa do not differ from the rest of the developing world. Any vision of sanitation for the Low-Cost Housing Project needs to identify efficient, sustainable and cost-effective ways of providing service that have the capacity to balance improvements in the quality of people's lives with support for the well-being of the environment.

2.3- Ecological sanitation: an answer to the required sanitation

Ecological sanitation is a system that makes use of human excreta and turns it into a valuable resource which can be introduced into agriculture in such a way that both the health risks and risks of polluting the environment are reduced to a minimum. (Morgan, 1998)

Ecological Sanitation is a holistic approach to sanitation and water management based on the systematic closure of local material flow-cycles (Werner *et al*, 2003). Ecological sanitation differs from conventional approaches in the way of considering human excreta as value matters. Urine and faeces are considered potential resources with distinct qualities, which could be used to restore soil fertility and increase food production (Esrey *et al,* 2001).

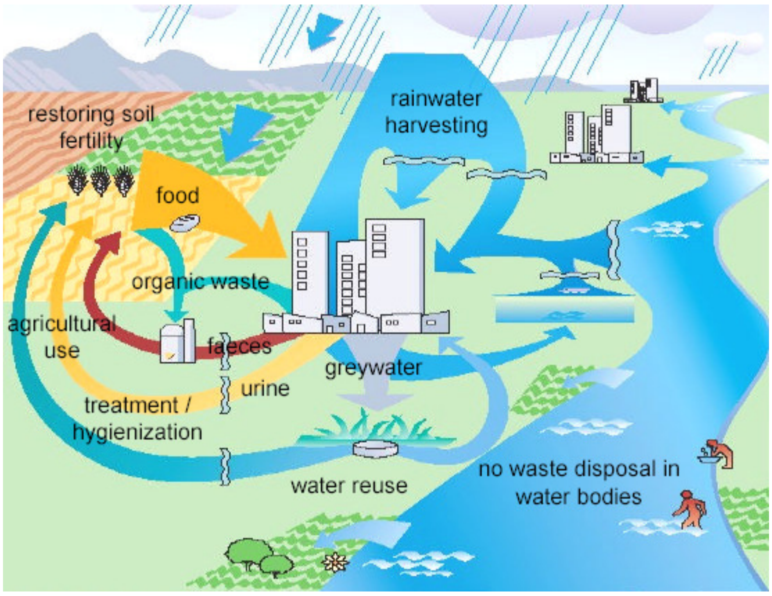


Fig 2.3- Closing the Loop of Nutrients (Werner, 2004).

<u>Advantages of Ecological Sanitation</u>

- Conservation of water resources due to lower water consumption and minimal water pollution.
- Improvement of health by properly sanitizing human excreta and prevention of disease spreading.
- Provides more appropriate, cost-effective, hence more affordable treatment solutions due to modular, decentralized, partial-flow systems.
- Substitution of chemical fertilizers with higher heavy metal content possible.
- Preservation of soil fertility, improves agricultural productivity and contributes towards food security.
- Can help to reduce poverty by saving income and generating income by selling ecosan products like fertilizer, biogas.
- Can support small business and enterprises to develop, e.g. construction workshops for special toilets, maintenance services, market for fertilizer products and biogas.
- Safe, hygienic recycling of nutrients, trace elements, water and energy.
- Compared to a pit latrine, ecosan toilets can also be constructed inside the house and provide a safer, more convenient, private and hygienic option.

Fig 2.4.- Advantages of the Ecological Sanitation Approach, (Früh, 2003)

Ideally, ecological sanitation systems permit the complete recovery of all nutrients from faeces, urine and greywater, benefiting agriculture and minimizing water pollution and health risks, as well as allowing economical use of water and its maximal reuse, particularly for the purpose of irrigation as well as the use of bio energy (Früh, 2003).

There are many advantages provided by the application of ecological sanitation, many of then are shown in the Fig. 2.4. It also offers hygienic and convenient services at a much lower cost than conventional sanitation. On the other hand, it does not use water, or very little water, and is therefore a viable alternative in water scarce areas. Furthermore, ecological sanitation is a system that encourages local initiatives and local leadership, from workshops that sell the toilets, to home gardens and fertilizer seller for agricultural land (Esrey, *et al,* 2001).

Ecological sanitation offers an alternative to conventional sanitation, intending to solve some of the humanity problems: infectious disease, environmental degradation and pollution, and the need to provide fertilizers to improve the agriculture in many regions with lack of it.

2.3.1- Ecological Sanitation in Ethiopia

According to Gunder Edström (2000), in 1996 the Society for Urban Development in East Africa (SUDEA) carried out an four year- ecological sanitation pilot project in Addis Ababa, specifically in the Urban Areas of Tekle Haimanoth, Merkato, 22 Mazoria and in the peri/urban areas Asko and Entoto. The objective of the project was to introduce this integrated system for sanitation and urban agriculture, with the intention to test the acceptability and sustainability of the system in different areas of the country.

According to the author, Ecosan was understood as the collection and composting of faeces in order to return them to the agricultural land, meanwhile the urine, collected separately, was injected or deposited in soil depending on the availability of water (Edström, 2000). More than 150 eco-sanitation toilets were built, beneficiating urban and periurban neighbourhoods which today grow vegetables in their home gardens.

Small pilot projects like the one above are found through the rural areas of Ethiopia and developing countries, and they serve as starting point to define the strategy to be applied in more ambitious projects, such as the GTZ low cost housing project in Addis Ababa. The constrains, difficulties encountered and particular the people attitude toward the ecological sanitation toilets, are some of the results that should be taken into account as background information.

2.4- Sanitation system: toilet technologies

The process of ecological sanitation starts in the toilet unit. The selection of the toilet technology depends on the type of primary process to be applied, due to the close connection existing between those two.

Otterpolh *et al.* (not specified) expressed that the toilet system is the most important tool for source control; its appropriated selection is the key feature to guarantee the sustainability of a sanitary concept ensuring the hygienic conditions and therefore high standards of living.

Today, there is a diversity of toilet systems, as a result of an intensive scientific research in this field that has took place in recent years. Separation toilets for low dilute water black water, vacuum toilets, dry toilets and separation toilet for urine treatment are some of the systems (Otterpolh *et al.,* not specified), ranging from high to low tech, being applied currently according to environmental, technical and financial circumstances.

Since the present project will be developed in a developing country, the most feasible sanitation options are dry toilets and low flushing toilets, both with urine separation. The expensive investment that represents the application of vacuum systems makes this a not viable option for the low cost housing of the central city areas of Addis Ababa. On the other hand, the recovery of urine and faeces is a key factor for the economical sustainability of the sanitation system, as it will allow the commercialisation of urine as fertilizer and treated faeces as soil conditioner. Therefore the separation of urine, and not the collection of both stream together, will be considered as the proposed option for this ecological sanitation project.

In the following section, descriptions of dry toilets and low flush toilet will be presented, together with practical experiences found around the world, focusing in developing countries.

2.4.1- Dry toilets with urine separation.

Dry sanitation is the disposal of human urine and faeces without the use of water as a carrier. Dry sanitation includes some of the most popular forms of low cost onsite sanitation, such as pit latrines, Ventilated Improved Pit (VIP) latrines, among others (Peasey, 2000). However, the application of dry toilets as starting points of ecological sanitation is intended to permit agricultural reuse or energy recovery of the products of human excrete. Therefore dry toilets could be defined as:

Dry toilets are sanitation facilities that allow the separately collection, further nutrients and energy recovery and agricultural reuse of human urine and faeces without the employment of water as carrier.

The technology of dry toilets has been applied for centuries in countries like Syria and China, where the value of dehydrated human excreta as fertilizer was already recognised by the farmers (Paesey, 2000). The classic example of an ecological sanitation system is the Vietnamese double-vault toilet (Fig 2.5 A), consisting of two processing chambers each with a volume of about 0,3 cubic metres placed on a solid floor of concrete, bricks or clay (Winblad and Simpson-Hébert, 2004). Over the past 25 years it has been introduced in several countries around the world like in China, where a modified version of the Vietnamese dehydration toilet was placed indoors in third and second floors (Winblad and Simpson-Hébert, 2004). In Mexico, a new design consisting on two toilet risers replacing the squatting slab was constructed in Cuernavaca with high degree of acceptability (Fig 2.5 C). A two-chambered solar-heated dehydration toilet has been built in Ecuador, consisting on the basic design of the Vietnamese double vault but provided with diagonally sloping lid made of wooden frame covered with this galvanised iron painted black (Fig 2.5 D) (Paesey, 2000). The most acknowledged example of soil composting is founded in Ladakh, India (Fig 2.5 E) where the extreme dry weather conditions allow collecting urine and faeces together. The two stocks make possible the existence of a lower room where the excreta is collected, meanwhile in the upper floor a vast amount of soil is kept. People excrete on the soil and push the soil and the excreta together down the drop hole, where due to the competition of microorganisms present in excreta and in soil, the sanitation of the organic material occurs (Winblad *et al*., 1998). Composting toilets for use in weekend houses were introduced in Sweden more than 50 years ago. The Clivusí Multrum shown in Fig. 2.5 F is the classic model. It is a single vault-composting toilet with combined processing of urine, faeces and organic household residues, consisting of a composting vault with a slanting floor, air conduits and at the lower end a storage space (Winblad *et al*. 1998).

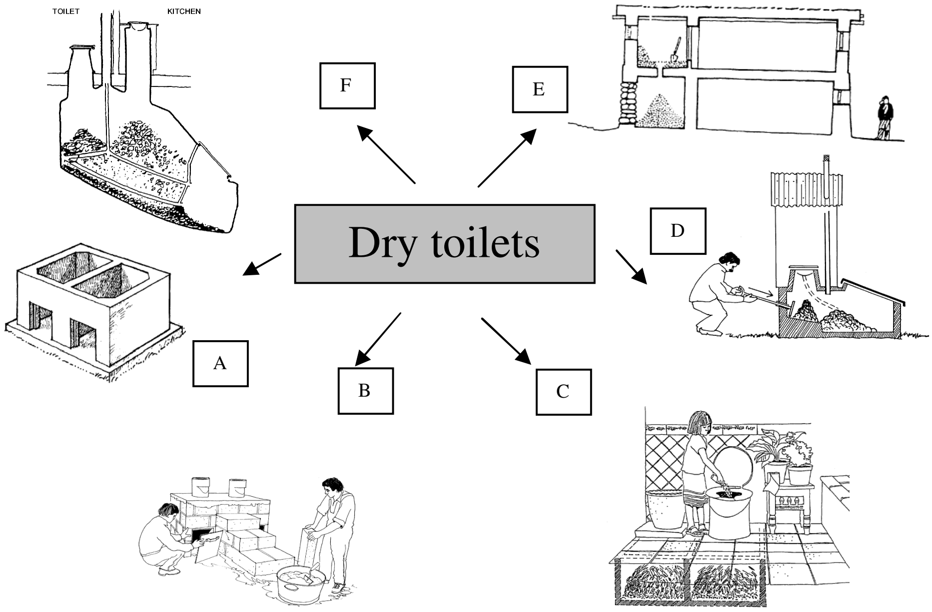


Fig 2.5- Different dry toilets technologies. (A) Vietnamese double-vault toilet (B) Typical dry toilet with urine separation (C) the Mexican version of the Vietnamese double-vault toilet with addition of additives (D) Solar heating processing chamber in Ecuador (E) Indoor, traditional dehydrating toilet in Ladakh, India (F) The Clivusí Multrum composting toilet from Sweden placed in the basement of a house. (Winblad *et al*., 1998)

2.4.2 - <u>Pour Flush toilets with urine separation.</u>

The pour flush toilets are very similar to the conventional water closets, with the difference that a smaller amount of flushing water is used, being for faeces and urine around 0,6 and 0,2 l respectively, allowing low dilution and therefore making possible the application of further low-land-requirement-treatments (data from Otterpohl *et al.*, year not indicated). This type of technology requires the separate installation of pipes for the separate transport of urine and faeces, therefore compared to the dry technology, it requires a higher capital investment. The separate transport of black water requires a high gradient in the sewer, and could encounter blockage of pipes. Urine could be transported with or without the use of water, however the last poses problems related to crystallisation and blockage of the pipe (Otterpohl *et al.*, year not indicated). However, when the biogas approach is going to be applied as treatment, the separate collection of urine in a low flush toilet has the additional advantage of reducing the reactor size of the methane plant, and that avoids too high ammoniac concentrations, which could inhibit the digestion and therefore the production of this energy-rich gas (Otterpohl *et al.*, year not indicated).

Low flush toilets have been implemented in some areas of Sweden with recognised success, such is the case of the project developed in Ekoporten – Norrkoping. In China, several examples of integrated systems of low flush toilets with biogas production can be found, however most of them collect and treat urine and faeces together (Xiagung and Hai, 2003).

According to Oldenburg *et al.* (2003) the main advantage associated to low flush toilets is the use of a most luxurious facility, which is likely to contribute to an increased willingness among the population to adapt such a solution.

2.5- Introduction to human excreta processing in ecological sanitation systems

It is essential to understand that, in order to make human excreta appropriate for the recovery of energy and/or nutrients, the treatment of faeces and urine in ecological sanitation systems is performed in most cases in two steps, referred as primary and secondary steps. These processes can be carried out on-site, at the household or neighbourhood level, or off-site, meaning that streams from several housing units and buildings are collected an treated in eco-stations. Combinations of these two options are also possible, and it depends on the availability of space at the point of source and the amount of excreta to be processed.

It is also common to find the application of ecological sanitation for the management of black water, meaning that urine and faeces will be collected and treated together. Examples are presented for instances in Otterpohl *et al.* (Differentiating management resources of water and waste in urban areas, year not indicated). However, this approach is not within the scope of this work.

For the development of this report, the on-site ecological sanitation management will be understood as the separate treatment of human faeces and urine, each process occurring in two steps, even if the distinction between the stages could be often diffuse (Jönsson *et al*., 2004).

2.5.1- <u>**Primary treatment:**</u>

The primary treatment of faeces is that which occurs during collection, being for dry systems normally located beneath the toilet (Jönsson *et al*., 2004) and in collection tanks from several toilets units in when flushing water is available. The purpose of the primary processing of faecal matter is to reduce the volume and weight to facilitate storage, transport and further treatment (Winblad *et al.* 2004). Furthermore, it is the first stage to destroy pathogenic organisms and to prevent nuisance (Esrey *et al.* 1998).

In the case of urine diverting toilets, the primary treatment of the urine also takes place during the collection stage, in small vessels or tanks with high capacity. The pathogenic risk associated with cross-contamination with faeces is reduced during this stage, due to the increase of pH from 5-7 (fresh urine) to 8-9 (in holding tank) (Johannson *et al.* 1997).

The classification of ecological sanitation toilets has been historically made according to the primary treatment to be performed (see Esrey *et al.* 1998; Jönsson *et al*., 2004; Peasey, 2000; Winblad *et al.* 2004, among others). It is then common to find in literature, especially among Swedish researchers, the terms "composting toilets" and "dehydration toilets" indicating the collection of faeces for certain period (6-12 months), decomposition (composting with addition of kitchen refuse with or without the addition of other organisms that compete for nutrients) or dehydration (ventilation and addition of dry material) and the increase of pH (addition of lime, ash or urea) (Winblad *et al.* 2004). However, other systems are also considered as ecological sanitation, even if the treatment is not performed near to where faeces and urine are excreted, such is the case of the use of biogas plants, where faeces and biological waste are anaerobically processed in order to obtain methane and sludge to be used in agriculture. This example is well demonstrated by Otterpohl, *et al.* (2002) where a vacuum/biogas concept is used to thermally sanitise and anaerobically ferment human excreta with shredded bio-waste. In some situations (short retention times, low temperatures) the degree of deactivation of pathogens is not achieved during the stage of anaerobic digestion, therefore the liquid fertilizer needs to be further treated before applying in the agricultural land. In this case, the anaerobic fermentation could be considered as the primary step of processing. Other methodologies have also been reported where the fermentation biogas technology is considered as the secondary treatment, as the faeces are collected in containers or digestible bags in an intermediate storage, where a preliminary treatment through pH increase and drying takes place (Köttner *at al.,* 2003).

In developing countries the primary treatment of faecal sludge has been traditionally performed by sedimentation (Aalbers, 1999). It has been easily done in household scale, in the form of septic tanks or just as an interceptor tank, allowing gravity dewatering, separation of suspended solid and reduction of BOD (biological oxygen demand). Commonly, these primary sedimentation tanks are designed to provide low hydraulic retention times (ranging from hours to a couple of days), time after which the effluent is transported to an stabilization pond system, designed to achieve different forms of treatment in up to three stages in series, depending on the organic strength of the input waste and the effluent quality objectives (Metcalf and Eddy, 1991). The use of wetlands and drying beds has also been reported for the further treatment of faecal sludge (Aalbers, 1999). However, all these technologies require large areas and are not suitable for urban quarters where the space is limited, such is the case of Arat Kilo and Piazza. Therefore they will not be considered as a feasible sanitation option, and will not be further discussed.

The approaches of ecological sanitation, and in particular the treatments applied as primary step, are multiple, however all of them make use of environmental factors known to kill microorganisms. These are increases in storage time, temperature, dryness, pH, ultraviolet radiation and competing natural organism (Winblad and Simpson-Hébert, 2004). In order to summarise the technologies available, the following table presents the most common primary treatments performed worldwide to treat separated products from ecological sanitation toilets, with and without water. In many cases, combinations of these treatments are found in practical experiences (refer to Winblad and Simpson-Hébert, 2004 for urban and rural examples and Otterpohl *et. al* (year not indicated) where 10 different semi central and decentral sanitation concepts are presented and discussed).

Table 2.1.- Most common primary treatments performed worldwide to treat separate products from ecological sanitation toilets, with and without water (from [1] Jönsson *et al.* (2004), [2] Winblad and Simpson-Hébert (2004), [3] Peasey (not specified), [4] Otterpohl *et al.* (not specified), [5] Gajurel *et al.*(not specified), [6] Björnsson (2000), [7] Schönning and Stenström (2004) and [8] Buest *et al.* (2004))

Water use	Excreta	Primary process	Concept / Comments
None (Dry toilets)	Faeces	Desiccation with drying additives	Collection in a ventilated chamber, with some dry additives such as ash, grass, leaves or dried soil, allowing the increase of the dry matter content and therefore decreasing the risk of odours and flies, as well as the pathogenic risk.[1]
		Desiccation with acid additives	The pathogenic reduction is reinforced when the additives have a high pH, such is the case of lime, urea and plant ash. The high pH together with the rapid decrease of the moisture level means a low biological activity, making the losses of organic matter and N very low. The nutrient composition of the additives also contribute to the to the total amount of nutrients.[1]
		Solar Desiccation	In humid climates und where the irradiation of sun is extended during the day, solar heaters could be used to increase the evaporation rate from the drying material. These have been constructed as black-painted aluminium sheet covering a part of the processing chamber exposed to the sun. It also increases slightly the temperature of the pile, making the pathogenic destruction faster.[2]
		Composting	The faeces are collected in a chamber together with kitchen and garden refuse and bulking agents. A biological aerobic decomposition of faeces by bacteria, worms and other microorganisms takes place with a careful control of temperature, moisture and ventilation to maintain the aerobic conditions. [3]
		Soil composting	Faeces are deposited in a processing chamber together with a liberal amount of soil. Ordinary soil is added after each defecation, often with wood ash. Most pathogenic bacteria are destroyed within 3-4 months as a result of competition with soil-based organisms and unfavourable environmental conditions. [2]
With low amount of flushing water and/or water for anal cleaning	Faeces	Solid separation	When a biogas plant is intended for secondary treatment, the faeces and flush water could be pass through a mechanical separator to reduce the volume of the inflow to the capacity of the digestor. [4] In case dry composting or dehydration is planned, the separation of phases allows further treatment depending on the characteristics of each stream.
			<u>Pre-composting tanks</u>: Called Rottebehälter in Germany, Austria and Switzerland, the pre-composting tanks consist of an underground concrete tank having two filter beds at its bottom or two filter bags that are hung side by side and used alternately in an interval of 6-12 months. The solid material partly dewatered and pre-composted can be further co-composted together with other biological waste. The filtrate could be sent to a centralized wastewater plant or be treated in wetlands. [5]
			<u>Compost filter</u>: The compost filter allows to retain the solids present in the brown water, and treat them biologically under aerobic conditions. The water level must be maintain below the filter material and the feeding must be switched between two or more compartments keeping low moisture during the composting process. The liquid phase could be further treated in any low or high technology process and the solid effluent could be further composed or directly used as fertilizer. [4]
		Aerobic treatment	An aerobic treatment with only nitrification of the liquid phase allows the production of a flow rich of nutrients. The sludge can be used as an input to the biogas plant, meanwhile liquid product can be mixed with the effluent of the digestor or direct applied in the agricultural fields. [4]
		Vermi-composting	Vermicomposting is the process by which organic materials are converted into humus with the use of specific types of earthworms, *Eisenia fetida* and *Eisenia andrei*, that breakdown the organic materials. They derive their nourishment form microorganisms that grow upon the organic materials and at the same time promote further microbial activity in the residuals.[8]
		Digestion	Consist of the anaerobic degradation of organic material with the resulting production of energy-rich methane and CO_2. It involves a well-organised and sensitive community of several microbial populations, whose environmental factors, such as pH, temperature, nutrients and toxic components, should be carefully controlled to enhance the degradation process and growth rate. [6]
Separation toilets; no waterborne transportation	Urine	Storage at ambient conditions	Pathogens present in urine are inactivated over the time under storage conditions. It is then considered a viable treatment option for urine to separately store it, providing that cross contamination with faeces is avoided. The recommended time for storage at temperature 4-20 °C varies between 1 to 6 months. Significant losses of nitrogen are obtained when the containers are exposed to open air. [7]
		Separate pressurised storage	Urine is easily treated during collection by separate storage in a pressure-equalized container to avoid the risk of losing N in the form of ammonia due to the high pH (8-9). [1]
		Increase of pH	The use of alkaline additives, such as urea or acids, to elevate the pH enhances the inactivation of pathogenic microorganisms. [1]
		Increase of temperature	Temperatures above 20 °C would further speed up the inactivation of potential pathogens, however it has not been tested nor quantified. [1]

2.5.2- Secondary treatment:

The secondary treatment takes place when the collection period of faeces and urine is over; taking place on-site (in the toilet, as in the double vault units, or in the garden) or off-site in an eco-station. The objective of the secondary treatment is to make human excreta hygienically safe enough to return to the soil, meanwhile making use, in certain cases, of the energy value contained and ensuring an easy transportation and handling of the products.

SECONDARY TREATMENT OF FAECES

The main objective of the secondary treatment of faeces is to render the faeces hygienically safe and to transform them into a state where it is odourless and visually non-repulsive, meaning that it should no longer be possible to recognize pieces of faeces or toilet paper (Jönsson *et al.,* 2004). In a broad sense, secondary treatment could be divided in thermophilic processes, such as incineration, composting and digestion, and chemical sanitation like addition of urea to elevate the pH. Further storage, as an easy and cheap method, is also considered a secondary treatment and has been used in many cases where the ambient temperature reaches 35°C or more, ensuring a fast die-off of pathogens in a total storage period of 1 year (Winblad and Simpson-Hébert, 2004). The anaerobic treatment or digestion, makes possible the utilisation of rich energy products in the form of biogas for the obtaining of energy. The following table presents a description, together with advantages and disadvantages of each sanitation process.

Table 2.2.- Secondary treatments performed worldwide to treat faeces (from [1] Jönsson *et al.* (2004), [2] Schönning and Stenström, [3] Stegmann, (2003).

Secondary Treatment	Concept	Technological Requirements	Advantages	Disadvantages
Incineration	Is a very aerobic process with essentially complete degradation of the organic matter. If the faeces are completely incinerated, all the N and S will be lost in the fume gas, while all the P and K will remain in the ash.[1]	Incineration has only been applied as a sewage sludge from wastewater plants in developed countries, where incineration plants with high technology have been implemented, consisting mainly on incineration chambers, stationary fluidised beds or rotary kilns always equipped with flue gas treatment to avoid gas emissions of SO_2 and NO_X. This type of technology requires high monitoring as the ratio air/fuel, among other process conditions, must be controlled[3]	Incineration will minimize de risk for transmission of disease related to the final use of the ash since essentially all pathogens will be removed. [2] The ash from successfully incineration is a concentrated and hygienic fertilizer high in P and K.[2] With faeces presenting high calorific values (for untreated sewage sludge of 25600 kJ/kg, the production of energy could be integrated[3].	Lost of nutrients: N and S of the final product. High capital investment. High operational costs. High monitoring and skilled professionals needed. Incineration systems have not been properly developed for effluents of ecological sanitation systems.
Thermophilic composting	It as very aerobic process which relies on the heat from the degrading organic matter to reach the temperature desired, >50°C, for a number of days to ensure safe reduction of pathogens.[2]	The degradation requires much oxygen and the total weight of the required air for the composting process is usually several times that of the substrate. A substrate based entirely on faeces is normally not enough to achieve thermophilic temperatures, especially if the faeces are mixed with ash or lime. Addition of supplementary, easily degradable substrates is needed, usually in amounts several times larger than the amount of faeces. These additions influence the nutrient	High degree of sanitation due to high temperatures achieved. The availability of K, S and P in composted material is high, if not leachate takes place. Nitrogen losses could be minimized through C/N ratios.	Difficulties encountered in reaching desired temperature. The combination of ammonia, high temperature, high pH and high aeration means that N is lost in the form of ammonia. Need for addition of excessive easily degradable substrate. Extensive inputs to operation and maintenance to achieve the desired

		concentrations in the compost. In addition to this, excellent operation and maintenance is needed to sustainably achieve thermophilic operation.[1]		temperature and rate of degradation. Problems with product of dry toilets since the high pH and low moisture inactivate the microbial activity.
Mesophilic composting	Mesophilic composting and aerobic degradation at ambient temperatures, are best characterised as low temperature variants of thermophilic composting, being are just as aerobic.[1]	The moisture content, aeration and the C:N ratio need to be appropriate for the process to proceed along with sufficient insulation and/or bulk to allow an increase in temperature.[2] The two main differences between the two types of composting are that the sanitation achieved through the elevated temperature in the thermophilic compost does not take place in low temperature composting, and that the need for additional easily degradable substrate,as well as for extensive inputs to operation and maintenance, is decreased.[1]	Less labour intense needed. The products of these processes are, when mature, as degraded as those of thermophilic composting and the end products of aerobic degradation at these temperatures, carbon dioxide and water, are also the same. Less addition of easily degradable substrate.	Longer composting time needed, since it inactivates pathogens to variable extents within weeks or months. Loss of N in the form of ammonia. Not sufficient sanitation and pathogens destruction. It is not recommended to rely on this temperature range in treatment of faeces, unless the mesophilic processes is combined with other process functions. Problems with product of dry toilets since the high pH and low moisture inactivate the microbial activity.
Storage	Storage in a dry state at ambient or increased temperature is another possible secondary treatment. The pathogen reduction increases with increasing ambient temperature. If the moisture level is kept low (<20%) during the whole storage, then the degradation is low and so are the losses of N and organics. [1]	The ambient temperature, pH and moisture etc. will affect the inactivation as well as biological competition. Since the conditions during storage vary, so do the die-off rates, it is hard to predict appropriate storage[2]. Addition of drying agent could encourage the pathogens destruction. Products of desiccation toilets are more suitable for the application of this technique. High requirements of labour is not needed, however the moisture content and well as pH should be monitored.	Suitable for desiccation toilets with addition of high pH or drying additives. Low labour required. Low losses of N and other nutrients.	Inactivation of pathogens is generally slow and could be ineffective. The storage time could range from months for bacterial reduction and to years for helminths. It is not recommended to rely on simple storage as a secondary treatment of faeces, unless it is combined with other process functions.
Digestion	Anaerobic digestion at thermophilic, mesophilic or ambient temperatures is another option for secondary treatment of faeces. Consist of the anaerobic degradation of organic material with the resulting production of energy-rich methane and CO_2.	Installation of a biogas plant with significant costs associated. It involves a well-organised and sensitive community of several microbial populations, whose environmental factors, such as pH, temperature, nutrients and toxic components, should be carefully controlled to enhance the degradation process and growth rate. Therefore the extensive inputs to operation and maintenance needed.	Low losses of N, having the sludge low proportion of ready available ammonia for the plant growth. Recovery of energy through production of methane for cooking or heating.	Medium investment costs. Medium maintenance costs. The sludge is not completely sanitized; therefore a tertiary treatment should be applied. Extensive inputs to operation and maintenance.
Chemical Sanitation	Sanitation of faeces by addition of urea has been applied successfully in municipal level, inactivating pathogens by a combined elevated pH and high ammonia concentration.	This process functions better if the faeces are in the form of sludge, in order to allow the urea to transform to ammonium by urease. The addition of lime or ash that increase the pH enhances the formation of ammonium. The addition of urea should be performed in a closed container	As this process do not involve degradation, neither organic mater nor N is lost. The ammonium content of the sludge is higher than that of urine and digested residue.	Need of additional chemicals (urea). It needs to be handle with care to avoid ammonia losses. Some input to operation and maintenance.

SECONDARY TREATMENTS OF URINE

There are several goals that can be achieved by the processing of urine (Maurer *et al.*, 2002):

- ✓ Stabilisation: urine is a highly concentrated solution that changes its composition after being excreted. For instances, due to the catalysed decomposition of urea into ammonia, the pH rises loosing the ammonia as a gas. By nitrifying a part of ammonia to nitrate or by addition of acids, it is possible to decrease the pH and prevent the hydrolysis of urea.
- ✓ Decrease the volume: in order to simplify the storage and transport.
- ✓ Production of a solid fertilizer: precipitating and stripping the ammonia is a way of recovering it with market opportunities.

Since the hygiene quality of the collected urine is normally very high compared to that of faeces, the secondary treatment of urine is only needed in large systems (i.e. systems where urine collected from one family is used to fertilize crops consumed by persons outside that family) where the fertilization is done less than one month prior to harvest. In this case, the further storage is the most used method, due to its simplicity and low costs (Jönsson *et al.,* 2004). This direct agricultural use has been successful demonstrated in many practical experiences in rural areas located in Sweden (examples in Johansson, *et al.* 1997, among many other) and pilots projects in developing countries. Another direct reuse could be to compost and digest the faecal matter together with urine to rise the nitrogen composition and keep the moisture of the system, however a significant loss of nitrogen will be perceived. Furthermore, Adamsson *et al.* (2003) demonstrated the use of urine in Aquaculture in a pilot project in Göteborg, Sweden.

For urban areas the separate storage and transport of collected urine has been proved to pose logistic and economical problems (Edström, 2000). Further concentration methods are needed to reduce the volume of urine to be transported, meanwhile ensuring small nutrient losses. There are some techniques for concentrate urine that have shown their potential to nitrogen recovery, such is the case of dewatering by evaporation with and without nitrification and freeze concentration (Behrendt *et al.*, year not specified). The use of reverse osmosis membranes could also be used for concentrating nutrients (Maurer *et. al*, 2003). Other approach would be the separation of the nutrients from the urine through chemical reaction. Such is the case of formation of struvite through the reaction of ammonia and phosphate with magnesium in alkaline conditions (Ronteltal *et al.* 2003). Lind *et al.* (2000), showed that by addition of small amounts of magnesium oxide (MgO) to human urine most of the phosphorus (95-99%) and part of the nitrogen (20-50%) can be recovered as precipitate, being crystalline struvite $[Mg(K, NH_4)(PO_4)\bullet 6H_2O]$ the major component of the precipitate (from Adamsson *et al.*, 2003). Behrendt *et al.* (year not specified) have also proposed the reaction of urea with Isobutylaldehyde, which forms the slow release fertilizer Isobuthylaldehyde-di-urea (IBDU) and studied the production of ammonium-water with concentration of at least 10% through stripping of ammonium. Stripping of ammonia usually requires high pH, which is usually achieve by the addition of 7,2 kg of NaOH or 7 kg of $Ca(OH)_2$ per kilogram of nitrogen (Maurer *et al.,* 2002). Zeolites and other minerals like clay or tuff have ion exchange properties and are used to absorb ammonium. A common approach is to pass wastewater through packed columns of zeolites, lowering the ammonium concentrations of 25-50 g NH_4-N/m^3 to 1 g NH_4-N/m^3 (Maurer *et al.,* 2002). Other cation exchange resins, cellulose acetate fibrets and polymer hydrogels have been also used for the adsorption of ammonium. All these technologies are however still in laboratory studies and pilots scale plants.

Today, a particular technique is receiving a lot of attention by the scientists. The dewatering by evaporation was studied by Niederste-Hollenberg *et al.,* (2003), finding that a reduction of volume (TCF) by the fold of 8 to 14 was achieved by the use of a rotary evaporator ($TCF=V_0/V_t$). Furthermore, they established a ratio of final concentration to initial concentration of ammonia of 90% of the TCF, indicating acceptable ranges of ammonia losses.

Fig 2.6- Residuals of urine after evaporation (Niederste-Hollenberg *et al*., 2003).

Mayer (2002) carried out a detailed feasibility study, in order to estimate the cost and energy requirements for urine evaporation, based on experimental results. In his study, urine was collected and the hydrolysis process was inhibited the by addition of sulphuric or acetic acid. Afterwards urine was evaporated at 200 mbar and 78 °C, increasing the nitrogen concentration from 9606 to 96522 g/Nm^3 and the total solids from 43 to 445 kgTS/m^3. Based on these data a technical vapour compression evaporation plant for was laid out for a volume reduction of urine by a factor 10. The calculated energy requirements were: 7 MJ/kg$_N$ electricity and 11 MJ/kg$_N$ fuel for steam production, corresponding with the values for seawater desalination given by other authors, reported as 150 - 180 MJ/m^3 distilled water (equivalent to 17 - 20 MJ/kg$_N$). The following conclusions were made by the author:

✓ During collection, the decomposition of urea was successfully prevented by addition of acid. Sterilisation of urine at 121 °C changed the chemical properties significantly. There were strong indications that at high concentration urea condensed to biureth.

✓ Evaporation of 90 Vol% was easily possible under vacuum. From a technical point of view, the urine showed no relevant changes of physical properties (e.g. increase of boiling point or viscosity).

✓ Energy consumption for evaporation with vapour compression (34 MJ/kg$_N$) is significant less than the energy requirements for production of nitrogen fertiliser. Therefore, Custom made evaporation plants did not seem to be more expensive than the estimated costs for implementing denitrification in WWTP. This is only valid for large-scale plants that serve for at least 30 000 inhabitants.

Maurer *et al.* (2003) also provided the data regarding energy requirement of a 10 fold thermal volume reduction of stabilised urine with one step distillation equal to 389 MJ/kg$_N$.

Finally, the decrease of volume by means of solar heating has been also reported in practical experiences, such is the case of the sanitation system implanted in Koulikoro – Mali (Bark *et al*., 2003). According to the authors, within two days each litre of liquid can be transformed into around 9 grams of powder. However this method should be improved upon in order to be economically viable.

3- Health risk associated to human excreta

In most developing countries the principal risks to human health associated with the consumption of polluted water are microbiological in nature, in particular due to excreta-related diseases, spread through faecal sludge which contain high concentration of pathogens –bacteria, viruses, protozoa and helminths (worms) causing gastro-intestinal (GI) infections in man (Strauss *et al.*, 2003). As indicated in Chapter 18 of "Agenda 21" of UNCED, "An estimated 80% of all diseases and over one-third of death in developing countries are caused by the consumption of contaminated water and on average as much as one-tenth of each person's productive time is sacrificed to water-related diseases." (Wichmann and Bartsch, 2000).

As one of the main goals of Ecological Sanitation is to capture nutrients present in the human excreta and recycle them back to agriculture, the heath risk related to excreted pathogens must be minimized in order to avoid the enhancement of disease transmission and an increase number of infections in human population that potentially can occur through urine and/or faeces.

The presence of disease-causing organisms in human excreta is the result of infection individuals, which is defined as the entry of the pathogen via e.g. the GI tract, the respiratory tract or the skin and its multiplication and establishment inside the host (Jawetz et al. 1987 from Höglund, 2001). Such infections do not necessarily manifest with clinical symptoms, but will lead to an excretion of the pathogens in question. For organisms infecting the gastrointestinal track, this excretion is mainly through faeces.

3.1- Routes of transmission

Transmission of infections can either be direct through different means of person to person contact, including short-distance airborne, or indirect (secondary), which includes vehicle-borne (food, water, fomites etc.), vector-borne, airborne long-distance and parenteral (injections with contaminated syringes) transmission (Beaglehole et al. 1993 from Höglund, 2001). These routes can largely be defined as faecal-oral (or urine-oral), since most involve either ingestion or inhalation through the oral cavity. Esrey *et al.* (1998) proposed the "F-diagram" to describe the transmission routes for enteric pathogens, in which pathogens excreted in faeces are transmitted via hands, through food or water and other fluids, infecting another person by ingestion (Fig 3.1).

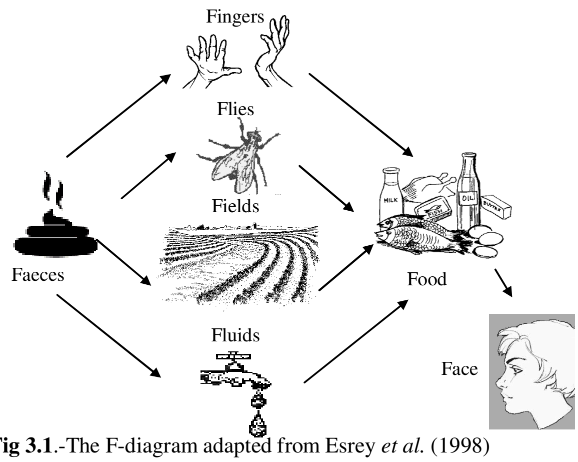


Fig 3.1.-The F-diagram adapted from Esrey *et al.* (1998)

The actual risk to public health that occur through excreta use is divide by Strauss (2000) in three broad categories: consumer risk, farmers or fishermen risk (agriculture and aquaculture workers) and nearby population risk. Schönning and Stenström (2004) on the other hand, include in their report Guidelines on the Safe Use of Urine and Faeces in Ecological Sanitation Systems the potential transmission routes related to dry toilets, including user of toilets, collection and transportation workers, treatment workers, fertilizer users and crops consumer.

In order to summarize the information regarding the potential health risks poses by the reuse of human excreta in food production, the following scheme is propose:

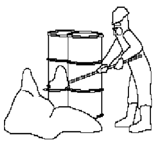
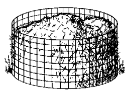
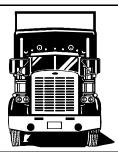
Route of Transmission		**Risk**	**Consideration**
	Direct contact at the toilet facility	Toilet users - Environmental risk	Related to personal hygiene and cleansing of the toilet. Proper use of ecological toilets is vital to achieve pathogen destruction. Individuals and home environment may be affected by direct contact. Fly breeding is related to wetness of the content. Improper constructed or localized toilets could also cause contamination of soil, surface- or groundwater.
	Collection and transport	Occupational risk when collecting and transporting the excreta	Through the primary handling individuals could be infected by direct contact, touching the material and subsequent accidental ingestion from contaminated fingers or utensils. Untrained staff and careless management attempt against public health of the community.
	Treatment	Occupational risk - Environmental contamination	Unsuitable choice of location, unsafe storage and open systems of treatment of human excreta could spread microorganisms in the environment. Occupational risk related to direct contact with excreta and further contamination.
	Transport and distribution of fertilizer	Occupational risk (Dealers and Farmers)	Secondary handling of compost or sludge. Possible direct contact with microorganisms. Unsafe handling of the material during charging and discharging the trucks. Lack of information among farmers regarding safe use of fertilizers.
	Fertilization of land	Occupational risk for farmers- also Animal/Cattle and Neighbouring Settlement.	Affecting the agricultural workers who are exposed to the waste and populations living near to a waste reuse scheme. Transmission of diseases to animals and transport of pathogens to the groundwater. Risk to contract gastro-intestinal infections if flood or furrow irrigations is practiced. Unsafe application of fertilizer in the top layer of the field. Hygienic risk of aerosols when spraying or sprinkling urine.
	Consumption of fertilized crops.	Health risks for consumers of crops	Contamination of foodstuffs may occur directly from use but also through unhygienic practices in the kitchen. Even if the fertilized crop will be cooked before consumption, surfaces may be contaminated and pathogens transferred to other foods or fluids.

Fig.3.2.- Potential risk related to ecological sanitation steps. (From Schönning and Stenström (2004), Strauss (2000), Höglund (2001), Esrey *et al.* (1998) and Winblad and Simpson-Hébert (2004))

3.2- Pathogenic Microorganisms in Faeces

Bacteria have been usually considered as the leading group of organisms causing gastrointestinal illness, in particular in developing countries, where outbreaks of cholera (*Vibrio cholera*), typhoid fever (*Salmonella typhi*) and shigellosis, causing diarrhoea, constitute major risks in relation to improper sanitation and contamination of water. Hepatitis E, *Salmonella*, *Campylobacter* and enterohaemorrhagic *E. coli* (EHEC) must also be taken into account due to their increasing frequency in urban and peri-urban areas (data from Höglund, 2001 and Schönning and Stenström, 2004)

Table 3.1- Pathogens that may be excreted in faeces with expected symptoms (Schönning and Stenström, 2004)

Group	Pathogen	Disease - Symptoms
Bacteria	*Aeromonas*	spp. Enteritis
	Campylobacter jejuni/coli	Campylobacteriosis - diarrhoea, cramping, abdominal pain, fever, nausea; arthritis; Guillain-Barré syndrome
	Escherichia coli (EIEC, EPEC, ETEC, EHEC)	Enteritis
	Pleisiomonas shigelloides	Enteritis
	Pseudomonas aeruginosa	Various; bacteraemia, skin infections, ear infections, meningitis, pneumonia
	Salmonella typhi/paratyphi	Typhoid/paratyphoid fever - headache, fever, malaise, anorexia, bradycardia, splenomegaly, cough
	Salmonella spp.	Salmonellosis - diarrhoea, fever, abdominal cramps
	Shigella spp.	Shigellosis - dysentery (bloody diarrhoea), vomiting, cramps, fever;Reiter's syndrome
	Vibrio cholerae	Cholera - watery diarrhoea, lethal if severe and untreated
	Yersinia spp.	Yersinioses - fever, abdominal pain, diarrhoea, joint pains, rash
Virus	Adenovirus	Various; respiratory illness.
	Enteric adenovirus 40 and 41	Enteritis
	Astrovirus	Enteritis
	Calicivirus (incl. Noroviruses)	Enteritis
	Coxsackievirus	Various; respiratory illness; enteritis; viral meningitis
	Echovirus	Aseptic meningitis; encephalitis; often asymptomatic
	Enterovirus types 68-71	Meningitis; encephalitis; paralysis
	Hepatitis A	Hepatitis - fever, malaise, anorexia, nausea, abdominal discomfort, jaundice
	Hepatitis E	Hepatitis
	Poliovirus	Poliomyelitis - often asymptomatic, fever, nausea, vomiting, headache, paralysis
	Rotavirus	Enteritis
Parasitic protozoa	*Cryptosporidium parvum*	Cryptosporidiosis - watery diarrhoea, abdominal cramps and pain
	Cyclospora cayetanensis	Often asymptomatic; diarrhoea; abdominal pain
	Entamoeba histolytica	Amoebiasis - Often asymptomatic, dysentery, abdominal discomfort, fever,chills
	Giardia intestinalis	Giardiasis - diarrhoea, abdominal cramps, malaise, weight loss
Helminths	*Ascaris lumbricoides*	Generally no or few symptoms; wheezing; coughing; fever; enteritis; pulmonary eosinophilia
	Taenia solium/saginata	Unapparent through vague digestive tract distress to emaciation with dry skin and diarrhoea
	Hookworm	Itch; rash; cough; anaemia; protein deficiency
	Shistosomiasis spp.	

More than 120 different types of viruses may be excreted in faeces, with the most common from the enteroviruses, rotavirus, enteric adenoviruses and human caliciviruses (noroviruses) groups (Tauxe & Cohen, 1995). Hepatitis A is recognized as a pathogenic virus of major concern when applying wastes to land and is considered a risk for water- and food-borne outbreaks, especially where the sanitary standards are low (Schönning and Stenström, 2004)

In developing countries, helminth infections are of greater concern. Especially the eggs (ova) of *Ascaris* and *Taenia* are very persistent in the environment, and therefore regarded as an indicator of hygienic quality (WHO, 1989). Hookworm disease is widespread in moist tropics and subtropics, and affects nearly one billion people worldwide. In developing nations, these infections exaggerate malnutrition and indirectly cause the death of many children by increasing their susceptibility to other infections that could normally be tolerated (Höglund, 2001)

Faeces contain by far more microorganism that urine, therefore they should be separated at the point of source and treated independently to reach hygienic standards to be applied on agricultural land.

The pathogens of concern for environmental transmission through faeces mainly cause gastrointestinal symptoms such as diarrhoea, vomiting and stomach cramps. Some of them may also cause symptoms involving other organs and severe sequels. Schönning and Stenström (2004) prepared a list of the pathogens of concern and their symptoms, which is presented in table 3.1.

3.3- Pathogenic Microorganisms in Urine

Urine is a clean though not sterile product. A number of bacteria have been found to cause infections in the urinal track, such is the case of E-coli who held responsibility of over 80% of the cases. However, they have not been reported to be transmitted to other individuals through the environment (Höglund, 2001).

The pathogens traditionally known to be excreted in urine are *Leptospira interrogans, Salmonella typhi, Salmonella paratyphi* and *Schistosoma haematobium* (Feachem *et al*., 1983 from Schönning and Stenström, 2004). *Leptospirosis* is a bacterial infection causing influenza-like symptoms and is in general transmitted by urine from infected animals and therefore it is considered an occupational hazard e.g. for sewage workers and for farm workers in developing countries. Infections by *S. typhi* and *S. paratyphi* only cause excretion in urine during the phase of typhoid and paratyphoid fevers when bacteria are disseminated in the blood. *Schistosomiasis*, or *Bilharziasis*, is one of the major human parasitic infections mainly occurring in Africa. When infected with urinary *Schistosomiasi*s caused by *Schistosoma haematobium*, the eggs are excreted in urine, sometimes during the whole life of the host. The eggs hatch in the environment and the larvae infect specific aquatic snail species, living in fresh water. After a series of developmental stages aquatic larvae emerge from the snail, ready to infect humans through penetration of the skin (Feachem et al. 1983 from Höglund, 2001).

In table 3.2 a list of the pathogens to be transmitted by the urine is presented, together with the importance of the transmission route.

Table 3.2- Pathogens that may be excreted in urine (Schönning and Stenström, 2004)

Pathogen	Urine as a transmission route	Importance
Leptospira interrogans	Usually through animal urine	Probably low
Salmonella typhi and Salmonella paratyphi	Probably unusual, excreted in urine insystemic infection	Low compared to other transmission routes
Schistosoma haematobium(eggs excreted)	Not directly but indirectly, larvae infecthumans via freshwater	Need to be considered in endemic areas where freshwater is available
Mycobacteria	Unusual, usually airborne	Low
Viruses: CMV, JCV, BKV,adeno, hepatitis and others	Not normally recognized other than single cases of hepatitis A and suggested for hepatitis B. More information needed	Probably low
Microsporidia	Suggested, but not recognized	Low
Venereal disease causing	No, do not survive for significant periods outside the body	-
Urinary tract infections	No, no direct environmental transmission	Low

Mycobacterium tuberculosis and *Mycobacterium bovis* may be excreted in urine (Bentz *et al.* 1975; Grange and Yates 1992 from Höglund, 2001) but tuberculosis is not considered to be significantly transmitted by other means than by air from person to person. *Microsporidia* are a group of protozoa recently implicated in human disease, mainly in HIV positive individuals (Marshall et al. 1997; Cotte et al. 1999 from Höglund, 2001). The infective spores are shed in faeces and urine, and urine is a possible environmental transmission route (Haas et al. 1999 from Höglund, 2001). Hepatitis B was also found in human urine and urine was suggested as a potential route of transmission in hyperendemic areas (Knutsson and Kidd-Ljunggren 2000 from Höglund, 2001). With regard to the possible spreading of HIV/AIDS, studies in the United States and Sweden have shown that the HIV virus cannot survive longer than 24 hours in urine (Edström, 2000).

The highest risk for the transmission of excreted pathogens via urine relates to the possible cross-contamination of urine by faeces of an infected person in the separating latrine (Strauss et al., 2003).

3.4- Non-pathogenic health risks associated to human excreta

Another potential risk associated with the reuse of excreta is the presence of chemical compounds contained in medicines consumed by humans. There are opposing opinions regarding the extent of the danger posed by these substances when applied in the agricultural land. The most unenthusiastic consideration is made by Strauss (2000) who expresses that it is still unknown whether they are attenuated or accumulated in soil, and stresses the possibility of their introduction in the food chain through crops uptake. According to Strauss *et al.* (2003), the wide and indiscriminate use of antibiotics in urban societies of developing countries, and therefore their manifestation in urban waste streams may turn out to constitute a greater threat to health that those from excreted pathogens. They also mention another relevant chemical contaminants: hormone active substances (HAS) and heavy metals. HAS, also termed “endocrine disrupting chemicals” (EDC), are excreted due to the consumption of rest of pesticides and contraceptive medicines. The major concern related to heavy metals is their conservative nature, which allows them to accumulate in the environment, particularly so in waste-amended soils.

Jönsson *et al.* (2004), in a more optimistic approach, maintain that the contents of heavy metals and other contaminating substances such as pesticide residues are generally very low in human excreta, and therefore the risk posed by these chemicals is negligible compared with chemical fertilizers (e.g. cadmium) and farmyard manure (eg. chromium and lead) (Table 2.6). Since urine contains only substances that have entered the metabolisms, the levels of heavy metals are very low, unlike faeces that consist mainly of non-metabolised material, carrying unaffected heavy metals through the intestine. Jönsson *et al.* (2004) state that the hormones produced by the human bodies and the pharmaceuticals present in urine pose only a low risk on the quantity and quality of crops. They suggest that the vegetation and soil microbes have been adapted during the course of evolution to be able to degrade the hormones excreted by mammals in terrestrial environments. Regarding pharmaceutical substance, they claim that most of these substances are derived from nature and therefore it is possible to degrade them with long retention times in the topsoil through microbiological activity. They also point out that in many countries the human consumption of pharmaceuticals is small compared to that by domestic animals, which are feed with antibiotic substances added as growth promoters. According to them, it is in any case better to recycle human excreta to arable land than to flush them into wastewater plants, in view of the fact that the retention time in such installations is too short for many pharmaceutical substances to degrade, leading to the discharge on recipient waters and the exposure of aquatic systems to mammal hormones in unusual large quantities.

Table 3.3- Concentrations of heavy metals (copper, zinc, chromium, nickel, lead and cadmium) in urine and faeces compared with farmyard manure (FYM) on organic cattle farms in Sweden (Jönsson *et al.,* 2004)

	Cu	**Zn**	**Cr**	**Ni**	**Pb**	**Cd**
	µg/kg ww					
Urine	67	30	7	5	1	0
Faeces	6667	65000	122	450	122	62
Cattle org. (FYM)	5220	26640	684	630	184	23

3.5- Recommended guidelines regarding the application of ecological sanitation technologies for the deactivation of pathogens

The application of ecological sanitation has been reviewed by many authors in order to study the survival of pathogens in the different environments to which they are exposed through different treatments (Faechen *et al.*, (1983); Esrey *et al.,* (1998); Höglund (2001); Schönning and Stenström, (2004); Jönsson *et al.*, (2004) among others).

In the following table, a summary of the survival of pathogens in different conditions is presented by Esrey *et al.* (1998).

Condition	Bacteria	Viruses	Protozoa	Helminths
	Survival time (d)			
Soil	400	175	10	Many Months
Crops	50	60	Not know	Not know
Nith soil, faeces, sludge 20-30 °C	90	100	30	Many Months
Composting / Anaerobic treatment at ambient temperature	60	60	30	Many Months
Thermophilic composting 50-60°C maintained for several days	7	7	7	7

Table 3.4 Survival time (d) of pathogens in day by different disposal/treatment conditions (adapted from Esrey et al., 1998)

As it can be seen, the presence of pathogens can be minimized by the use of different strategies known to kill microorganims, such is the case of exposing them to high temperatures. In general, storage, temperature and time have been recognized as easier and safer barriers, which minimise the risk of transmission.

For instances, Feachem *et al.* (1983) proposed a time vs. temperature diagram in order to show the correlation existing between these two parameters for the inactivation of different pathogens. According to their findings, the thermophilic processes (e.g. thermophilic and mesophilic composting, anaerobic degradation, incineration) should be performed using high temperatures > 45°C for periods > 1 month in order to ensure the inactivation of Ascaris eggs, which are the most resistant microorganisms.

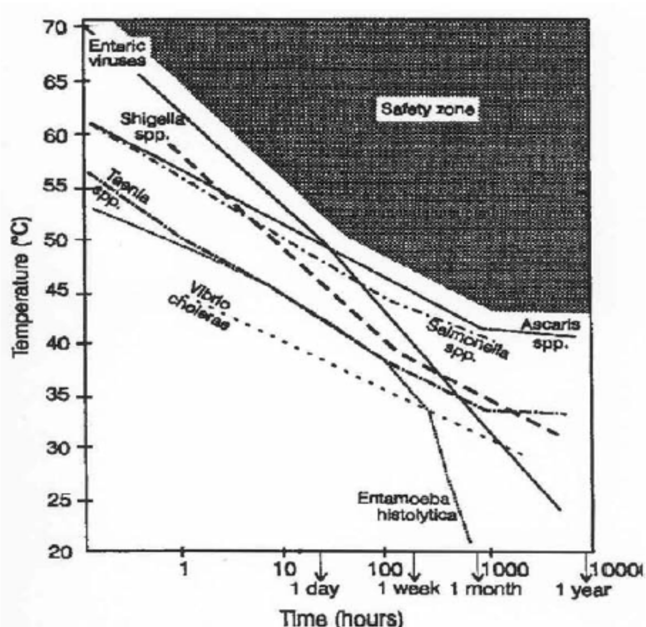


Fig 3.3- Combination of time and temperature of pathogens elimination. (Feachem *et al*., 1983)

The thermal inactivation of pathogens has also been studied by Tchobanoglous *et al.* in 1993 (from Strauss *et al.*, 2003). The following table shows their findings regarding the die-off of selected pathogens during composting treatment.

Table 3.5 Thermal Inactivation of Selected Excreted Pathogens (after Tchobanoglous et al. 1993)

Microorganism	Duration of thermal inactivation
Escherichia coli.	Death within 1 hour at 55°C and within 15-20 minutes at 60°C
Salmonella sp.	Growth ends at 46°C; death within 30 minutes at 55-60°C and within 20 minutes at 60°C
Entamoeba histolytica cysts	Death within a few minutes at 45 °C ad within a few seconds at 55°C
Taenia saginata	Death within few minutes at 55°C
Ascaris lumbricoides eggs	Death in less than 1 hour at temperatures over 59 °C

According to the authors, a general rule of thumb for pathogen suppression is to maintain the composting process at 55oC to 65 °C for 3 consecutive days.

The table 3.6 shows the proposed guidelines based on urine storage time and temperature by the Swedish EPA. These guidelines may be considered as recommendations on how to use urine in agriculture in order to minimise the risks for transmission of infectious diseases and as a part of risk management (Schönning and Stenström, 2004).

Table 3.6 Recommended Swedish guideline storage times for urine mixture[a] based on estimated pathogen content[b] and recommended crop for larger systems[c]. (Schönning and Strenström, 2004)

Storage temperature	Storage time	Possible pathogens in the urine mixture after storage	Recommended crops
4°C	≥ 1 month	Viruses, protozoa	Food and fooder crops that are to be processed
4°C	≥ 6 months	Viruses	Food crops that are to be processed, fodder crops[d]
20°C	≥ 1 month	Viruses	Food crops that are to be processed, fodder crops[d]
20°C	≥ 6 months	Probably none	All crops[e]

[a] Urine or urine and water. When diluted it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/l.

[b]Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognized for causing any of the infections of concern.

[c] A larger system in this case is a system where the urine mixture is used to fertilize crops that will be consumed by individuals other than members of the household from which the urine was collected.

[d] Not grasslands for production of fodder.

[e] For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

Proposals for the elimination of pathogens in faeces through storage has also been cited by some authors. For instances, Garujel and Wendland (2004) ilustrate the suggested recommendation for dehydrated faeces reuse made by Strauss and Blummenthal in 1990.

Table 3.7 Suggested recommendations for dehydrated faeces reuse (cited in Garujel and Wendland, 2004)

Storage condition	**Vault storage period required**	
	Without subsequent sun-drying	**Without subsequent sun-drying**
At 17-20°C average (highland, subtropical)	18 months	12 months
At 28-30°C acerage (lowland, tropical)	10-12 months	8-10 months

According to the authors, there is there is no single best strategy for health protection; each situation requires thus its own specific approach. The following remarks can be regarded as being applicable to most urine diversion systems and reuse of their faecal products (Austin, 2001):

- ✓ Wood ash is a good additive due to its relatively high pH, which assists pathogen die-off. It also virtually eliminates odour and flies, and the toilet is therefore more hygienic.
- ✓ Faeces are likely to dehydrate better, thus assisting pathogen die-off, if they are collected and stored in a heap and turned occasionally, rather than in a closed container or compartment.
- ✓ Faecal coliforms, which include pathogenic bacteria, may be present in large numbers (orders of magnitude in excess of current guidelines) up to a year after defecation, and possibly longer, even with low moisture contents.
- ✓ The vast resistance of faecal streptococci towards unfavourable environmental conditions is evident. These organisms are indicative of decaying faecal matter.
- ✓ Salmonella, a bacterium present in faecal matter, can result in severe gastro-enteritis. These organisms are seen to be relatively hardy; however, they can also be found in bird droppings and are therefore often present in ordinary soil.
- ✓ Sunlight (UV radiation) is a good destroyer of pathogens.
- ✓ Re-hydration of dry faecal matter can result in many organisms becoming viable again.

In Sweden the EcoSanRes Programme, in conjunction with the Swedish Institute for Infectious Disease Control (SMI) and with the Swedish University of Agricultural Sciences (SLU) developed in year 2004 the guidelines for safe use of urine and faeces in ecological sanitation systems (Schönning and Stenström, 2004). The guidelines aim to educate ecological sanitation users about how to handle the urine and faeces in a safe and beneficial manner and thus promote the use of human excreta in agriculture. In the document, the following recommendations are presented:

ECOLOGICAL SANITATION TOILETS –GENERAL

- ✓ Urine diversion is recommended for several reasons; one is decreased risk for disease transmission.
- ✓ Faecal collection should normally occur above ground.
- ✓ Faecal collection should occur in a closed compartment without risk of seepage to groundwater or to the surrounding environment. Twin-pit collection is preferred.

✓ Urine should be collected with minimal risk for faecal contamination. Urinals are a good complement to urine-diverting toilets.
✓ Solar heating of the collection devices for urine and faeces may be beneficial for pathogen inactivation.
✓ Handling and transport systems should involve minimal contact with the faecal material.

URINE – TREATMENT AND USE
✓ Urine involves low risk for transmission of disease.
✓ Dilution of the urine should be avoided.
✓ Faecal contamination of urine is possible and therefore urine may contain enteric pathogens.
✓ At household level the urine can be used directly.
✓ Urine should, in large-scale systems, be stored for one month at 20°C before use. In addition a withholding period of one month between fertilization and harvest should be applied.
✓ For vegetables, fruits and root crops consumed raw, a one-month withholding period should always be applied.
✓ In areas where *Schistosoma haematobium* is endemic, urine should not be used near freshwater sources.
✓ Urine should be applied close to ground and preferably mixed with or watered into the soil.

FAECES- TREATMENT AND USE
✓ Faeces should be treated before it is used as fertilizer.
✓ Primary treatment (in the toilet) includes storage and alkaline treatment by addition of ash or lime.
✓ 1-2 cups (200-500 ml; enough to cover the fresh faeces) of alkaline material should be added after each defecation.
✓ In small-scale systems (household level), the faeces can be used after primary treatment if the criteria in Table 3.8 are fulfilled.
✓ The treatments in Table 3.8, along with incineration, can be used as secondary treatment (material removed from toilet and treated) at household level.

Table 3.8 Suggested alternative recommendations for primary (and secondary) treatment of dry faeces before use at the household level. No addition of new material (Shönning and Stenström, 2004)

Treatment	Criteria	Comment
Storage (only treatment); Ambient temperature 2-20°C	1.5–2 years	Will eliminate most bacterial pathogens; regrowth of E. coli and Salmonella not considered if re-wetted; will substantially reduce viruses, protozoa and parasites. Some soil-borne ova may persist
Storage / Ambient temperature 20-35°C	>1 year	As above
Alkaline treatment	pH >9 during >6 months	If temperature >35°C and moisture <25%, lower pH and/or wetter material will prolong the time for absolute elimination

✓ Secondary treatments for larger systems (municipal level) include alkaline treatments, composting and incineration (Table 3.9).

Table 3.9 Alternative secondary treatments suggested for faeces from large-scale systems (municipal level). No addition of new material (Shönning and Stenström, 2004)

Treatment	**Criteria**	**Comment**
Alkaline treatment	pH>9	Hypothesis: If temperature >35°C or moisture < 25%. Lower pH and/or wetter material will prolong the time for absolute elimination
Composting	Temperature >50°C for >1 week	Minimum requirement. Longer time needed if temperature requirement can not be ensure.
Incineration	Fully incinerated (<10% carbon in ash)	
Storage	As above Table 3.8	Time modification needed based on local conditions. Large systems needs a higher level of protection than at household level.

✓ Alkaline treatment can be done by (further) addition of ash, lime or urea.
✓ The pH after alkaline treatment should be at least 9 and the material should be stored at this pH for at least six months to one year. (Total elimination may not occur, but a substantial reduction will be achieved).
✓ Composting is mainly recommended as a secondary treatment at large scale, since it is a difficult process to run. Temperatures >50°C should be obtained during at least one week
✓ Storage at ambient conditions is less safe, but acceptable if the conditions above apply. Shorter storage times can be applied for all systems in very dry climates where a moisture level <20% is achieved. Sun-drying or exposure to temperatures above 45oC will substantially reduce the time. Re-wetting may result in growth of Salmonella and E. coli.
✓ Personal protection equipment should be used when handling and applying faeces.
✓ Faeces should additionally be mixed into the soil in such a way that they are well covered
✓ A withholding period of one month should additionally be applied, i.e. one month should pass between fertilization and harvest.
✓ Faeces should not be used for fertilization of vegetables, fruits or root crops that are to be consumed raw, excluding fruit trees.

3.6-International Regulations and recommendations regarding use of human excrete in agriculture.

The use of wastewater and faecal sludge in agriculture has been regulated through different recommendations in a global, national and local level. For instances, the World Heath Organisation published in 1989 the Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture*,* with the objective of encouraging the safe use of wastewater and excreta in agriculture and aquaculture in a manner that protects the health of the workers involved and of the public at large (Mara and Cairncross, 1989). According to the guidelines, health protection considerations require that some treatments be applied to domestic sewage, municipal wastewaters and nightsoil in order to remove pathogenic organisms. Other health protection measures are also considered, including crop restriction, waste application techniques and human exposure control.

The WHO (1989) guidelines for wastewater reuse in agriculture recommended that treated wastewater should contain:

✓ ≤1 viable intestinal nematode egg per litre (on an arithmetic mean basis) for restricted or unrestricted irrigation; and
✓ ≤1000 faecal coliform bacteria per 100 millilitres (on a geometric mean basis) for unrestricted irrigation.

On the other side, the guidelines regarding the use of excreta (nightsoil and excreta derived products such as sludge and septage) in agriculture established that the sludge should cointain:

✓ ≤ one helminth egg per kilogram
✓ ≤ 1000 faecal coliforms per 100 g.

The Ordinance on the Utilisation of Bio-wastes on Land used for Agricultural, Silvi-cultural and Horticultural Purposes has been applied in Germany since 1998, (Anonymus, 1998). According to it, the products from biological waste treatment requires an epidemic and phytohygienical clearance by a direct and an indirect process control together with end product tests on salmonella. The test result is considered satisfactory if none of the samples taken contain Salmonellae.

The U.S. Environmental Protection Agency (EPA) developed in 1994 a set of guidelines for the management of biosolids. The Standards for the "Use of Disposal of Sewage Sludge Rule" (Subpart D of 40 CFR 503) establishes the limits for pathogens in sludge (EPA 1994). Biosolids are classified as class "A" or class "B" with respects to pathogens. Class A compost, which contains safe and acceptable levels of pathogens, is considered safe for application to food and non-food plants. The end product is considered a safe soil amendment (fertilizer) with minimal health consequences if it meets the following criteria:

✓ Contains <1000 MPN of faecal coliform per gram
✓ Contains <1 A. lumbricoides egg per 4 gram

Compost is designated class "B" if pathogens are detectable, but have been reduced to levels that do not pose a threat to public health and environment as long as actions are taken to prevent exposure to the biosolids after their reuse or disposal. The federal requirements for Class B compost state that the end product will be considered a safe soil amendment (fertilizer) for ornamental plants if it meets the following criterion:

✓ Contains <2,000,000 MPN of faecal coliforms per gram

4-Characterisation of human excreta in Ethiopia

In Appendix 2, calculations regarding the number of inhabitants in the study area are performed, according to the supposed number of inhabitants who will live in each building to be constructed. Taking into consideration the maximal number of persons expected, a population of 1980 ≈ 2000 is determined.

In order to propose feasible treatment methods and further use of the human excreta produced by the study population, the following chapter will be devoted to the characterisation of human urine and faeces regarding amount and nutrient composition. Through literature review, data will be extrapolated with the aim of proposing values for the future products of the Arat Kilo and Piazza areas.

4.1- Amount of produced human excreta

The amount of faeces and urine produced per capita per day may vary for different regions, due to different dietary habits and climate conditions. According to Drangert (1998) a person excretes less than 500 l of urine and 50-180 kg (wet weight) of faeces in a year depending on water and food intake. Jönsson *et al.* (2004) suggest that the digestibility also influences the amount of faeces excreted, being 51 kg/cap·year for the Swedish population and 190 kg/cap·year for inhabitants in Kenia. In a general sense, it is estimated by Aalberts (1999) that the amount of faeces produced ranges from 69 - 520 g/cap·day, while the urine production ranges from 845 - 1500 g/cap·day. In table 3.1 a compilation of human excretion data for different regions is shown.

Table 4.1- Amount of faeces and urine produced per capita per day in nightsoil for different regions (Aalbers, 1999)

Region	**Faeces** (g/cap*d)	**Urine** (g/cap*d)	Source
Africa	400	1500	(Mann, 1976)
USA	86	1055	(Snell, 1943)
China	69	845	(Snell, 1943)
Europe, North America	100 - 200 (wet faecal weight)		(Edwards, 1992)
developing countries	130 - 520 (wet faecal weight)		(Edwards, 1992)
Vietnam	1370 (faeces + urine)		(Nimpuno, 1983)
Thailand	1000 (faeces + urine)		(Stoll & Parameswaran, 1996)

Precise data for the production of excreta in Ethiopia is not available in the literature, however for the development of this study it will be assumed 300 g of faeces and 1,5 l of urine per person per day, taken from pre studies elaborated by Meinzinger *et al.* (2005), which is located inside the average range observed by Aalbers.

In Appendixes 3 and 4, calculations of the future amount of excreta produced by the 2000 inhabitants of study population is presented, giving as a result 600 kg/d (18 ton/month) of fresh faeces and 3 m^3/d (90 m^3/month) of urine.

4.2- Water content of human excreta

Human faeces contain a large proportion of water, ranging from 70 to 85%, having however a high content of dry matter (around 25%) composed by organics and microorganism. Urine, on the other side, contains mostly water, 93 to 96%, with a dry solids content of some 50 to 70 g per person per day (Drangert, 1998).

For the matter of this study the water composition of faeces will be assumed as 80%, meanwhile for urine it will be taken as 95%.

4.3- Nutrient composition of human excreta

The excellent nutrient value of the human excreta is based on the fact that the body of an adult person retains only a small proportion of the plant nutrients that he/she consumes. The body of a growing child however, does take up and integrate some nutrients to the body's tissue. For instances, nitrogen is accumulated as proteins in youngsters, meanwhile phosphorus is used to build up bones and muscles and potassium is incorporated into nerves (Jönsson *et al*., 2004). Despite of this difference in nutrient assimilation between elder and youth, the human body is in any case, and at any stage of life, inefficient regarding its nutrient retention, being estimated during the period of growing (12-17 years) at 2%, 6% and 0,6% for N, P and K respectively, according to a study performed based on average diet and body gain on Swedish children (Jönsson *et al*., 2004). Once the body is fully developed, the intake of plant nutrients is then close to cero, which makes the human excreta a rich source of inorganic plant nutrients such as nitrogen, phosphorus and potassium, as well as organic matter.

There are a few measurements regarding the composition of nutrients in human excreta published in the literature, which differ from each other depending on the study population due to eating habits and differences in metabolisms.

The consumption of proteins has been identified by Jacks (1997) as one of the parameters for the nitrogen content. For instances, 4 kg of nitrogen per year would be found in the urine production of Swedish inhabitants consuming 70-80 g of proteins per day, exceeding the nitrate values for Nigerian two or three times, whose protein intakes are between 25g/d and 45 g/d. (Drangert, 1998).

In the case of the urine, the concentration of nutrients also depends on the liquid intake which could be in the range of 0,8 –1,6 little at day for a grown person. Consumption of larger amounts of water will dilute the urine; meanwhile excessive sweating is translated into concentrated urine.

The partition of nutrients between urine and faeces depends upon how digestible the diet is, as digested nutrients enter the metabolism and are excreted with the urine, while undigested fractions are excreted with the faeces. For the Swedish population, for instances, 88% of N and 67% of the excreted P is found in the urine and the rest in the faeces, meanwhile in other regions with less digestible diet it has been found a different distribution, such is the case of China, where 70% of the excreted nitrogen and 20-65 % of the phosphorous of its inhabitants is found in the urine (Jönsson *et al*., 2004). A general estimation given by Strauss (2000) indicates that most of the organic matter is contain in the faeces, while most of the nitrogen (70-80%) and potassium is contained in urine. According to him, phosphorous is equally distributed between urine and faeces. The following table shows a summary of nutrient data from the most highlighted sources:

Table 4.2.- Nutrient composition of human excreta (urine and faeces) according to different authors.

Source		N	P	K	C
		g/p*d			
Strauss, M (200) (Switzerland)	Total	12,3	1,6	3,3	30,0
	Urine	10,9	0,8	2,5	-
	Faeces	1,4	0,8	0,8	-
Swedish EPA (1995) (Sweden)	Total	12,5	1,5	3,5	-
	Urine	11,0	1,0	2,5	-
	Faeces	1,5	0,5	1,0	-
Otterpohl et al. (2002) (Germany)	Total	11,9	1,8	3,3	-
	Urine	10,7	1,0	2,7	-
	Faeces	1,2	0,8	0,6	-

As observed in table 4.2, the values reported by the authors do not differ widely from each other, however it must also be considered that the study population in all cases are very similar, considering food habits and living conditions. In order to estimate the composition of excreta in Ethiopia, a different method should be applied, extrapolating the data published for the European population. It should be then taken into account that the different composition of excreta between different regions reflect differences in the uptake of the consumed crops, and therefore a correlation could be made between the amount of excreted plant nutrients and the food intake, on which data is fully available for countries, such as Ethiopia, where deep investigations regarding composition of excreta have not been done.

In this way, H. Jönsson and B. Vinnerås (2004) developed a method to calculate the composition of excrete using available data from the Food and Agriculture Organization (FAO) statistics on the available food supply in different countries. They proposed relationships between nutrient content of excreta and food intake (Eq.1 and Eq.2), using as correlating data that reported for the Swedish population. The inputs of these estimations are the values called "Total food protein" and "Vegetal food protein" found in the FAO web page "Nutrition data – Food supply – Crops primary Equivalent". The equations are presented as follow:

$$N = 0{,}13 \cdot Food\ \ protein_{TOTAL} \quad \text{Eq. 1}$$

$$P = 0{,}011 \cdot \left(Food\ \ protein_{TOTAL} + Food\ \ protein_{VEGETAL}\right) \quad \text{Eq. 2}$$

According to Jönsson (2004) there is a strong positive correlation between the content of protein and the phosphorus present in the food. The vegetal protein is counted two times in Eq. 2 since the vegetable foods contain on average twice as much phosphorus per gram of protein as the animal. The authors sustain their proposed formulas by comparing the values obtained for the Chinese population using Eq 1 and Eq 2 (4,0 kg/cap·year for N and 0,6 kg/cap·year for P) with those reported by Gao *et al*. (2002) (4,4 kg/cap·year for N and 0,5 kg/cap·year for P).

The low deviation shown by the proposed expressions will allow to estimate as well the composition of excreta in Ethiopia, using as parameters the values found in the FAO data base $Food\_protein_{TOTAL}$= 53.9 g/cap·d and $Food\_protein_{VEGETAL}$= 47, 9 g/cap·d. In this case, the values obtained are 7,0 g N /cap·d and 1,1 g P/cap·day. To use these values in the course of this investigation is regarded as more accurate than assuming the published data for the European inhabitants, due to the existing difference between the protein intake in the regions.

Even though the authors do not suggest an equation for the calculation of potassium concentration in excreta, they show estimated values of this nutrient for Uganda (3,8 g/cap·d). As not data for Ethiopia is available and do to the similarities found in N and P production in these two African countries (7,0 g/cap·d and 1,1 g/cap·day respectively) the potassium concentration in excreta for Ethiopian will be assumed as 3,8 g K/cap·d.

Assuming that the digestibility of the Ethiopian diet is similar to that shown in Uganda, the proportion of nutrients founded in urine will be 88% for N, 75% for P and 71% for K. The composition of carbon will be assumed as the one founded by Strauss (2000), due to the lack of information in African areas in this matter.

According to the values obtained using the proposed equations and the assumptions above exposed, the estimated composition of excreta for Ethiopian population is shown in the following Table:

Table 4.3.- Proposed composition of the human excreta for the Ethiopian population.

	N	P	K	C
	(g/cap*d)			
Urine	6,4	0,8	2,7	-
Faeces	0,6	0,3	1,1	-
Total	7,0	1,1	3,8	30,0

5-Proposed sanitation options

The Technical University of Braunschweig (Institute for Sustainable Architecture and Settlement Planning), together with GZT/Low-Cost Housing Project and the City Government of Addis Ababa, have developed the urban design for the Arat Kilo and Piazza inner city quarters. The building units have different characteristics and are designed to maximise the use of space without compromising the feasibility of the project, neither the comfort of the future residents.

For the realisation of the present report, a study population of 8 building units with an estimated maximal number of residents of 2000 will be considered (See Appendix 2). The location of the study buildings is presented in figure 5.1.

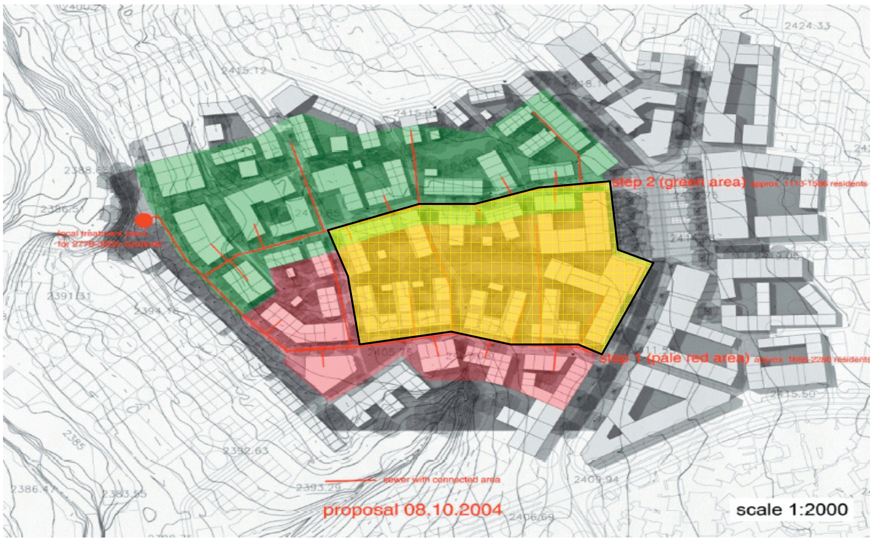


Fig 5.1- Urban plan. Population of the UPESSAA project

According to the Final Report of the Preliminary investigation performed by the Institute of municipal and industrial wastewater of the TUHH (Meinzinger, 2005) the two recommended toilets technologies that could be effective as sustainable wastewater management methodologies are dry toilets and low flush toilets, both with urine separation (for description, see section 2.4). The subsequent primary and secondary treatments available, as well as the quality and quantity of the products for agricultural reuse, strongly depend on the type of facility to be installed.

SELECTION CRITERIA

In order to select the toilet technology that represents a more feasible alternative for the study area, a scenario for each technology will be described (**Scenario A: dry toilet** and **Scenario B: low flush toilet**), where the following features will be evaluated:

- ✓ Toilet system to be installed.
- ✓ Primary treatment recommended → analysis of selection, logistics of maintenance, quantity and quality of product, and costs.
- ✓ Secondary treatment recommended→ analysis of selection, logistics of maintenance, quantity and quality of product as fertilizer, and costs.

For the selection of primary and secondary treatments for each scenario a qualitative technical assessment will be performed, in order to integrate the local characteristics of Addis Ababa (summarized in Appendix 1) and the technical features and requirements of each technique. In this sense, the following technical indicators will be evaluated for each possible treatment (primary and secondary):

	Evaluation in table		
✓ ***Robustness***: sensitivity of the process concerning toxic substances, shock loads, seasonal effects, careless use, ect.	3:Excellent	2:Good	1:Bad
✓ ***Professional Expertise needed***: skilled-workers needed to maintain the system.	3:None	2:Moderate	1:Large
✓ ***Labour input needed***: non-skilled labour needed for maintenance	3:None	2:Moderate	1:Large
✓ ***Availability of Agents:*** possibility for the future users to obtain the correct agent	3:High	2:Moderate	1:Small
✓ ***Ease of handling of product:*** ease to collect and transport the products.	3:Easy	2:Moderate	1:Difficult
✓ ***Quantity of product:*** amount of product expected to handle and transport.	3:Low	2:Medium	1:High
✓ ***Space required:*** on-site area needed to perform the treatment	3:Small	2:Medium	1:Large
✓ ***Fertilizer quality of the product:*** quality of the product expected	3:Excellent	2:Good	1:Bad
✓ ***Sanitation obtained***: inactivation of pathogens obtained.	3:Excellent	2:Moderate	1:Bad
✓ ***Experience:*** practical experiences founded in Ethiopia and other developing countries.	3:High	2:Medium	1:Low

A detailed assessment, including requirements, logistics, quantity and quality of product, will be carried out only for the feasible treatments, e.g., those treatments that, according to the evaluation, obtain the maximal number of points. A cost analysis, including investment and operation costs will be also used to allow a comparison between the two scenarios.

As the two options include urine separation, the calculations, analysis and proposals for urine management and use will be identical for both options, and therefore it will be treated separately.

5.1- Scenario A: Dry toilets with urine separation

5.1.1-<u>Description of the system to be used</u>

As stated by Meinzinger and Otterpohl (2005), dry urine-separation toilets will be implemented in housing units located in buildings up to four storeys, however for the matter of this study it will be considered the application of this technology to the 2000 inhabitants. The dry system to be installed will allow the processing of faeces inside every single building, instead of conveying it away to a treatment plant.

The toilets will be located outside of the apartments, due to cultural and technical reasons. Made of porcelain, ceramic or other available fabrication material, the toilets could be installed as squatting or sitting, depending on the future use (public or private), and located at an elevated level in order to prevent intrusion of cleaning water. Each toilet will be provided of a two-vault chamber as the one described in Section 5.4.1 as the Vietnamese double vault dehydration toilet. The collecting period for the first vault (A) will be 4 months, time after which it will be closed to allow the idle stage meanwhile the second vault (B) will be then used for another 4 months. After a period of 8 months, the dry content of the vault A will be pushed into a funnel, allowing the faeces to fall down into a gathering tank. The toilet bowl should provide for urine separation meaning that there is a separate opening and drainage pipe in front of the toilet bowl.

Even though the final plan of the buildings as well as the disposition of the toilets have not yet been decided, for the matter of this project, the following figure shows the assumed design of the location of the dry toilets.

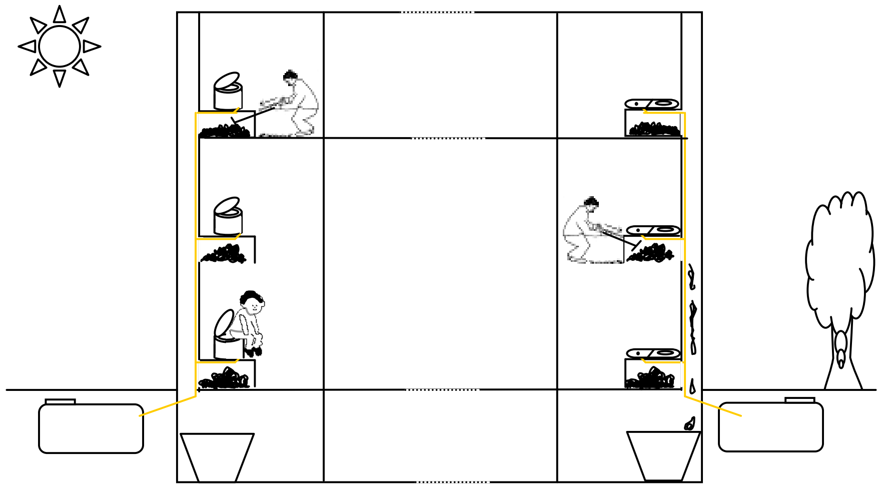


Figure 5.2- Design of the location of the dry toilets assumed for this project.

5.1.2 Primary treatment of products from dry toilets for the study area

In Table 2.1 the five different methods to be applied as primary treatment of dry toilets products are described, mainly consisting in composting or dehydration, being soil composting, addition of additives and solar exposure simple variants of the original two.

The following table shows the evaluation of the applicability of the five different dry technologies for the inner areas of Arat Kilo and Pizza and following, an analysis of the assessment can be found.

Table 5 .1- Evaluation of suitability of dry sanitation technologies based on technical indicators.

Technical Indicators	**Composting**		**Dehydration**		
	Soil composting	**Composting**	**Solar dehydration**	**With drying additives**	**With alkaline agents**
Robustness	3	1	-	3	3
Professional Expertise needed	3	1	-	3	3
Labour input needed	1	1	-	3	3
Availability of Agents	1	2	-	3	3
Ease of handling of product	1	2	-	2	3
Quantity of product	1	3	-	1	1
Space required	1	1	-	2	2
Fertilizer quality of the product	2	2	-	2	2
Sanitation obtained	1	2	-	1	3
Experience	1	3		3	3
TOTAL	**15**	**18**	**Not viable**	**23**	**26**

SOIL COMPOSTING: Due to the urban location of the study area, the use of soil-composting sanitation system is not going to be considered as a possible option of primary treatment. Even though this system is regarded as robust and requires not skilled monitoring and low labour intensity, it also presents significant disadvantages. As expressed by Winblad and Simpson-Hébert (2004), this type of system has worked well in rural areas for hundred years, but it has presented problems in cities, where households have no access to soil. On the other hand, the use of vast amounts of soil, approximately five times that of faeces, will increment the volume and weight of the product from the sanitation system of a population of 2000 persons estimated and 50 000 projected, and therefore will increase the cost of transport and logistic, jeopardizing the sustainability of the system. Furthermore, the only addition of soil will not sanitize sufficiently the human excreta, as not elevation of pH is obtained, being the temperatures also not higher than the ambient temperature, showing low bacterial activity for the decomposition of the organic matter. As expressed by Schönning and Stenström (2004) the only addition of soil can not be regarded as a unique treatment for faeces, posing a high health risk for workers at the collection and transport stage.

COMPOSTING: the use of composting toilets will require a careful control of variables such as temperature, airflow, moisture, C:N ratio and other factors in order to optimise conditions favourable for the aerobic bacteria growth. For instances, the faeces should be mixed with carbon rich material such as kitchen and garden refuse during the stage of collection, to allow availability of N and C to the bacteria, worms or other organisms that will break down the faeces and produce compost. This fact will require relaying on the inhabitants willingness to cooperate by adding carbon source material to the toilets, which could be chaotic as other garbage that will inhibit the aerobic degradation could be also added. On the other hand, composting toilets require sufficient air and stirring to avoid smells and to ensure high temperatures (>50 °C). The mechanisms for monitoring the aeration and stirring will need a special design that has not been considered yet, and skilled professionals that should steer each unit of the suburb. Regarding the quality of the product, the presence of high temperatures, high pH and high aeration means a significant loss of Nitrogen in the form of ammonia (up to 50%) and the bacterial degradation consumes the organic matter in an approximately degree of 40-60%. Nevertheless, the availability of K, S and P in composted material is high, and the produced material improves the water-holding and buffering capacity of the soil (Jönsson *et al*. 2004). Unfortunately, due to the large scale of the project in the areas of Piazza and Arat Kilo and the excessive monitoring required, it is estimated that this process might not be suitable for the first stage of processing, thus being more appropriated as a second treatment once the collected material is transported to an eco-station. Vermicomposting of faecal material is also understood as a composting treatment, but using special types of worms (*Eisenia fetida* and *Eisenia*), which convert the excreta in a humus type material. It presents several advantages as the soil-conditioning product exhibits good pathogenic quality after 3 months. Vermicomposting requires also high skilled monitoring to control the process conditions and the different endemic species should be tested under local conditions in order to identify the most appropriate for the treatment of faeces of the study area. As well as the thermophilic composting already described, the Vermicomposting process will be taken into account as a secondary process and for the primary treatment of flush toilet product.

SOLAR DESICCATION: the solar desiccation toilets are a variant of simple dehydration toilets, in which the collecting vaults are covered by a metal sheet to allow irradiation on the material to increase evaporation. For Addis Ababa with a daily average of 9 hours of sunshine during the dry season, it could signify a good option for the dehydration of faeces, especially due to the high humidity of the city. However the installation of the passive solar panel requires a southern orientation and a disposition to avoid blockage of the panel to solar irradiation, which may not be always achieved in all units of the different buildings. Furthermore it will require the installation of such sheet for each double vault toilet installed in each housing unit, which could increment the costs of construction without meaning a sound technology due to the "shadows" problems. Redlinger *et al.* (2001) have however stated the positive correlation existing between solar exposure and high degree of sanitation of faeces, according to a study carried out in Ciudad Juarez, Mexico, in which SIRDO (dry composting latrines) were evaluated. Moreover, Moe and Izurieta (2003) detected no viable *Ascaris* in biosolid samples from solar toilets in El Salvador when the average temperature was 37°C or higher. Therefore, the solar exposure could be considered as part of secondary treatment, once the excreta is collected and transported to an eco-station.

ADDITION OF DRYING AGENTS: the addition of dry soil to faeces after each defecation has been practiced since ancient times, and its drying advantages are well known today and further exploited to avoid smell and to achieve low moisture. Furthermore, the simple addition of soil or other adsorbent material could be regarded as a very robust system that requires low monitoring and labour force. Its fertilizing quality has also been recognised since only small losses of nitrogen are expected when the fast drying takes place. However, the pH, the most critical factor for the inactivation of faecal coliforms and bacteria, is not elevated by the merely addition of earth (Moe and Izurieta, 2003). Therefore the sanitation of faeces is not achieved thoroughly. As fairly good sanitation of faeces should be obtained before transport to avoid risky conditions for the workers, it is better to combine dry soil with a pH-elevating chemical.

ADDITION OF ALKALINE AGENTS: the addition of alkaline agents presents several benefits as a sanitation option: it reduces the smell, improves aesthetical conditions, reduces flies breeding, decreases moisture content and promote pathogen die-off through elevation of pH (Schönning and Stenstöm, 2004). Due to its robustness and low little process monitoring, the dehydration toilets with addition of alkaline agents are capable of handling populations of thousands of persons, whenever the necessary user-education for the maintenance of the unit and logistics of collection is provided. Even though only a little reduction of volume is achieved, the dry product is safe and easy to handle, allowing simple collecting and transportation for further treatment. The sanitation effect of additives such as lime (pH= 10,5), ash (9,4) and specific lime-mixed soil (pH 8.8) has been proved by Moe and Izurieta (2003), who observe a rapid deactivation of coliforms in El Salvador. Regarding the fertilizing effect, if the drying is fast and a low moisture level is achieved, the losses of both organic matter and nitrogen are small, however the organic matter is less stable (Jönsson *et al*, 2004). Furthermore, the final product, with a very alkaline character (pH > 8) can affect a further composting process or, when direct applied, it might have negative consequences in crop production in alkaline soils. However, Winblad and Simpson-Hébert (2004), for instances, recommend desiccation with alkaline additives for urban areas, with the participation of the municipal authority collecting the dry matter after primary treatment. There are many examples of application of desiccation toilets in urban areas like in Asia and Latin America, which experience and results could be integrated for the design of most convenient sanitation option for Addis Ababa. In the study area, with a temperature reaching 20°C through the year, an extended die-off of pathogens and the complete drying of the organic material could be reached with planned time of storage of 8 months (collection and idle phases).

5.1.2.1- Considerations for dry toilets with addition of alkaline agents as primary treatment

DESICCATING AGENT: the type of desiccating agent added to the drying toilet after each defecation varies according to the availability of minerals in each country, influencing the choice of a secondary treatment. For instances, wood ash is, according to Chinese practice, not recommended to add as an absorbent if the faecal material should be composted since that would result in higher losses of nitrogen (Schönning and Stendström, 2004). On the other hand, the excessive use of lime, with a high pH, could also inhibit the post composting of the material, due to the hard conditions for the aerobic bacteria to grow.

For the matter of this project it would be estimated the use of a mixture of 50% earth and 50% lime, with a density of ρ= 1225 kg/m^3 (see Appendix 5), due to the availability of lime and earth in the mineral market of Ethiopia (2500 metric tonnes of lime produced in year 1999) (Mobbs, 1999) (see Appendix 4) and the value of lime (CaO) as a soil conditioner.

The amount to be applied to each defecation influences drastically the extent of the dehydration process as well as the labour intensity of collection and transportation. Therefore it should be a compromise and should be further determined by the designers of the collection containers. According to the literature, the exact quantity of dry material to be added to the excreta varies. From the data provided for the Vietnamese double-vault toilet an estimation of the daily added material per person was made in Appendix 4 arriving to 143g/d ≈ 150 g/d. According to Peasey (2000), the Mexican ecological sanitary unit requires ideally the addition of 500 g per user per day of ash, lime and soil in equal proportions. Schönning and Stendström (2004) suggest that the amount and quality of ash added may vary, but a rule of thumb indicates that at least 1-2 cups (approx. 200-500 ml) should be added after each defecation. In table A.6 (Appendix 5) an estimation of the future produced product for the study population using different amounts of drying agents was carried out, concluding that a drying agent amount average of 300 g/p·d (proportion faeces : agent = 1:1) will be assumed, in order to ensure the total covering of the surface of the excreta to avoid fly breeding and smell, but without exceeding on amount in order not to compromise the feasibility of the sanitation technology.

Regarding logistics, it is recommended the formation of a small enterprise or a cooperative to manage the dry whole sanitation system. Among its duties, it could also perform the buying, mixing, distribution and selling of the dry agent. In Appendix 6 the required calculations of the drying-agent logistics are performed, assuming a total amount of drying agent needed of 60 m^3 every 4 months. Since the mixing proportion of the drying agent will be 1:1, 30 m^3 of each component should be bought from the mineral industry each 4 months. According to the estimations, packages of 25 kg will be distributed among the families every two weeks. It is recommended to provide each sanitation unit with a bucket to keep the drying agent available for the user and a designed cup with the appropriated volume, tied to the unit, to guarantee the correct proportion faeces/drying matter. Further details of the duties to be performed by the enterprise or cooperative will be discussed at the end of the section in order to integrate the activities that will be performed as secondary treatment.

WET ANAL CLEANSING: The inhabitants of Arat Kilo and Piazza are expected to be mostly wipers, i.e., to use solid material for anal cleaning, due to the 84 % of Christian population living in Addis Ababa. For the 13 % of Muslims, who use to wash after defecation, a separated pipe for anal cleaning water could be integrated in the toilet system and further treated with the grey water, to avoid the intrusion of water in the processing chamber.

DRY ANAL CLEANSING: Dehydration toilets can receive dry cleaning materials such as toilet paper; however it will not decompose completely. Therefore it is strongly recommended the use of trash cans to collect toilet paper and other sanitary napkins. The awareness of the user is the key feature in this matter.

VENTILATION: Ventilation is strongly recommended in areas such as Addis Ababa, where the humid climate and long rainy season could retard the dehydration process. Furthermore it will help to reduce smell and flies problems. As the design of the sanitation system allows an easy method of ventilation, a pipe in the roof of each building above the product fusel can be integrated.

5.1.2.2-Quantity of the dry faecal product and logistics of collection and transport

The amount of fresh faeces that will be produced in 4 months for the total population of 1980 individuals will be 71 280 l, approximating to 2000 inhabitants, the total amount of faeces will be 72 m^3 (see Appendix 3). Considering a water content of 80% v/v and a reduction of the moisture content of the faecal material to less than 25% through evaporation and addition of dry material, the dry volume for the study population will be 28,8 m^3 (See Appendix 5). However, even though the desiccation process reduces the volume of faeces in a 40%, the total volume reduction of the faecal matter to be handled and treated is almost the same as the original, due to the addition of dry material after each defecation. Using a mixture 50% earth and 50% lime, with an approximate density of ρ= 1225 kg/m^3, in a 1:1 proportion of faeces and excreta, the total volume of drying agent in 4 months will be 58,78 m^3 (See Appendix 5).

The total amount of faecal product to be collected, transported and treated every 4 months is then the addition of 28,8 m^3 of dry faeces and 58,8 m^3 of drying agent, giving a total of 87,6 ≈ 90,0 m^3.

COLLECTION:
The toilet system, composed by two vaults, will allow to keep one vault in use (collecting vault) and another in a storage condition (idle vault), allowing the faeces to dry for a period of 4 months. After a total time of 8 months (collection and idle phase) it will be required to empty the idle section to permit its use to compile again the fresh excreta. A “gathering tank” will be then positioned in the basement of the building to collect the dry excreta from several housing units, however its capacity will depend on the number of floors of the building and the number of toilet units to be served by each container. As the design of the buildings is not between the scope of this study, the gathering stage will be regarded in an overall sense, however in order to propose a cost related to investment of this scenario, an assumption of a gathering tank serving 10 toilets will be taken.

Figure 5.3 shows the recommended disposition of the gathering tanks. The transfilling of the dry excreta from the gathering tank to the tipper truck (supposed capacity 8 m^3) might pose difficulties, due to the amount of faeces to be removed, however it is estimated to be performed by showing. It is recommended the construction of a ramp from the basement to the ground level to facilitate the transport of the dry material in wheelbarrows and to avoid the contact of the inhabitants with the excreta when it is passed through the common areas (stairs, corridors, ect).

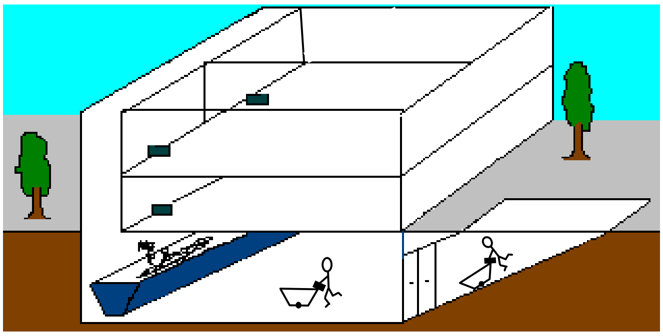


Fig 5.3- Recommended disposition of the gathering tank

Due to the capacity of the tipper truck, 12 rides every 4 months will be needed to transport the faecal product from the urban areas to the eco-station. Further calculations can be found in Annex 7.

5.1.2.3- Quality of the dry faecal product

The total amount of nutrients that can be recovered from human faeces varies according to the collecting strategy to be applied. For instance, the use of water to transport faeces will lead to a migration of valuable nutrients such as N, K and P into the liquid phase. According to Vinnerås and Jönsson (2003), the highest concentration of nutrients is obtained if the faeces are collected without water.

Jönsson *et al.* (2004) established that during the drying process, some nitrogen is lost as ammonia and some very easily degradable organic matter also degrades and is lost as carbon dioxide and water. Once the moisture level reaches low values, the biological degradation slows down, but the risks of loosing nitrogen still remains, especially if slow drying takes place. As Addis Ababa presents a very humid climate with long and strong rainy seasons, a slow drying must be expected with a possible risk higher than 50 % of nitrogen losses. (Trémolières *et al.* 1961 from Jönsson *et al.* 2004).

Due to the strong dependence of nitrogen concentration in faeces to the drying conditions, the dry faeces are not regarded as a reliable source of nitrogen. However, due to good retention of K and P, the dry faeces are considered valuable soil-conditioner for agriculture, of which application increases significant the plant yield. In addition to supplying macro- and micronutrients, faeces contain organic matter, which increases the water-holding and ion-buffering capacity of the soil, serves as food for the microorganisms and is important for improving soil structure (Jönsson *et al.*, 2004).

Apart from the nutrients already existing in the faeces, the different additives used in the drying treatments contribute to the total content of nutrients and organic matter in the treated faecal product. For instances, soil contain N, P, K, Ca, Mg, and S meanwhile lime contributes with carbon and oxygen. Therefore it is difficult to estimate the composition of the dry faecal material if the characteristics of the drying agent to use have not been defined.

For the matter of future comparisons, the nutrient composition expected from the dry faeces will be assumed as high. However, the dry and unoxidized matter will need to be further treated in biological processes in order to make the nutrients available for the plants, meaning that a composting process or a digestion will be necessary to adjust the properties of the product (Del Porto and Steinfeld, 1999). The addition of lime and might pose problems to the biological secondary treatments, as the bacterial activity could be inhibit due to the increase of pH (>8), therefore a careful monitoring and maintenance of the composting process must be followed to allow the future use of the dry product.

From the sanitation point of view, the addition of pH-elevating chemicals has shown a great potential in inactivation of pathogens (Redlinger *et al.*, 2001; Moe and Izurieta, 2003; Schönning and Strenström, 2004). Taking the data provided by Moe and Izurieta (2003) obtained in their studies in El Salvador, it can be assumed that the drying-agent proposed by UPESSA will have similar characteristics to the lime-mixed soil, with a pH ≈ 9, ensuring fast inactivation of faecal coliforms. However, it is possible that *Ascaris* will remain even in high pH ranges, since the most critical factor for its deactivation has been found to be temperature and not pH (Moe and Izurieta, 2003). Schönning and Strenström (2004) recommend as a general rule that ensuring pH> 8 will increase the pathogen die-off. Other authors have suggested the possibility of regrowth of bacterial pathogens once the dry faeces are moistured or if they are mixed with soil Austin, 2001 from Schönning and Stenström). Furthermore, Porto and Steinfeld (1999) indicate that dehydrating pathogenic bacteria can prompt pathogens to become endospores (a form that can survive for decades until rehydrated), returning to their full potency.

5.1.3- Options for secondary treatment of dry products for the study area

In Table 2.2 different methods to be applied as secondary treatment of dry toilets products are described and analysed, emphasizing the advantages and disadvantages presented. The following table shows the evaluation of the applicability of these technologies for the product of desiccation treatment applied to the faecal matter of the inner areas of Arat Kilo and Pizza and following, an analysis of the assessment can be found.

Table 5.2- Evaluation of suitability of dry sanitation technologies based on technical indicators.

Technical Indicators	Storage	Incineration	Dry fermentation	Sanitation with urea	Composting
Robustness	1	-	1	3	3
Professional Expertise needed	3	-	1	2	1
Labour input needed	2	-	1	2	1
Availability of Agents	3	-	2	1	3
Ease of handling of product	1	-	1	1	3
Quantity of product	1	-	2	2	3
Space required	1	-	1	1	1
Fertilizer quality of the product	1	-	3	3	3
Sanitation obtained	1	-	1	3	3
Experience	2	-	1	1	3
TOTAL	**18**	**Not viable**	**14**	**19**	**24**

STORAGE: it could be a viable solution in dry and hot climates where addition of drying additives has been used as primary treatment, however due to the low temperatures reached during the rainy season (7-15°C), storage can not be considered as a potential secondary treatment option in

Addis Ababa. To reach a good sanitation, the moisture level of the product should be below 5%, in order to eliminate the *Ascaris* egg that will remain from the primary treatment (Schönning and Sternström, 2004). However, in such a humid climate as the one in Addis Ababa, it will be only reachable after years of storage, which is not a feasible methodology, as the accumulation of excreta produced by 2000 persons (18 ton/months) will need vast roofed areas to avoid intrusion of water and spreading of the material.

INCINERATION: due to the low energy content of the material after alkaline treatments, to incinerate the dry faecal matter may pose some difficulties. As the installation and maintenance of an incineration plant requires high investment and operational costs as well as highly skilled operating and maintenance staffs, and therefore does not represent any feasible option, it is not going to be exhausted in this analysis.

DRY FERMENTATION: this technique has been reported by Köttner *et al.* (2003) to be performed in a batch wise operation in Algeria, France and Germany since the 1940. According to the authors, it could be suitable to ferment solid waste from waterless toilets that have been powdered with ash and other desiccant agents. The low biomass yield from anaerobic treatment and the retention of energy in the methane are considered to be the main advantages of anaerobic digestion (Björnsson, 2000). However, the low energy available for the microorganisms to growth makes them vulnerable and sensitive to changes (Schink, 1997; from Björnsson, 2000). Therefore, highly skilled operating and maintenance staffs are required to monitor parameters such as pH value, redox potential, volatile fatty acids, moisture content, acidity and alkalinity and substrate structure (Köttner *et al*, 2003), in particular when the dehydrated material offers such scarce conditions for the microorganisms to survive. For instances, the mobility of the methanogens within the substrate is gradually impaired by an increasing solid content, and the biogas yield may suffer as a result (GTZ Biogas I, not specified). Due to the low moisture level of the dry material (expected ≤ 25%) water should be added (200l/t reported by Köttner *et al.* 2003), which could cause the re-growth of pathogens that have been inactivated in the previous step (Porto and Steinfeld, 1999). Furthermore, a primary step should be performed, where the dry faeces must be mixed with carbon rich substrate (grass cuttings, plant waste, manure, straw, bio waste, food waste), aiming to have “acidic” and “alkaline” material in equal ratios (Köttner *et al.* 2003). In order to ensure a good fermentation process, a homogeneous liquid substrate should be achieved, which should be stirred to maintain the process stability within the digester. However, agitation through gas injection for instances is only feasible with a dry matter content below 5%, meanwhile mechanical agitation becomes problematic above 10% of dry matter (GTZ b, not specified). Regarding the lime and earth present in the dry faeces, it actually could be beneficial for the buffering capacity of the system, as the volatile fatty acids (VFA) and acetate produced during the digestion tend to lower the pH of the digester liquor, having adverse effects on methanogens microorganisms. Thus, the presence of calcium hydroxide ($Ca(OH_2)$) will provide the ion bicarbonate equilibrium to bring about a change in pH (Marchaim, 1992). On the other hand, it might be necessary the application of a third process, such as thermophilic composting, in order to achieve a good removal of pathogens and thus allow its application in agricultural land, as the temperature achieved during digestion is not enough high (a couple of degree above ambient temperature) to act as inhibitor of *Ascaris* or coliforms residuals. Köttner *et al* (2003) proposed the pre-composting of the material to elevate the temperature to higher than 50°C. However, it would mean more labour input and excessive monitoring of the process. Finally, the most important advantage of the application of digestion, the obtaining of biogas for the community use will be lost, as the bio-digestors will be installed in the eco-station, out of the inner city areas. All of the above mentioned, make the application of digestion a possible however difficult technology for the study case, thus the small number of practical experiences in developing countries found in literature for dry toilets products. However, the combination of (1) sanitation through lime application, (2) aerobic pre-composting and (3) further digestion could be in the future a valid methodology to ensure the maximisation use of resources and reduction of pathogen risks. But due to the current little technical expertise and the low experience in the managing of such complicated systems, it is recommended its further exploration in laboratory scale to optimise the critical parameters.

SANITATION WITH UREA: The treatment of separated and collected faecal matter with urea seems to be an efficient and safe way of achieving hygienically safe material within 2 months of treatment at room temperature (Vinnerås *et al.,* 2002b). This process has been used as a sanitation process for large-scale treatment of faecal sludge in municipal level. The enzyme urease, which naturally occurs in faeces, degrades the urea at high pH to ammonia, which is toxic for microorganisms (Vinnerås *et al.,* 2002b). The good potential of urea as disinfectant was studied by Vinnerås *et al.* (2002b), where the addition of 3 % urea-nitrogen to faeces resulted in no detection of E.coli and Salmonella after 5 days, a reduction of enteroccoci to $2\log_{10}$ and a viability of Ascaris eggs of 90%. Apart from the excellent sanitation effect, the application of urea also contributes to the low degradation of the faeces, leaving the C and N for the microorganisms in the soil to thrive on after application, thus being an excellent fertilizer (Jönsson *et al.*, 2004). At the same time, the fertiliser value of the faecal matter will increase, as the added urea nitrogen is still available as a plant nutrient after the treatment (Vinnerås *et al.,* 2002b). Regarding technical requirements, this process functions better if the substrate is in the form of sludge, since this condition ensures a stable equilibrium between ammonium and ammonia (Jönsson *et al.,* 2004). Moreover, the treatment with urea should be performed in a closed container where air exchange is low, as this prevents the ammonia produced from being lost (Vinnerås *et al.,* 2002b). These two requirements mean that: sufficient water should be added to achieve the fluid state of the 90 tons of dry faeces, and (2) the sludge should be closed, which would signified high investment costs in containers, jeopardizing the feasibility of the treatment for the study area. As the recommended dosage is 30 g of urea nitrogen per kg of material to treat (Vinnerås *et al.,* 2002b) (2700 kg of urea every 4 months), the main drawback related to this process for the inner city areas of Piazza and Arat Kilo relates to the obtaining of urea in Ethiopia and the increased costs. Today, the high demands of chemical fertilizer are generated due to the encourage of the government of Ethiopia making credit available to farmers, encouraging more fertilizer use (FAO, 2005). However, the imports are during some crop-seasons not enough to cover the demands, emerging parallel markets, elevating the costs of the urea from 260-300 birr/ quintal to more than 550 birr/quintal, as occurred in the year 2003 (FAO, 2004). The dependence to chemical fertilizer should be decreased in order to ensure a sustainable agricultural activity in Ethiopia and therefore, the application of ecological sanitation technologies should supply natural fertilizers, not strengthen the dependency on imported chemicals. Based on the above, this secondary treatment would represent additional costs and not reliable supply, if chemical import dependant. However, due to the excellent sanitation achieved and the value as fertilizer, the use of urea should not been completely dismissed, on the contrary, deeper investigation should be carried out regarding the obtaining of urea from anthropogenic sources, e.g. urine. Fresh urine contains 0,27 ± 0,05 M urea, only little ammonia and a pH of 6.2 (Ciba-Geigy, 1977 from Rontentalp *et al.*, 2003), therefore the recovery of urea from urine could be possible by evaporating the water excess and maintaining a low pH to avoid production of ammonia. Further details regarding production of urea from urine and its possible application to dry faeces will be found in section 5.3.

COMPOSTING: the composting of the dry matter produced in the primary step could achieve the desired stabilisation of the organic material and the required pathogen destruction. The thermophilic composting relies on the heat from degrading organic matter to reach the temperature desired >50 °C for a number of days to ensure a safe reduction of pathogens (Schönning and Strenström, 2004). However, Vinnerås *et al.* (2002a) reported the disinfection by composting of faeces from desiccation toilets performed in Ethiopia and in Mexico, where no significant rise in temperature, apart from an approximately 10°C increase above the surrounding temperature, took place. The drying additive added in the form of lime or ash, had in those cases a negative effect on the composting procedure, as the concentration of organic matter decreases, leaving less energy available to increase the temperature. To achieve sufficiently high temperatures, a high-energy amendment, in the form of kitchen and garden refuse, has to be added to the material. This essential requirement should not pose a source-dilemma for the study case, since the biowaste could be obtained from the inhabitants of the area, however correct logistics of operation should be integrated to run the collection of the waste and screening process. Furthermore, due to the large amount of material to be treated, a large-scale composting will be possible, which has been identified to reach disinfection temperatures fairly easily due to its temperature stability deriving from the large mass (Strauss *et al.*, 2003; Vinnerås *et al.,* 2002a). Another critical parameter of composting identified is the oxygen requirement, which could be several times that of the substrate (Haug, 1993 from Jönsson *et al*., 2004). Different complicated designs of aeration systems for wet composting has been reported by Aalberts (1999), which require high operational costs and close monitoring. However, in dry composting the higher dry matter content makes natural ventilation possible as the thermal movement in the material gives enough oxygen if the structure is porous (Vinnerås *et al.,* 2002a). Therefore the aeration of the process could be ensured only by addition of some bulky material and regular turning (Strauss *et al.*, 2003). One of the great advantages of this process is that the monitoring does not have to be as intense as in the case of the small-scale composts, such in composting toilets. However, composting is a biological process and the more closely it is monitored and controlled, the easier it is to get a well functioning process, therefore the need of skilled labour force. Regarding the quality of the product, the compost is regarded as an excellent K, S and P fertilizer, with a great organic matter stability, which improves the water holding and the buffering capacity of the soil (Jönsson *et al.*, 2004). As thermophilic temperatures are reached, a good sanitation is obtained, however it must be ensured a homogeneous temperature in the whole pile because if low temperature zones are present, the pathogens will not be deactivated within all material and there will therefore be an increased risk for re-growth of pathogenic bacteria in the low temperature zones after thermal composting that has to be considered (Vinnerås *et al.,* 2002a). However, due to the already existing know-how and the many advantages related to this process, composting will be selected as the most suitable secondary treatment.

5.1.3.1- Considerations and design of composting treatment for the product of dry toilets

SOLID ORGANIC WASTE SOURCE: The importance of the correct ratio C:N for the microbial growth has been expressed in Appendix 7. Mixing various feedstocks of different C/N ratio allows a total control, ensuring that the high nitrogen material (green= grass, garden plants, kitchen scraps) and high carbon content material (brown= dried leaves, plants, branches and woody materials, faeces) are mixed in equal volume proportions. For the composting of dry faeces with organic waste, a C:N ratio between 20-30 : 1 gives a good aerobic degradation. According to a pilot study performed by IWMI and SANDEC (2002) in Kumasi –Ghana, a faecal sludge/solid organic waste ratio of 1:2 in volume was enough to achieve good conditions for aerobic composting. Furthermore, compare with a 1:3 ratio, the recommended 1:2 ratio allows higher amounts of treated faeces, less volume to be handle, easier mixing, low costs and less labor input, without diminishing the quality of the product obtained.

In Appendix 8 different considerations regarding the amount which is produced and the fertilizing quality of municipal solid waste proposed by IWMI and SANDEC (2002) can be found. However, an average of 170 g/p·d of organic solid waste will be assumed as the quantity produced by the inhabitants of Addis Ababa at the household level (Meinzinger, 2005).

In Appendix 9 calculations regarding the amount of household waste (HW) produced by the study population are performed, where for the period of 4 months, a total amount of 76,5 ≈ 80 m^3 was obtained. However, as the ration solid organic waste (SOW)/ dry faeces (DF) will be assumed as 1:2, the total amount of organic waste needed is 180 m^3. In order to compile the needed amount of organic waste, a total amount of 103,5 ≈ 105 m^3 of sorted market and agricultural refuse (MAW) should be collected in four months, which amounts to 6,47 m^3/week.

The compilation of the HW will require the pre-sorting of the waste at household level, meaning that active campaigns for classification of waste (organic / non organic) for the inhabitants should be carried out. Assuming that all the organic waste will be sorted, the HW to be collected every week amounts to 4,46 ≈ 5 m^3. However, as other waste could also be present, it is assumed that a total of 8 m^3 /week of pre-sorted HW will be transported to the eco-station (8m^3 =capacity of the truck).

The collection of MAW will be less consumer-dependent, however different supplier of garden, market and agricultural refuse should be contacted. For instances, an agreement with the Solid Waste Management Team, in the Environmental Health Department of Region 14 Health Bureau, should be achieved, since they are in charge of the management of solid waste in Addis Ababa (Enda Ethiopia and Preceup, 1999). This should ensure the delivery of at least 105 m^3 of potential organic refuse needed during periods of 4 months to implement the composting procedure, which means a delivery of 7 m^3/week. As not all the refuse will be suitable for the composting, it is assumed that 10 m^3/week of refuse will be received to be further sorted. It will be understood that the suppliers will deliver the MAW to the eco-station, therefore no consideration regarding logistics and transport will be made.

SOLID ORGANIC WASTE SORTING: IWMI and SANDEC (2002) reveal, based on the study performed in Kumasi-Ghana, that sorting amounts to 30 % (in average) of the operation and maintenance costs of composting process. According to their experience, the time needed as well as the amount of positive sorting (material to use in composting) obtained depend strongly on the source. For instances, the percentage of sorted waste is higher in market waste than in municipal waste, as the first is characterized by higher amounts of biodegradable. Therefore the sorting process for market waste varies between 3-9 hours per m^3. On the other hand, the sorting of municipal waste is more labor intense, requiring 16 hours per m^3.

For the matter of this study, it will be assumed that not all, but only the organic fraction of the household waste will be deliver to the eco-station. However, due to the problems that could be encountered, a sorting procedure will be performed, with an average of labor input of 10 hours/m^3. The sorting of the MAW delivered from different sources will be also performed at the eco-station, with an average of labor input of 6 hours/m^3.

The calculation of logistics and labour input of sorting can be found in Appendix 9.

It will also be assumed that the negative sorted material (the not suitable matter for composting), will be collected by the municipality to further landfilling.

COMPOSTING PILES- STARTING THE PROCESS OF COMPOSTING: it is important to understand that, if the composting system to be designed is compared to a reactor, being the OSW (organic solid waste) and dry faeces (DF) the reactants, the limiting reactant would be the OSW. The collection, delivery and storage of the DF will not affect the composting process, as the material collected from the study area could be stored in the eco-station and it is always available for the composting procedure. The availability of OSW, on the other hand, will depend on its production and delivery from its different sources, which is assumed to be weekly. Therefore it would be supposed, that a new composting system will be prepared and started every week.

The total OSW available every week will be HW= 4,46 ≈ 4,50 m^3 plus MAW= 6,47 ≈ 6,5 m^3 amounting to 11 m^3. This will mean that only 5,5 m^3 of dry faeces will be composted every week, giving a total of 16,5 m^3 of composting material.

In Appendix 7, the different composting technologies for open systems are described. For this project, the windrow type will be selected. According to the WHO guidelines, composting in 10-50 m long piles of 1,5-2 m height and 2-4 m width is recommended (Schönning and Stenström, 2004). However, due to the amount of material available, a windrow of 6,6 m long x 2,5 m wide x 1 m high= 16,5 m^3 will be used, ensuring that every week only one pile of composting will be started, which will allow close monitoring and easy handling of material.

In Appendix 7 the importance of the water content for the composting procedure is described. According to it, moisture of 40-60 percent by weight through the pile is ideal. In order to do so, water should be added by sprinkling by a hose pipe after the piles are already done. Around 55 m^3 of water should be added in the initial step to ensure the correct moisture level (50% weight). A well should be drilled in the eco-station to obtain the water for the continuous watering.

COMPOSTING PROCESS: According to the results obtained by IWMI and SANDEC (2002), the thermophilic process could last from 4-5 weeks and the maturation step from 3-4 weeks. It will be assumed that the composting process will occur in a total of 2 months (8 weeks), however the practical experience will point out the actual time according to local conditions. The compost pile has to be turned to ensure aeration and homogenisation of the temperature, ensuring that all the compost will be exposed to thermophilic conditions. The need of turning is more critical during the first stage of the process, therefore it will be recommended to turn the pile twice at week during the first 4 weeks, then once at week. Once again, the optimum turning period will be given by the experience. The moisture should be also kept optimal to ensure the correct conditions for the microorganisms growth, therefore they should be constantly irrigated, for instance at the time of turning. As 8 composting piles will be operational every month, the monitoring of each cell should be performed carefully. Therefore the important role of the manager of the system (e.g. engineer) to run the process correctly, indicating turning -watering periods, as well as monitoring the variable of the process to apply contingency plans.

5.1.3.2-Quantity of the compost

The reduction achieved during the composting has been cited by many authors (Vinnerås *et al.,* 2002a; Jönsson *et al.*, 2004; IWMI and SANDEC, 2002; among other). According to the results obtained by IWMI and SANDEC (2002), a raw estimation of 50% volume and 30% weight reduction can be assumed through the application of thermophilic composting. The 60 tonnes of soil and lime that is present due to the primary process are not going to be degraded. Therefore the reduction percentage is only going to be applied in the solid organic waste and the faeces. In Appendix 9, the calculation of final volume and weight of the compost are performed for every 4 months and monthly, obtained a total production of 26325 kg of fine compost to sell every month.

5.1.3.3-Quality of the compost

As expressed in section 5.1.2.3 the dehydration procedure carried out as primary treatment will ensure a good sanitation, due to the high pH provided by the addition of lime. If the primary process is well monitored and all the measures are followed, it is estimated that the dry faeces collected after 8 months will present a low concentration of coliforms and pathogenic microorganisms. However, from the sanitation point of view, the presence of *Ascaris* could still poses a risk, since high temperatures are needed to achieve total deactivation of such pathogens. As the composting process will be performed in a large scale (16 m^3), ensuring sufficient moisture and carbon source, it can be assumed that every composting pile will have enough stability and good conditions to ensure thermophilic composting, reaching temperatures of 55 °C. A good operation of the aerobic composting should be able to kill all pathogenic microbes, weeds and seeds if the temperatures are maintained > 55°C for a 24 hours period (Strauss *et al.*, 2003). According to studies performed by Scott in 1952, a complete Ascaris eggs die-off can be achieved in 7 weeks, however >95% die-off can be achieved within little more than 3 weeks already (Strauss *et al.*, 2003).

Regarding the nutrient composition, in table 5.3 a lists of data shows the percentage of some nutrients in compost using raw material including human waste. As it can be seen, the composition of nitrogen is low compared with other compost made from such material as organic municipal refuse, woodchips, sawdust, etc., even though that human faeces originally content more nutrients that those listed before. The reason for composts produced from human waste not exhibiting higher nutrient value contents than other composts might be due to nitrogen losses, as ammonia, during the storage, pre-treatment and treatment. However, the compost can be regarded as an excellent K, S and P fertilizer, with a great organic matter stability, which improves the water holding and the buffering capacity of the soil (Jönsson *et al.*, 2004). Furthermore, the Composting Council in 2000 summarises the benefits of compost as follows (Strauss *et al.*, 2003).:

- ✓ Improves soil structure, porosity and density, thus creating a better plant root environment.
- ✓ Increases infiltration and permeability of heavy soils, thus reducing erosion and runoff.

✓ Improves water holding capacity, thus reducing water loss and leaching in sandy soils.
✓ Supplies a variety of macro and micronutrients.
✓ May control or suppress certain soil borne plant pathogens.
✓ Supplies significant quantities of organic matter.
✓ Improves cation exchange capacities of soils and growing media thus improving their ability to hold nutrients for plant use.
✓ Supplies beneficial microorganisms to soil and growing media.
✓ Improves and stabilises soil pH.
✓ Can bind and degrade specific pollutants.

Constituent	% Dry Wet	Reference
Nitrogen (as N)	1,3 - 1,6	Shuval *et al.* (1981)
	1,3	Obeng and Wright (1987)
	0,35 - 0,63	Kim, S.S. (1981)
	0,45	Byrde (2001)
Phosphorus (as P2O5)	0,6 - 0,7	Shuval *et al.* (1981)
	0,9	Obeng and Wright (1987)
Potassium (as K2O)	-	Shuval *et al.* (1981)
	1,0	Obeng and Wright (1987)
Organic Matter (%TVS)	12 - 30	Kim, S.S. (1981)
Carbon (C)	46 - 50	Shuval *et al.* (1981)
	13	Byrde (2001)

Table 5.3- Nutrient level in compost for which human waste was one of the raw materials (from Strauss *et al*., 2003)

5.1.4- <u>Management and Logistics analysis</u>

MANAGEMENT OF THE SANITATION SYSTEM: The management of the sanitation will be performed by a cooperative or small enterprise which will carry out all the activities regarding the primary and the secondary steps as well as the contacting the agricultural farms in order to market and distribute the compost produced. According to the calculations performed in Appendixes 6 and 9, a total of 10 new employments will be created in order to run the faecal sanitation procedure: an engineer who will manage together with a secretary and a technician all the matters regarding the logistics of the process, and 7 workers, who will perform the activities. It is expected that the first year of running must be monitored by engineers (e.g. GTZ), who can share the know-how with locals. Later, the process can be run by locals themselves. Further details regarding activities to be performed, as well as labour input needed can be found in Appendixes 6 and 9 (tables A.10 and A.17).

ECO-STATION: All the activities will be carried out at an eco-station, which should be located in the suburbs of Addis Ababa. With a total area of 750 m^2, it will be equipped with:
✓ Area for the storage, mixing and packing of the drying agent (soil and lime) which should be large enough to hold the material at least for 2 weeks in case of setbacks. Since the material should be dry enough to perform the dehydration procedure at the source point, it is recommended to roof the area avoiding extra watering during the raining season.
✓ Area for the unloading and storage of dry faeces, which should be able to hold 90 m^3 of dry faeces every four months. This area should be also roofed.

✓ Solid waste delivery, unload and handling area, which will be large enough to contain the weekly load of 8 m^3 of HW plus 10 m^3 of MAW. Due to the high rains during the raining season the intrusion of water should also be avoided by roofing the area.
✓ Composting area, where 8 windrows of compost will be permanently in operation. It also must be roofed.
✓ Loading of compost.

The calculation of the area needed is performed assuming that piles of at least of 1 m will be ensured.

Table 5.3- Estimation of the area needed for the building of the eco-station Scenario A

Unit	Storage capacity needed		Area needed (m^2)
Drying material storage	m^3/week	16	36
Dry faeces storage	m^3/4 month	90	90
SOW reception / sorting	m^3/week	18	25
Composting Area	m^3/week	24	255
Compost storage	m^3/week	16	25
Total area			750

The following figure shows the possible design of the eco-station in scenario A

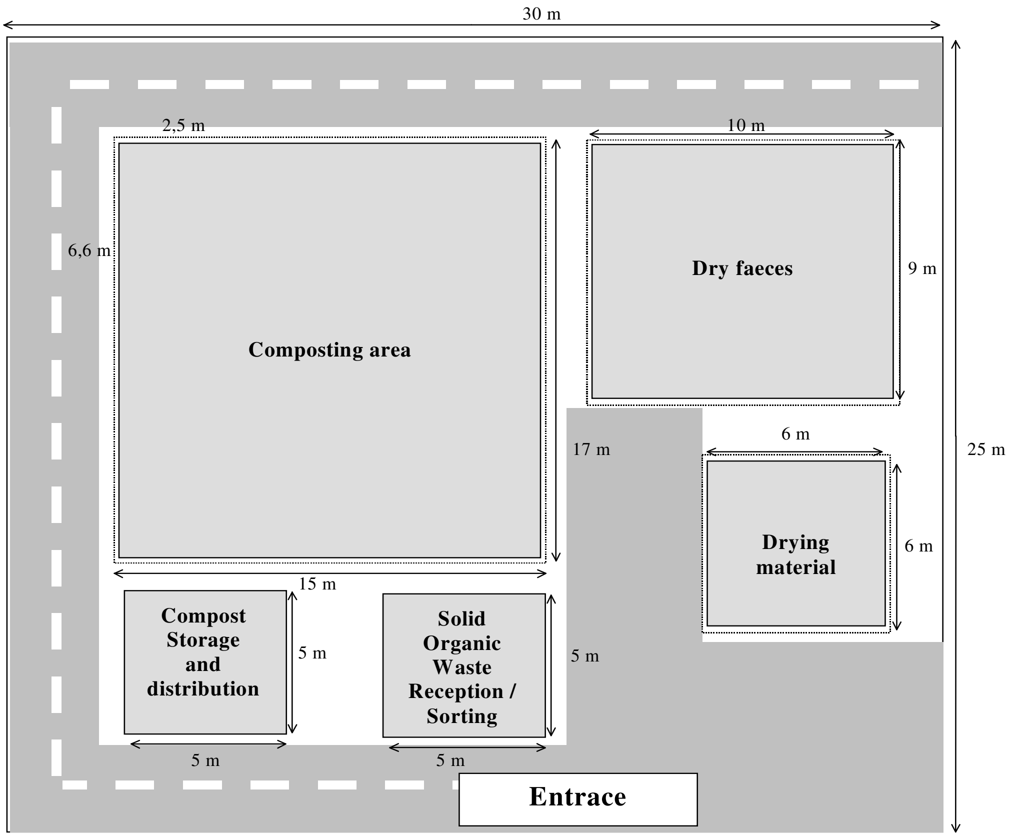


Fig 5.4- Eco-station of Scenario A

5.2- Scenario B: Low flush toilets with urine separation.

5.2.1-<u>Description of the system to be used</u>

As stated by Meinzinger and Otterpohl (2005), pour flush toilets with urine separation will be implemented in buildings with more than 4 storeys, where the construction of dry toilets is not possible. To allow comparison with the dry technology, the assessment of this technology will be performed to the 2000 inhabitants.

The toilets will be equipped with a low flush system to avoid high dilutions of the faeces, with a maximum flushing volume of 3 l per flush. Urine should not be mixed with water in order to allow its further treatment and economical transportation, therefore the toilet bowl should provide for urine separation meaning, like a separate opening and drainage pipe in front of the toilet bowl.

The toilets will be located outside of the apartments, due to cultural and technical reasons. Made of porcelain, ceramic or other available fabrication material, the toilets could be installed as squatting or sitting, depending on the future use (public or private). An important part of the system will be constituted by the pipelines, which will transport the brown water to the treatment unit. However it will strongly depend on the type of primary treatment to be used, especially whether it will be performed inside the buildings or outside. The transportation systems available are:

✓ Conventional sewers -gravity-flow-

In the conventional sewer system, the municipal wastewater is discharge directly for treatment and disposal by means of gravity, achieved by a natural slope in the topography or extended excavation work to lay the pipes. Normally, the pipes have diameters in the range of 150 to 600 mm and the depths can reach 0.5 to 8 meters. Due to the well documentation already existing on the application and performance of this gravity flow system, it is broadly accepted (Metcalf & Eddy, 1991).

✓ Small bore sewer system -SBSS-

This system is particularly useful in areas where deep-excavation is costly, since it allows the pipe to exchange slopes between positive and negative ones at a variable grades, unlike conventional sewers, which must continuously slope downward. According to Metcalf and Eddy (1991), the basics of this concept is that if one of the sewers is installed with a net positive slope from the inlet to the outlet, wastewater put in at an upper end will eventually exit from the lower end. The Small bored sewer system is used for flows with a low solids content, to avoid the clogging of the small diameter of the pipes.

5.2.2-<u>Options for treatment of product from low flush toilets for the study area</u>

In Table 2.1 the different methods to be applied as primary treatment of flush toilets products are described. The following table shows the evaluation of the applicability of the different treatment of low flush toilet products for the inner areas of Arat Kilo and Pizza and following an analysis of the assessment can be found.

Table 5.4- Evaluation of suitability of flush sanitation technologies based on technical indicators.

Technical Indicators	Pre-composting tank	Rottenbehälter/ Vermicomposting	Anaerobic digestion
Robustness	2	2	3
Professional Expertise needed	3	1	1
Labour input needed	1	3	1
Availability of Agents	3	3	2
Ease of handling of product	1	3	1
Quantity of product	1	3	2
Space required	2	3	2
Fertilizer quality of the product	1	3	2
Sanitation obtained	1	3	2
Experience	1	1	1
TOTAL	**16**	**25**	**17**

Pre-composting tanks (Rottenbehälter): this is a relatively new technology, which has been applied in rural areas of Germany, Austria and Switzerland with success and acceptance of end-users to replace the septic tanks or the connection to central sewer systems. It is based on the liquid-solid separation, where the units retain the excreta and filter the water, which is further treated in close to nature systems (e.g. wetlands) and discharge into the watercourses. The installation of the system, composed of an underground tank made up of monolithically concrete slab and two filter beds at its bottom or two filter bags that are hung side by side, could be an option for the Arat Kilo and Piazza areas in Addis Ababa. It has shown to be operable by the end-users, who use one of the two valves for a period of 6-12 months and exchange to the other, leaving the first one to pre-compost and dewater for the same period. System for 4 to 40 persons have been already installed giving a sanitation solution and offering a nutrient-rich matter, which could be further composted with kitchen and garden refuse and used as soil conditioner (Garujel et al, 2002). According to Garujel *et al.* (2002) the solid material in the inactive bag contains however a high percentage of water (79-88%) and the temperature reached during the collection and idle periods were below to 20°C (even less than ambient temperature), indicating the low sanitation obtained through this process. With such conditions, unable of inactivate pathogens, the risk of transmission of diseases is huge (particularly during the handling and transportation of the material), considering that the management of such amount of humid excreta produced by 2000 people would require excessive maintenance and care by the workers, who are not used to this technology. Furthermore, the filtrate will still need to be treated in wetlands, as it has been done in Europe, but due to the lack of space in the inner city areas of Arat Kilo and Piazza, this condition might not be achieved. It could be treated together with the grey water in the trickling filters, but this addition will increase the organic and nutrient load to the wastewater system, due to the high nutrient washout that comes from the long exposure of the filter cake of faeces with the flushing water (Vinnerås and Jönsson, 2003). This condition, on the other hand, makes the faecal matter a partly degradated material with already too high percentage of lost nutrients, reducing the fertilizing quality of the product. The high moisture content can indeed induce anaerobic degradation, posing a risk of odour nuisance or even explosion and it will also pose problems for the further aerobic composting, due to the excess of water. Finally, the lost of the water head due to the flow through the pre-composting tank, makes the use of sucking pumps a need of the process, incrementing the investment and operation costs. Therefore, this technology is not going to be selected for the scenario B.

Vermicomposting/Rottenbehälter: one of the main concerns regarding the application of Rottenbehälter alone, is the health risk posed by the handling of humid faecal material from the point of generation to the eco-station, where it would be further composted. One solution of this problem would be the application of earthworms, which breakdown the organic material, in order to activate the idle phase into a real composting, instead of a simple pre-composting stage. Vermicomposting has shown to convert the faecal material into a moist earth-like material over a 3 months period without any additives. One or two further months will produce an excellent humus provided it will not become too dry (Buest *et al.,* 2004). By using earthworms species such as *Eisenia fetida* and *Eisenia andrei* the sanitation missing link is giving to the pre-composting tank, since these earthworms derive their nourishment form microorganisms that grow upon the organic materials. At the same time, they promote further microbial activity in the residuals so that the faecal matters that they produce, is much more fragmented and microbial active than what the earthworms consume. During this process, the important plant nutrients in the organic material-particularly nitrogen, potassium and calcium are released and converted through the microbial action into forms that are much more soluble and available to plants than those in the parent compounds (Buest *et al.,* 2004). The application of the vermin culture still does not solve other problems associated to the use of rottenbehälter, which is for instance the washout of nutrients and pathogens in the filtrate, which needs to be further treated. However, the production on-site of a high quality earth-type humus would eliminate the need of a secondary treatment and therefore the transport to an eco-station, which must be built and managed. It is then a decision between high skilled needed operation, related to the maintenance of the Vermicomposting system and further investments related to secondary treatments. There is still a concern regarding the robustness of the system, due to the intricate handling of the filled filter bags and the special treatment that the vermin culture needs, regarding maintenance and harvesting of compost and worms, however, providing professional expertise and a extended extension program for workers, this technology could be implemented in Arat Kilo and Piazza areas of Addis Ababa.

Anaerobic digestion: The application of anaerobic digesters was introduced in Ethiopia about 6 years ago for the fermentation of animal dung and also household effluent. Institutions like SELAM Technical and Vocational Center, Zerom Biogas and GTZ have been involved in the installation and training for further operation of digesters in many parts of the country (Meinzinger and Otterpohl, 2004). However, this already gained expertise relates to rural area, with only little experience in Addis Ababa, thus the application of inner city areas as Arat Kilo and Piazza, might present some technical and logistic problems. It is in any case essential, to point out the numerous benefits of this technology, reason why in Appendix 11 some calculations are presented in order to illustrate the potentials of this biogas digester in the city areas of Addis Ababa. With the installation of one digester of different capacities (10-106 m^3) for each building, the primary treatment of 12,5 m^3/d of brown water can be achieved, providing 30 day of retention time. The installation represents low capital costs (around 500 Birr / m^3, data from Kellner (2001)), as it could be adapted to the local situation, and indigenous materials could be used for it construction. Examples are founded in China, where local made bricks have been used traditionally (Van Buren, 1979). Furthermore, according to GTZ and ISAT (year not specified a), a well functioning biogas system could also bring economical benefits by the production of energy rich methane, the production of high quality fertilizer, import substitution and environmental protection. For instance, the setting up of the 8 biogas plants with a total capacity of 486 m^3, would mean the production of 36 m^3/d of biogas with 76% of methane, assuming a production of 60 l of biogas / kg of fresh excreta similar to those of pig manure (GTZ and ISAT, year not specified b). The biogas produced could be used for cooking in the communal areas, however, according to pre studies performed by Meinzinger and Otterpohl (2004), there might be some problems regarding the acceptance of using the methane for cooking, but due to the versatility of the product, it could also be used for lighting or as source of energy of many electrical equipments. Assuming a mass reduction of 2% of the incoming substrate, the production of 12 ton/d of liquid fertilizer is achieved, which due to the decomposition and breakdown of parts of its organic content, provides fast-acting nutrients that easily enter into the soil solution, thus becoming immediately available to the plants, making the digested sludge in a rich fertilizer. However, due to the huge amount produced, further dewatering will be needed in order to make the transportation economically viable. Regarding the sanitation achieved, Van Buren (1979) through his experience in China, expressed that after fermentation the slurry contained 95% fewer parasite eggs, and a 99% reduction of *schistomose* eggs and young hookworms. However, more current guidelines recommend the post composting of the sludge in order to achieve high temperature to destroy those pathogens and parasites that have survived the anaerobic digestion treatment (GTZ and ISAT, year not specified b). Unfortunately, the efficiency of the biogas digestor during the cold seasons of Addis Ababa still has to be evaluated. Furthermore, the management and monitoring of the system in urban areas for 2000 people will require the presence and careful control of high skilled personal and an extended training program, in order to achieve not only the necessary know-how but also the understanding and the sense of property among the users in order to diminish the risks associated to the production of methane. The management of such large amounts of sludge in the city area, the needed further composting treatment and the lack of know-how, make the application of biogas a not viable option under the current situation. Once the technical and social problems are overcome, the biogas production will bring lots of benefits to the community.

5.2.2.1- Considerations and design of Rottenbehälter/Vermicomposting as treatment.

It was assumed a water use of 6 l/p·d, in case of double flushing or two times visiting per day. Assuming a 85% moisture content (Garujel *et al.,* 2002), the water retention in the faecal cake was also calculated, obtaining less filtrate. Using a system composed by two sacks of volume 3,125 m^3 (1,25 x 1,25 x 2), a period of 6 months for the collection and idle phase is achieved, arriving a total number of units of 52, using security factor. Since, the Vermicomposting does not need extra substrate, further considerations of volume requirements are not needed. The container in which the two filter sacks are to be hung should be 2,0 x 2,0 x 3,0 m.

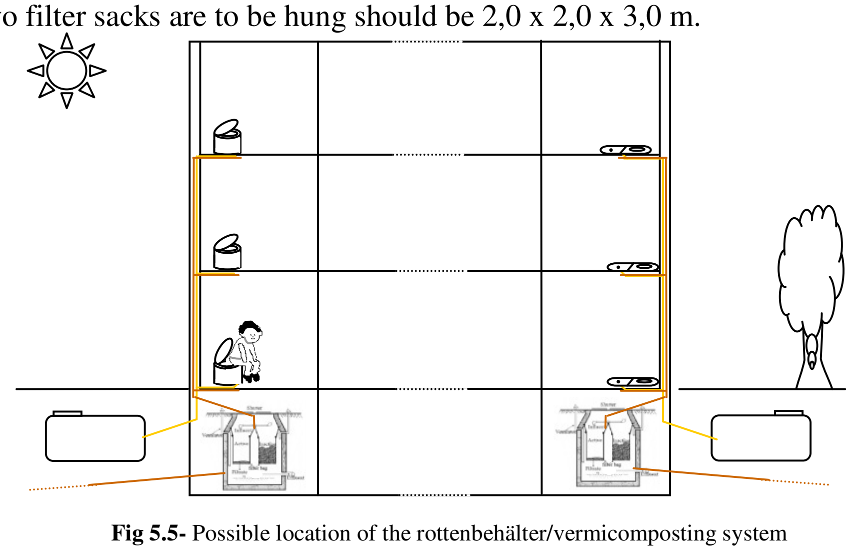


Fig 5.5- Possible location of the rottenbehälter/vermicomposting system

Even though the final design of the building is not defined, the following figure can give an idea of how the units could be distributed in the buildings. In order to make use of the gravity force, the different effluents of the household could be conveyed to one unit, however, due to the dependence of the design to the real plan, only an estimation can be given.

FILTRATED EFFLUENT: The effluent from the Rottenbehälter is to be transported with small bore sewers to the treatment unit, which is recommended to be performed with the grey water in trickling filters, due to the lack of space for the installation of wetlands. According to the results presented in Appendix 10, a total flow of 10,49 ≈ 12 m^3 of filtrate must be then treated in the trickling filters, which construction and design is not within the scope of this project. However, it must be provided a high BOD removal and sanitation achieved, due to the leachate of nutrients and pathogens into to the water.

MAINTENANCE (from NIIR, 2005): The various species of earthworms have different environmental requirements, which are necessary for their propagation and continued health. These requirements will inevitably dictate whether one particular "family" of worms will be suitable for culture in any given circumstance. For instance, the two most commonly-used worms for Vermicomposting, *Eisenia foetida* and *Lumbricus rubellus*, are the most popular precisely because of the ease in replicating the environmental conditions they prefer. Perfectly suited to an indoor existence, the culturing of these animals presents next to no problem, requiring only a minimum of effort, and presenting no hardship for those who share their place of residence. The fact is, in the absence of the normal hazards these worms usually face in their outdoor habitats, they are found to grow faster, stay healthier, live longer, and reproduce at an increased rate indoors. Thus, indoor culture turns out to be heaven for them, and a great benefit to the "Iandlord" who will have a great new way to convert his organic waste materials into good compost. These requirements can be broken into three main areas, which are presented in the following paragraphs. (It is assumed that the worms in question have already been housed in an adequate bedding material, and are being supplied with a sufficient quantity of food.).

✓ Aeration: Compost piles should allow plenty of air into them. This is usually accomplished by using some kind of "bulky" ingredients (such as straw, old weeds, etc.) or by turning to get more air into the pile. Worms need to breath, just like most other living creatures. The process of osmosis makes a worm rather different than those with lungs, but the end result is pretty much the same. In addition to this, the decreasing amount of fresh oxygen can result in an increase in heat, and the increase in heat will result in a similar rise in the oxygen requirements of the worm. Fortunately, the whole situation is easily rectified, and only requires very infrequent attention. About once every two or three weeks, the top few inches of the bedding should be gently stirred, allowing for the escape of any built-up gases. This will also go a long way toward preventing the bedding from becoming too densely packed. The lower levels of the bedding can also be stirred, but on a far less frequent basis.

✓ Moisture Content: The sack contents should be kept moist but not soaked. It has to be taken into account that the earthworm is actually a creature of the water, and therefore it is not hard to accept that moisture constitutes the most urgent of its requirements for life. As in most things in life, a suitable balance must be found and maintained for optimum performance, keeping in mind that this balance may have to be altered to accommodate specific needs. Excess water can lead to anaerobic conditions.

✓ Temperature: Temperature requirement for optimal results is 20-30° C. However, survival of earthworms is even at lower temperatures and up to 48° C air temperature. The most suitable temperature range for *Eisenia foetida* and *Lumbricus rubellus* have been shown to fall between 13 - 22°C, a range, which is also quite convenient for the city areas of Arat Kilo and Piazza. Temperatures which fall outside this range can affect the worms in several different ways, not all of which are as final as death.

HARVESTING THE COMPOST AND WORMS: After 6 months of Vermicomposting, the compost should be ready and the worms should be recovered for further use. There are three basic ways to separates the worms from the finished compost. One way involves moving the finished compost and worms over to one side of the bin and adding new bedding material and food waste to the other side. Worms in the finished compost should move over to the few bedding with the fresh food waste. The finished compost can then be removed. A second way to remove the worms is to build a small harvester frame of mesh bottom. Placing the worm compost on the frame will allow to sift the worms out. Larger pieces of compost can be returned to a new batch of bedding and worms. The compost also can be placed in small piles on a trap in the sun (or under bright lights inside). Because worms don't like light, they will wiggle to the bottoms of the piles. After waiting 10 minutes, the upper inch or more of finished compost from each pile could be removed until the worms are reached, allowing the worms to again wiggle to the bottom of the pile and repeat the process. Eventually one might end up with a pile of finished compost and a bal of worms. The worms can be added back to a new bin of waste (NIIR, 2005).

TRANSPORTATION OF COMPOST: The transfilling of the compost to the tipper truck (supposed capacity 8 m^3) is estimated to be performed by showing. As in the scenario A, it is recommended the construction of a ramp from the basement to the ground level to facilitate the transport of the compost in wheelbarrows. Since the transportation will be needed only twice a year, the rent of a truck instead of acquisition will be suggested. Assuming a volume reduction of 30%, the total amount of the compost produced every 6 months will be ≈ 102 m^3, which will be transported in 13 trips to the agricultural field.

5.2.2.2-Quantity of the compost

The total production of compost is presented in Appendix 10, table A.19, giving a total amount of 102 m^3 every 6 months.

5.2.2.3-Quality of the compost

The compost produced by earthworms species such as *Eisenia fetida* and *Eisenia andrei* is of great sanitation quality, since these earthworms derive their nourishment form microorganisms that grow upon the organic materials. At the same time, they promote further microbial activity in the residuals so that the faecal matters that they produce, is much more fragmented and microbial active than what the earthworms consume. During this process, the important plant nutrients in the organic material-particularly nitrogen, potassium and calcium are released and converted through the microbial action into forms that are much more soluble and available to plants than those in the parent compounds (Buest *et al.,* 2004). Problems regarding the acceptance of this fertilizer could be encountered, due to the low experience of this technology achieved in Ethiopia.

5.2.3- Management and Logistics analysis

The management of the sanitation will be performed as in scenario A by a cooperative or small enterprise which will carry out all the activities regarding the maintenance of the

Vermicomposting cultures, as well as the contacting the agricultural farms in order to market and distribute the compost produced. According to the calculations performed in Appendix 10, a total of 10 new employments will be created in order to run the faecal sanitation procedure: an engineer who will manage together with a secretary and a technician all the matters regarding the logistics of the process, and 7 workers, who will perform the activities. It is expected that the first year of running must be monitored by engineers (e.g. GTZ), who can share the know-how with locals. Later, the process can be run by locals themselves. Further details regarding activities to be performed, as well as labour input needed, can be found in Appendix 11.

5.3- Management of urine

According to the previous studies, it is recommended to separate urine in order to recover in an effective way the nutrients present in it, avoiding the contact with faeces, which pose the biggest amount of pathogens. In table 2.1, different primary treatments of urine are shown, including storage at ambient conditions, pressurised tanks with increase of pH or temperature. Due to the high scale of the project, providing sanitation to an estimate of 2000 people, simple storage is going to be selected, allowing transporting it to the agricultural fields to be used as fertilizer.

In section 2.5.2 a presentation of different secondary treatments of urine are found, which aim to reduce the volume of the urine to make the transportation more economical, to stabilise the urine or to produce solid fertilizer. All these techniques are still in laboratory scale, and do not provide a feasible option for the management of human waste in Ethiopia. The following table shows the evaluation of the applicability of three selected methodologies that could be feasible for the inner areas of Arat Kilo and Pizza and following an analysis of the assessment can be found.

Table 5.5- Evaluation of suitability of technologies for volume reduction of urine based on technical indicators.

Technical Indicators	**Solar dehydration**	**Thermal Volume reduction**	**Further storage**
Robustness	1	1	3
Professional Expertise needed	1	1	3
Labour input needed	1	2	2
Availability of Agents	2	1	3
Ease of handling of product	3	3	1
Quantity of product	3	3	1
Space required	1	3	2
Fertilizer quality of the product	3	3	3
Sanitation obtained	3	3	3
Experience	1	1	3
TOTAL	**19**	**21**	**24**

SOLAR DEHYDRATION: The decrease of volume by means of solar heating has been used in a practical experience in a medium sized city in Mail called Koulikoro (Bark *et al*., 2003). According to the authors, within two days each litre of liquid can be transformed into around 9 grams of powder. However with an estimated amount of 21 m^3 of urine produced every week in the study area, a total surface of 2100 m^2 will be needed to expose a layer of 10 cm of urine to the sun, if the collection time will be assumed as 7 days. If the labour intense is increased in such a way that the collection of urine is decreased to 3 days, a total area of 891 m^2 has to be provided within the urban city parts. The lack of space is only one of the reasons that compromises the feasibility of this option, taking into account that during the raining seasons intense showers cover Addis Ababa, thus plastic covers must be provided to the needed surface to avoid water intrusion. Furthermore, it has been also reported that during the months June-September, a low sunshine of 3 hours per day can be encountered. Therefore the sun drying of urine does not represent an option for the study case.

THERMAL REDUCTION OF VOLUME: The dewatering by means of evaporation described by Mayer (2002), Maurer *et al.* (2002) and Niederste-Hollenberg *et al.* (2003) must also be considered as an option to reduce the volume of the urine. The installation of a vapour condensation evaporation plant, is considered a too sophisticated technology for the management of the aprox. 3 m^3/d of urine to be produced, however the low energy requirement of 34 MJ/kg_N to reduce the volume of urine in 90%, makes this technology a very promising method for the future. If a simple batch distillation is planned, the energy requirement of 389 MJ/kg_N jeopardises the feasibility of the solution. Assuming a concentration of nitrogen of 4,13 g/l (derived in chapter 4.3) and a production of 3 m^3/d of urine, 4820 MJ/d are needed to reduce the volume by the fold of 10. Even though the thermal reduction of volume of urine could be a feasible option, specially if the energy is provided, for instances, by a biogas plant, it won't be considered as possible in the short-middle term for the study area.

FURTHER STORAGE: a more reasonable option would be to collect the urine by means of a suction truck after a certain period and transport it to the agricultural field, where it could be further stored according to international recommendations. A general description, together with the definition of the different components of separate management of urine is discussed as follow.

5.3.1-<u>Considerations for the proposed urine management system:</u>

After excreted, the urine passes through a separate pipe system to a holding tank, which is connected to one or more households. The urine is collected and removed by a tank truck or suction truck, which can be driven by the farmer, who uses the urine as fertilizer, or by the cooperative or small size enterprises who will also run the faeces management. Such transports consume energy, and it is obviously an advantage if the distance between the inner city areas Arat Kilo and Piazza and the place where the fertilizer is applied is short. Since urine must be stored separately to ensure that it is sanitized before being applied, storage tanks will often be needed near the farmland where the fertilizer will be used. They can also function as a convenient store of fertilizer for the farmer.

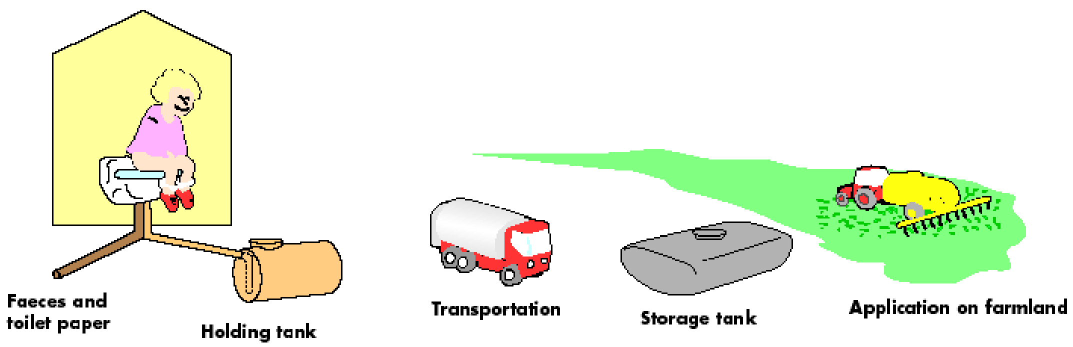


Fig 5.6- Diagram illustrating a urine separation system from toilet to field. (Johansson *et al.*, 1997)

TOILET TECHNOLOGY: The technological options existing for urine diversion and collection include many different designs of urinals and toilets connected to a holding container via pipe or channel. Urine diversion toilets come in many forms: squatting plate, seated pedestal, and urine diverting toilet insert. Urinals are recommended since they offer a standing convenience for men while urinating. For women and girls, squatting urinals are preferred for public toilets (GTZ, 2005a). Urine-separating toilets differ from ordinary toilets in that they have two bowls, a front bowl for urine and a rear bowl for faeces and toilet paper (see Fig. 5.6). The size and design of the bowls and the flushing technique vary from one model to another (Johansson et al., 1997). Toilet and urinal designs are available as water flushing and waterless systems. Flush systems collect urine in diluted form, requiring larger piping and storage, and possibly treatment and transport, components. Waterless systems collect undiluted urine and require smaller piping and storage capacity. Toilets and urinals are typically constructed of ceramic, concrete, fibreglass or plastic.

Fig 5.7- Urine-separating units: on the left, the Dubbletten from BB Innovation & Co AB, on the center, the DS toilet from Wost Man Ecology AB (Johannson *et al*., 1997) and on the right an urine diversion squatting pan used in China (GTZ, 2005a)

PIPE SYSTEM: the urine passes through a separate pipe system to a holding tank. Studies have demonstrated that metals used in toilet seals and pipes react, in particular, with the phosphates in the urine (Johansson *et al.,* 1997), therefore, no metals should be used for the pipes and installations. According to GTZ (2005a) drain pipes and tubing are preferably made of durable plastics such as polyethylene. The transport of urine without the use of water poses problems related to crystallisation and blockage of the pipe. Johansson *et al.* (1997), in inspections at the sanitation systems of the Swedish towns Understenshöjden and Palsternackan, founded that where the pipes were laid at a sufficient inclination (at least 1%) and the diameter was large (110 mm) the amount of sludge that had formed on the bottom was negligible after 2-2.5 years of operation. There were no indications of future problems. Where, however, the inclination was less than 1%, or there were backfalls, or the inclination was sufficient but the diameter of the pipes too small (50 mm), heavy, viscous sludge formed on the bottom, and this was considered likely to present future problems for the flow. For the constructions of the pipe system of the Arat Kilo and Piazza inner city areas, the following recommendation made by Johansson *et al.* (1997) should be followed:

✓ The urine pipes must not be ventilated (due to the risk of odour and ammonia losses) and must be made completely watertight by means of welded joints or equivalent.

✓ The pipes should be laid at an inclination of at least 1% and should be at least 75 mm (preferably 110 mm) in diameter. Backfalls in the pipes can cause stoppages.
✓ The pipes and tanks should not contain metals or harmful substances that may be released or react with the urine.
✓ The pipe system should be designed in such a way as to facilitate inspection and cleaning.
✓ The pipes can be flushed as necessary at normal water pressure or by jet cleaning.

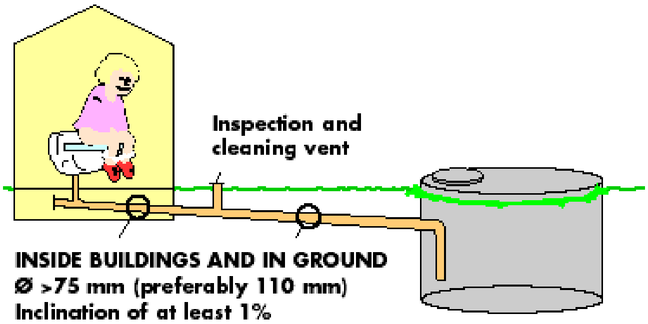


Fig 5.8- Recommendations concerning inclination and dimensions of pipes (Johansson *et al.*,1997).

HOLDING TANKS**:** in large-scale urine separation systems the urine mixture is collected from all the households and diverted into one or more tanks. The number of tanks and the way they are connected varies. Either all the urine collected is diverted to one or more central tanks, or it is collected in smaller local tanks with shorter pipe systems. The latter system reduces the risk of groundwater leaking into the pipes and of the urine solution leaking out (Johansson *et al*., 1997).

The tanks are of fibreglass plastic or other plastic material, preferably Polyethylene. The volume of the containers will depend on the collection period expected to be performed by the vacuum truck of capacity $8m^3$. Experiences in Sweden have shown that the use of 30-40 m^3 has been successful providing collection periods of once a year. However it would be recommended the installation of one tank for each building with the capacity of storing urine for two months. Taking a security factor of 20%, the volume of the tanks will range from 5 to 47 m^3 (see Appendix 12). The manhole of the holding tank should be located close to the incoming urine pipe, so that it is easy to inspect the pipe. The tanks should be filled from the bottom, which will be the case if the incoming pipe is bent towards the bottom of the tank (see Fig 5.8). If containers of great capacity cannot be constructed, several tanks placed in parallel, and not serially connected, should be constructed, so that they can be filled alternately.

TRANSFILLING AND TRANSPORTING: A thin layer is formed of particulate-rich bottom sludge with high levels of nitrogen, phosphorus, calcium, magnesium etc., but this is not likely to affect the emptying of the tanks. A vacuum truck of $8m^3$ of capacity will be used every two months to empty the holding tanks. In Appendix 12 is calculated that a total number of 27 trips are needed in order to transport the $180m^3$ of urine produced every 2 months.

STORAGE TANKS AND AGRICULTURAL USE: Prior starting of the sanitation system, agreements with the future users should be made in order to define the needs of the particular crops in the near areas to Addis Ababa. This will be important to decide the size of the storage containers.

As a rule of thumb, the urine of one person per day (1,5 l) could be used to fertilize $1m^2$ of crops. According to Jönsson *et al.* (2004), the local recommendations for the use of urine in cultivation should be used, but if no data is available the application rate of commercial mineral fertilizer (urea and ammonium) should be followed in order to calculate the use of urine. In 1997, the yield after a dose of about 100 kg of nitrogen/ha in the form of human urine was 80% of that following a dose of 90 kg of mineral fertilizer nitrogen per hectare with ammonia losses amounting to 5.9% (20 tonnes/ ha) (Johansson *et al.,* 1997). Therefore 1,45 kg of nitrogen from human urine is equivalent to 1 kg of mineral fertilizer.

If local recommendations are not available, another way of calculation could be to estimate the amounts of nutrients removed by the crop. According to FAO/WFP (2004), cereals are the most important crops in the surroundings of Addis Ababa, with a total area of plantations of 10 400 ha. Of the 19000 tonnes of cereals produced, 56% is wheat (10640 tonnes) and 30% teff. The Swedish Food Authority published a list of the removal per metric ton of harvested edible fraction, from which the relevant crops for the study case were selected and listed in table 5.6 (these amounts should be multiplied by the estimated harvest to get the amounts of plant nutrients removed).

Table 5.6- Amounts of N, P and K (kg/ha) removed per metric ton of harvested edible fraction for selected crops (Swedish Food Authority, from Jönsson *et al*, 2004)

	Crop Amount kg/ha	**N kg/ha**	**P kg/ha**	**K kg/ha**
Cereals				
Maize, dry	1000	15,1	2,1	2,9
Maize, fresh	1000	6,2	1,1	2,9
Wheat	1000	14	3,6	3,8
Sorghum	1000	15,5	3,6	3,8

Assuming that all the urine produced in the study area is recovered, a production of app. 1100 m^3/y of urine will generate a total of 7040 kg of nitrogen fertilizer (concentration in Ethiopia =6,4 g_N/l). If it is understood that only wheat producers will be contacted, and that the urine will be only used for the production of this cereal, a total of 50 hectares can be fertilized.

For the matter of this project it will be assumed that two farmer sites of a surface of 25 ha each will be using the total production of urine at year (1100 m^3/y).

There are many options regarding the type of storage container that could be used. According to Johansson *et al.* (1997) the selected option to storage urine in a agricultural site in Lake Bornsjön–Sweden, was to use “balloon tanks” made out of rubber, which are airtight, require little construction work, are reasonably priced and minimize nitrogen losses during storage. If necessary, they can also be moved.

Fig 5.9- Storage of human urine at Lake Bornsjön (Johannson *et al*, 1997)

It is recommended to install two tanks with a capacity of 180 m^3 in each field site (A and C in field 1; and B and D in field 2), rather than one large, in order to allow separate storage of sanitised and non-sanitised urine. Every two months one storage tank will be filled, starting with tank A in field 1 in month 2, followed in month 4 by tank B in field 2. In month 8, when tank D is going to be filled, the urine contained in tank A could be applied into the field, since 6 months of storage have been achieved and therefore sufficient time for sanitation at 20 °C is given.

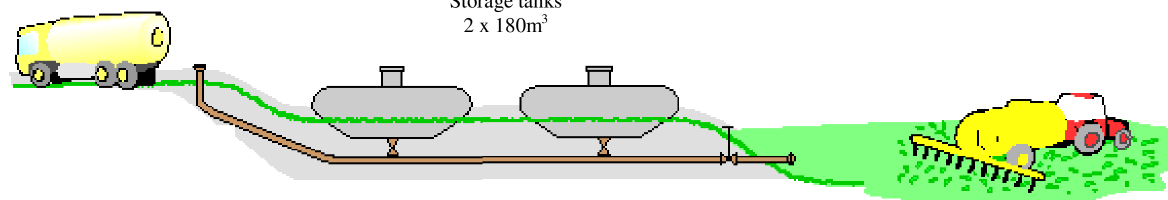


Fig 5.10- Proposed storage and application in agricultural field (from Johansson *et al.,* 1997)

5.3.3.3-**Quantity and quality of the urine**

In order o collect urine as much as possible, it is important that residents know how to use the toilets properly and that they are satisfied with the system. If not, there is a greater risk that they will not bother to separate the urine and that the separation system eventually will be replaced by a conventional system. If the system is used in a correct way, app. 1100 m^3/y of urine with a total of 7040 kg of nitrogen will be produced. Human urine is a quick-acting fertilizer that can replace mineral fertilizer in cereal crop production

At excretion, the pH of urine is normally around 6, but can vary between 5 and 8. Of the N, 75-90% is excreted as urea, which in the presence of urease, is quickly degraded to ammonium and carbon dioxide and the hydroxide ions produced normally increase the pH to 9-9.3. Ammonium is directly plant-available and an excellent N fertilizer, which is verified by the fact that urea (which is degraded to ammonium by urease in the soil) and ammonium are two of the most used N fertilizers in the world. The plant availability of urine N is the same as that of chemical urea or ammonium fertilizers. The P and K in the urine is almost entirely (95-100%) inorganic and is excreted in the form of ions. These ions are directly plant-available and thus it is no surprise that their plant availability has been found to be at least as good as that of chemical. S is mainly excreted in the form of free sulphate ions, which are directly plant-available. This is the same form as the S in most chemical fertilizers and thus the fertilizing effect of S in urine and that in chemical S fertilizers should be the same (Jönsson *et al.,* 2004). The relationship between nitrogen, phosphorus, potassium and sulphur is well-balanced and, with appropriate doses, broadly corresponds to the needs of cereal crops (Johansson *et al*., 1997).

Regarding the sanitation achieved, it is assumed that after 6 months of storage no pathogens will be found, taking into account that at pH of 9 no organisms will survive.

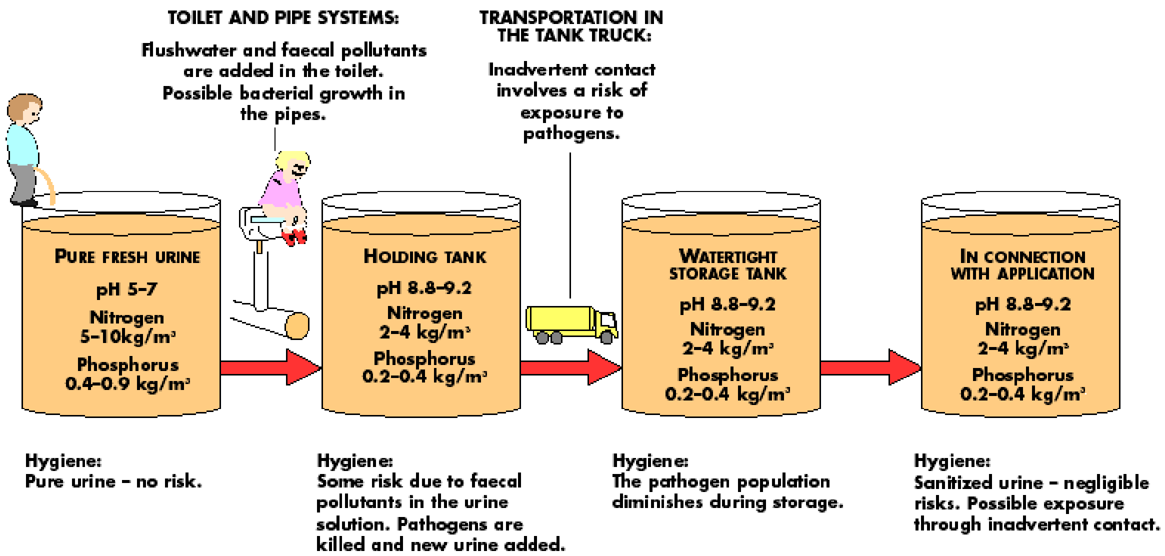


Fig 5.11. The pH level, the content of nutrients and the hygienic quality of fresh human urine and the urine/water mixture at various stages of recirculation from toilet to field.

6- Cost analysis

This section presents the economic factors considered in the two scenarios for the treatment of faeces and the proposal of management of urine.

6.1 General information and assumptions

6.1.1 Investment costs

The cost information was mainly based on the data gathered and presented at the Addis Ababa Sanitations Improvement Project Volume 2 Wastewater Master Plan, and in the report presented by Meinzinger and Otterpohl (2005). However, not all the information required was available in these reports. Therefore, other assumptions were made taking into account prices found in internet and relating costs to those given by the references and personal communication to specialists. In order to simplify calculations, it will be assumed that all the items will be paid at the beginning of the project, so no depreciation of the items will be taken into account.

Table 6.1-List of items related to investment costs

Item	Unit	Unit Cost (Birr)
Land Acquisition	m^2	5
Roofted Area	m^2	800
Excavation/Earth Work	m^2	40
Pipe system (250 mm)	m	85
Pipe system (150 mm)	m	50
Installation of pipes	m	85
Construction of well	-	1000
Gathering tank ($3m^3$)	-	1500
Rottenbehälter unit	-	20000
Urine Storage Tank	m^2	120
Tipper truck ($8m^3$)	-	771000
Vacuum Truck ($8m^3$)	-	850000
Monitoring Equipment	-	3000
Kit Wheelbarrows + Shovels	-	800

In order to evaluate each scenario, it is necessary to consider the economic life time of all the equipments, works and pipelines, the following table shows the times indicated by Meinzinger and Otterpohl (2005).

Table 6.2 Estimated life time of the equipment and works

Item	Life Time (years)
Civil work and pipelines	40
Equipment (tanks)	25
Transportation	20

Additional items to consider in the investment cost are the allowances for technical contingencies and the design and construction supervision costs. These were considered to be 10% and 8% respectively from the total investment cost.

6.1.2 Operation and maintenance

The items considered in the operation and maintenance costs were the personnel and material costs, which included a proportional value of investment, additional additives (dry agent or flush water), other specific costs related to the treatment (e.g.Vermicomposting) and energy costs. The personnel requirements for each scenario were estimated based on the hours needed to performed each duty, which information can be found in Appendixes (Appendix 6 (Table A.10) for primary treatment of Scenario A; Appendix 9 (Table A.17) for secondary treatment of Scenario A; Appendix 10 (Table A.21) for Scenario B and Appendix 12 (Table A.26) for urine management). The personnel salaries were based on the information given by Meinzinger and Otterpohl (2005) and finally, the administration work was considered to be 10% of the total staff costs.

Table 6.3 Personnel Salary

Employee	Salary (birr/month)	
Engineer	1500	
Technician	600	
Unskilled worker	400	
Driver	500	
Administration	%	10

The costs related to materials were calculated as a percentage of the investment costs. For the pipe system 0,5% of the investment costs were considered as materials costs, tanks and earth and roof work 1%, well 5%, transportation units 10% and shovels and wheelbarrows 20%. The costs of dry agent and flushing water were considered in order to define the gained value by using dry sanitation systems. Extra expenses of Vermicomposting culture were also assumed. The cost of renting a truck for the delivery of compost was also assumed, as well as the energy costs implicated in emptying, transporting and transfilling the raw material and products, according to the number of trips.

Table 6.4 Other operational costs.

Item	unit	Unit Cost (Birr)
Dry agent	kg	0,05
Flushing water	m^3	3
Other (Vermicomposting)	-	1000
Transport of compost to field (Rent truck)	-	300
Energy (oil+electricitiy) Per trip	trip	30

6.2- Costs of each scenario

In the following tables, a summary of the costs related to the management of urine and faeces in the two scenarios are given. The trade of the products (compost and urine) are also considered, which prices are taken from Meinzinger and Otterpohl (2005). The total cost per household unit is given at the end of the table.

Table 6.5- Summary of cost of Scenario A.

	Primary treatment	Secondary Treatment	Land	Urine management	Total
Investment cost (birr)	868200	324800	3750	1107123	2519288
Operation cost (birr/month)	10058	4260	-	8795	23113
	Compost (kg/month)	Price of compost (birr/kg)	Urine (m^3/month)	Price of urine as fertilizer (birr/m^3)	Total (birr/month)
Products Trade Revenues	26325	0,2	90	25	7515
Neto Operational costs	(Operation costs- Compost and urine revenues)				15598
Total cost of Sanitation per household (faeces+urine)	(400 households of 5 members)				39

Table 6.6- Summary of cost of Scenario B.

	Treatment of faeces		Urine management		Total (birr)
Investment cost (birr)	1271002		1107123		2378125
Operation cost (birr)	9296		8795		18091
	Compost (kg/month)	Price of compost (birr/kg)	Urine (m^3/month)	Price of urine as fertilizer (birr/m^3)	(birr)
Compost Revenues	2810	0,2	90	25	2812
Neto Operational costs	(Operation costs- Compost and urine revenues)				15279
Total cost of Sanitation per household (faeces+urine)	(400 households of 5 members)				38

The detailed costing of every scenario is presented in the Annex 13.

6.3- Economic Viability – Comparison between scenarios

In order to identify the economic viability of the project, an investment criteria should be used. The most common investment criteria is the Net Present Value (NPV) and is defined as follow:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+k)^t} \qquad \text{Eq. 3}$$

NPV= Net Present Value
C_t= Costs in year t
B_t= Benefits in year t
k= discount rate

t= number of years from the present
n= total number of the years of the analysis period.

Applying the net present value method, the investment can count as being profitable as its NPV is positive, meaning that the interest rate on capital is higher than the assumed discount rate (GTZ, year not specified c). The aim using this method is to combine the costs of investment with the costs included during the time the system is operating, in order to give the base for a comparison between different scenarios with different operation and maintenance costs.

The scenarios A and B were evaluated for a time of 30 years, time in which the investment, the operational costs and economical benefits were calculated. In order to bring all the costs to the year of investment, a discount rate of 8% was considered (following the example of GTZ with a biogas plant). The results are shown as follow:

$NPV_{\text{Scenario A}}$= 412 091 birr

$NPV_{\text{Scenario B}}$= 314 035 birr

From the results presented above it can be said that from the economic point of view scenario A results more profitable. According to the definition, to have a higher NPV means that the interest rate on capital is higher than the assumed discount rate. The results in both cases indicate that the return on investment for a project in sufficiently high to cover its average capital costs.

7- Final analysis and recommendations

It has been well demonstrated throughout the development of this project, how ecological sanitation, through its different technologies could provide a solution to the sanitation crisis existing today in Addis Ababa, by a well controlled and monitored collecting, treatment and disposing system of the human excreta according to particular characteristics of each stream and the local, economical and environmental requirements. With the potential benefits of reusing the nutrients into agriculture, in the form of composted faeces and collected urine, ecological sanitation could also enhance the economical growth of the agricultural areas, in particular in the cereal plantations, in the near peri-urban districts of the Ethiopian capital, reducing the import dependency to mineral fertilizer. Furthermore, the treatment of faeces and urine separately will bring the environmental benefit of not discharging black water into the watercourses, releasing the stress on the ecosystem and procuring better hygienic and aesthetic conditions of the city and a rise of the living conditions of the inhabitants. As ecological sanitation includes some low technology systems, which require high labour input, it could also provide new jobs, contributing to reduce the 42% of unemployment in the region.

In order to provide a solution, rather than diminishing the health standards of the population, particular attention has to be given to the international regulations and recommendations, regarding the pathogenic risk and the proper procedure that has to be followed when treating and re-using human waste into the agricultural land. In this sense, in chapter 5, two proposed scenarios where given to study the feasibility and suitability of two sanitation options: Scenario A: Dry toilets with urine separation and Scenario B: Low flush toilets with urine separation. The selection of the suitable treatment of urine was also performed in chapter 5.3, where storage was considered the most realistic alternative for the management of urine. Since only one option was given for yellow water, it was not included in the analysis of the scenarios. After the application of selection criteria and a deep analyse of all the technologies available for the treatment of faeces with and without water, two proposed options were given.

Scenario A is based on the installation of double vaults dry toilets, with the addition of a earth-lime mixture as a drying alkaline agent. The second stage of the process refers to an aerobic composting procedure, which should be performed in an eco-station. Scenario B is based on a relatively new technology called Rottenbehälter/Vermicomposting, which has the additional advantage of having the primary and the secondary treatment in the same tank, producing a good quality earth humus inside the buildings, therefore no eco-station is needed.

A starting point of the final selection will be the economical evaluation. According to the analyses of cost, the tariff that would be charged to each family is in both scenarios very close, being for scenario A 39 birr/month and for scenario B 38 birr/month. Therefore, it cannot be used as a parameter of decision. Regarding the investment costs, the scenario A seems to be 141 163 birr more expensive, representing 5% additional investment than scenario B, which can also be disregarded. A significant difference is found in the calculations regarding the Net Present Value of the systems, which showed that the scenario A was 23% more lucrative than Scenario B ($NPV_{Scenario\ A}$= 412 091 birr $NPV_{Scenario\ B}$= 314 035 birr).

Apart from the economical viability analysis, which produced valuable data for decision, the similarities encountered in the costs study, does not allow basing the selection of scenarios purely on economical facts. Therefore, the feasibility according to local conditions will also be an important issue that must be taken into account. The selection criteria used to define the treatments, which were integrated in the scenarios A and B, should be then used to elucidate the selection between these two. Drying with addition of alkaline agents achieved 26/30 points, meanwhile composting as the secondary treatment got 24/30 points, therefore the total selection criteria points for the Scenario A will be assumed as 25/30 (an average between the two treatments). Scenario B reached a total number of points of 25/30. This first qualitative analyses express that the scenario A and B are equally suitable for the given conditions of the Arat Kilo and Piazza city areas. Therefore, some extra considerations will be made. For instance, the Scenario B has some advantages that must be cited: first at all, the use of a flush toilet could help to increase the acceptance by the users, and in addition, the use of water has been proved to be a more robust technology for the transportation of faeces. With the two process occurring inside the building (dewatering and Vermicomposting), the need of an eco-station in eliminated, which also diminishes the number of trips to the eco-station and agricultural field to carry the compost. This has additional environmental benefits by reducing the greenhouse effect emissions and the use of mineral combustible. Furthermore the quantity of product is considerable low, since no extra substrate is needed, making the management of the sludge more feasible which must be disposed only 2 times at years. On the other hand, scenario A has the advantage of being a very robust process, presenting not real complication at the time of storing and collecting the faeces. A special characteristic of this system is that the use of water for flushing the excreta is removed, allowing on one side to save this vital resource for other applications and avoiding the nuisance of non-functioning WC during water shortage periods. A particular weak point found is the dependency to dry agents and extra substrates for composting, which could jeopardize the functionality of the project. Furthermore, Scenario A represents a more labour intense method, requiring 40% more effort than the Scenario B.

A key factor that must be taken into account is the amount of compost produced in each scenario. For instance, in scenario A 26 325 kg/month of compost are produced meanwhile in scenario B only 2810 kg/month of compost is obtained. This huge difference of 10 fold arises due to the large amount of earth, lime and municipal and household waste that should be added in the first case to reach the sanitation procedure standards when drying and composting human excreta. Therefore, the potential market of this product has to be established; if there are difficulties posing compost from human faeces as soil conditioner in the market, then scenario A should not be taken. If it is impossible to sell the compost, then the 2810 kg of compost coming from scenario B could also be used in the green areas of the neighbourhood or in horticultural eco-walls, with a total number of 3500 containers of 5 l each, to contain the total amount of compost produced in 6 months. However, the fact of producing more compost could also be beneficial if there is a potential market. If the compost could be sold completely to the farmers, it will bring extra revenues to the sanitation system. This advantage can be seen for instance, in the cost analysis, where according to the Net Present Value analysis, the installation of the scenario A would result in a more profitable option.

Taking into account all the information above expressed, it is convenient to evaluate the suitability of the two systems based on a pondering study. In this sense, the qualitative evaluation made in chapter 5 will be enriched by the addition of other parameters, such as acceptability, costs and use of water and by weighing the factors to reach 100%. For the case of those criteria parameters which resulted identically for the two Scenarios in the previous analyse, no consideration in going to be made.

Even though all of the indicators have great significance, they will be differentiated according to what it is considered to have more importance for the specific conditions of Addis Ababa and the appropriated sanitation system. The highest value in this scale was given to the indicator "acceptance", since these types on non-centralised systems require high awareness and disposition from the users to maintain the system. The "use of water" and "costs" were also high weighted as well as "robustness". The following results can be observed:

Fig 7.1- Selection of scenario A and B, based of pondering criteria

Parameter	Pondering Factor (%)	Evaluation of Scenario		Evaluation with pondering factor	
		A	B	A	B
Robustness	10	3	2	30	20
Professional Expertise needed	5	2	1	10	5
Labour input needed	5	1	3	5	15
Availability of Agents	5	1	3	5	15
Ease of handling of product	-	3	3	-	-
Quantity of product	-	3	3	-	-
Space required	5	1	3	5	15
Fertilizer quality of the product	-	3	3	-	-
Sanitation obtained	-	3	3	-	-
Use of water	20	3	1	60	20
Experience	5	3	1	15	5
Acceptance	25	1	3	25	75
Costs	20	3	2	60	40
TOTAL	**100**	30	31	**215**	**210**

According to the results it will be recommended the implementation of Scenario A, dry toilets with urine separation, since it represents the more profitable option and offers further advantages. However, it must be taken into account the increased logistics and labour input required, and the need of a market for the amount of compost produced. Furthermore, a very deep campaign to raise public awareness has to be carried out, in order to teach the future end users not only on the use and maintenance of the toilets units, but also in the separation of kitchen and garden waste.

It will be at the end a decision of the planners of the project, whether dry or low flush toilets will be applied. In both cases, advantages and disadvantages will be found, however it will be always suggested to follow the recommendations made in chapter 5 at the time of planning and operation of dry toilets with addition of drying agent followed by composting, and low flush toilets with dewatering and Vermicomposting.

8- Conclusions

Addis Ababa, the capital of Ethiopia, host today around 3,5 million of people, from which more than 85% live in slums with high population density and precarious sanitation conditions. A new low cost building project is being carried out by GTZ in the inner city areas of Arat Kilo and Piazza, in order to offer a good living conditions to 50 000 inhabitants, meanwhile ensuring the extension of the capacity building of local professionals. In the frame of this great engineering project, a feasible sanitation option is needed, looking forward to a sustainable solution that could close the cycle of water and nutrients. Ecological sanitation has shown to be an effective alternative providing sanitation in developing countries, where there is a missing treatment link between consumption and disposal of municipal wastewater. The composition of human excreta was determined for the inhabitants of Ethiopia, taken into account the protein consumption and related data found in the literature. This was useful to evaluate the possible fertilizing value of the human excreta produced in the study area. International regulations and recommendations regarding the treatment and re-use of human excreta were reviewed and integrated to the proposed sanitation options. Two scenarios where analysed and evaluated for a population of 2000 persons, in order to propose suitable sanitation options to Arat Kilo and Piazza inner city areas: Scenario A (dry toilets) and Scenario B (low flush toilets), both with urine separation. In the two cases it was recommended that urine be collected in tanks located underneath the ground for a period of 2 months and transported to two farm locations of cereal plantations in the areas near the city, where it was going to be stored for a period of 6 months, which according to the international recommendations, is the proper time to ensure no pathogenic risk at Addis Ababa ambient conditions. Regarding the management of human faeces, for each scenario, different alternatives for primary and secondary treatment were evaluated. A selection criteria was designed taking into account different parameters such as robustness, professional expertise, labour input, quality of product, among other. For the dry sanitation scenario, the following technologies were assessed as primary treatment: soil composting, composting, solar dehydration, addition of drying material and alkaline treatment; for the secondary process storage, incineration, dry fermentation, sanitation with urea and composting were evaluated. For the low flush scenario, Rottenbehälter, Rottenbehälter/Vermicomposting and Anaerobic degradation were taken into account. After the application of the evaluation criteria, the following results arrived: the optimal solution for scenario A was the installation of double vaults dry toilets, with the addition of a earth-lime mixture as a drying alkaline agent. The second stage of the process referred to an aerobic composting procedure, which should be performed in an eco-station. Scenario B was based on a relatively new technology called Rottenbehälter/Vermicomposting, which has the additional advantage of having the primary and the secondary treatment in the same tank, producing a good quality earth humus inside the buildings, therefore no eco-station is needed. These two options were economically analysed through the calculation of investment and operation/maintenance costs, as well as the application of the Net Present Value, showing that even though the investment of Scenario A was more expensive it was more profitable. A final qualitative assessment based on selection parameters was performed, using the already existing criteria plus three new factors: costs, acceptance and water use. The parameters were pondered according to importance in the local conditions, producing that Scenario A (dry sanitation) was the most suitable option for decentralised sanitation under Addis Ababa conditions, even if some factors most be manage carefully, such is the case of a great amount of compost that must be marketed, a great input in logistics and labour and a clear dependency on extra additives and substrates.

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Appendixes

Appendix 1: Regional Characteristics of the population of study for the UPESSA project in the Arat Kilo and Piazza inner city areas.

In order to select the most suitable ecological sanitation system for the Arat Kilo and Piazza areas in Addis Ababa, a group of local variables must be considered. In the following table a summary of the regional conditions is presented, together with relevant characteristics associated to the selection of sanitation systems.

Table A.1- Local Variables of Addis Ababa influencing the choice of the ecological sanitation system.

Local Variable			**Comments**
Climate	Temperature	15°C - 18°C (<20°C)	The temperatures could reach 24 °C, however it is rare. Storage and sanitation of faeces and urine should have a minimum time of 6 months.
	Precipitation	13-300 mm	Critical period from July to September, "hard rain" expected. Open-air storage should be limited during the season to avoid spreading of pathogens.
	Sunshine	3 h /d (Rainy season)- 9 h /d (Dry season)	Solar desiccation of faeces and evaporation of urine could be an option for the dry season.
	Humidity	Dry season: 29-65 Rainy season: 43-86	Humid
Urban	Population Density	632 inhabitants/ha in slum areas	Crowded conditions. No space available for urban agriculture near the study area.
	Conditions of roads	Poor	Difficulties for transport of products
	Religion	85% Christian 13% Muslin	Low percentage of washers, treatment of anal cleaning water could be done together with grey water.
	Sex distribution	51.6% are females while 48.4% are male.	Option of urinals for men should be considered
Social/ Cultural	Sanitation practices	Use of latrines	Functioning flush water toilets are rare in low-income areas.
	Acceptances excreta in agriculture	Medium	Difficulties of acceptance due to pre-conceived ideas about human excreta as fertiliser
	Women/ Youth	Women in charge of domestic activities.	Main target group for training for sustainability of sanitation system.
Financial resources	Community		
	Individual	Low income, 60% of population below to the poverty line.	Savings in water costs should be encouraged
Technical Capacity	Universities	University of Addis Ababa and the Alemaya College of Agriculture near Harar. 7 junior colleges offering specialized training in agriculture, technology, trade and commerce.	The Addis Ababa University poses a Technology Faculty with careers as chemical and civil engineering, whose engineers could be trained to perform the technical management of the sanitation system.
	Labour capacity	Unemployment of 42%	High labour force potential
Agricultural Activity	Agricultural Land	Currently 677 hectares of land is irrigated annually.	Possibility of distribution of ecological sanitation products in areas near to Addis Ababa.
	Crops	129,880 quintals of vegetables are cultivated	Possible application of fertilizer.
	Use of Fertilizers		
	Homestead garden	Possible in small scale.	Practiced, though small space available.
Institutional Support	Government Support	Weak	Burocratic constrains.
	NGO		
	Cooperatives	Several cooperatives for agricultural activities.	Should be contacted in order to negotiate the market of organic fertilizer.

Appendix 2: Calculation of population of study for the UPESSA project in the Arat Kilo and Piazza inner city areas.

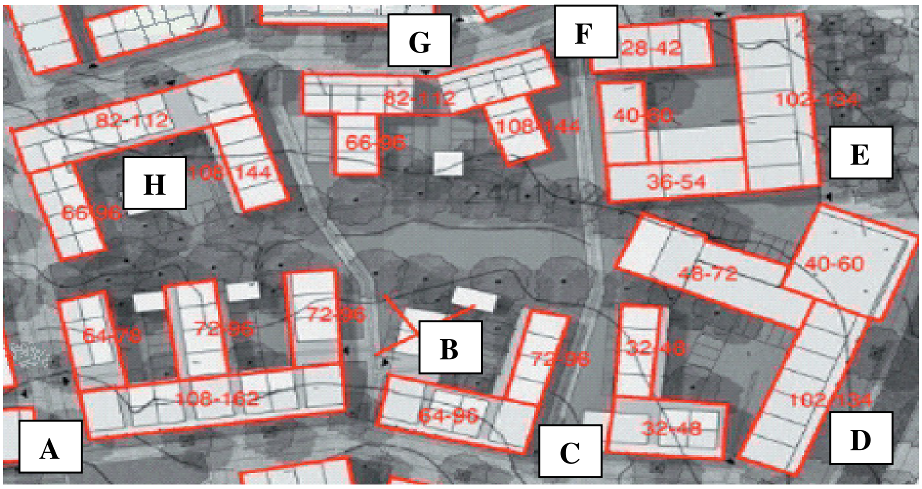

Figure A.1.- Estimated number of inhabitants in the study area

The estimation of the future number of inhabitants in the study area was performed by the Technical University of Braunschweig (Institute for Sustainable Architecture and Settlement Planning), which can be observed graphically in the figure A.1. According to the proposed urban design, the UPESSA project will have as a study population of 8 building with a maximum of 2000 residents. In order to propose the logistics for the management of residues, each building has been given a code (letters A to H), to which references are made in order to calculate the production of urine and excrete.

Table A.2.- Minimum and maximum number of inhabitants

Building Code	Inhabitants				MIN	Inhabitants				MAX
A	64	72	72	108	316	78	96	96	162	432
B	64	72	-	-	136	96	96	-	-	192
C	32	32	-	-	64	48	48	-	-	96
D	102	48	40	-	190	134	72	60	-	266
E	40	36	102	-	178	60	54	134	-	248
F	28	-	-	-	28	42	-	-	-	42
G	66	82	108	-	256	112	96	144	-	352
H	66	82	108	-	256	96	112	144	-	352
Total					**1424**					**1980**

It is estimated that in each housing unit will live five persons and that not all the buildings will have the same number of floors. For instances, the outer buildings D and E will be 6 storey- buildings, meanwhile B und G will have less than 4 levels, possible 3 or 2.

Some of the buildings will have a huge population; such is the case of the building A with ≈ 430 inhabitants. On the contrary, other buildings, for instances the building C and F, will have an estimated population of less than 100 persons.

The maximal possible population for each building will be used in order to calculate the quantity of urine and excrete, therefore 1980 ≈ 2000 will be the study population of the project.

Appendix 3: Calculation of quantity of human faeces excreta produced by the population of study for the UPESSA project in the Arat Kilo and Piazza inner city areas.

According to the analysis of the chapter 4, the amount of excreta per person in Ethiopia is taken as 300 g/p·d. The following calculation shows the daily and monthly production of faeces in the inner city areas Piazza and Arat Kilo.

Table A.3.- Total amount of faeces per day

Housing Unit	$Inhabitants_{MAX}$ (-)	$Mass_{faeces}$ (kg/d)
A	432	129,6
B	192	57,6
C	96	28,8
D	266	79,8
E	248	74,4
F	42	12,6
G	352	105,6
H	352	105,6
Total	**1980**	**594**

Design data

$Mass_{faeces/person}$ (g/d*p)= 300

$Mass_{faeces/person}$ (kg/d*p)= 0,3

$Volume_{faeces/person}$ (l/d*p)= 0,3

Total mass of faeces per month (kg/month)= 17820 ≅ 18 ton/m

Total volume of faeces per month (l/month)= 17820 ≅ 18 m^3/m

Appendix 4: Production of mineral commodities in Ethiopia (1995-1999).

(Metric tons unless otherwise specified)

Commodity		1995	1996	1997	1998	1999 e/
Cement, hydraulic e/		611,437 4/	663,000 r/	750,000 r/	775,000 r/	700,000
Clays: e/ 5/						
Brick		7,000	7,000	6,000	6,000	5,000
Kaolin (China clay)		15	15	16	15	15
Diatomite		150	150	150	125	120
Feldspar e/		4,000	4,000	5,000	5,000	4,000
Gold, mine output, Au content	kilograms	4,500	2,500	3,000	2,500	2,000
Gypsum and anhydrite, crude		124,000	124,000	120,000	100,000	100,000
Lime		3,091	3,100	2,500	3,000	2,500
Pumice e/ 5/		360,000	360,000	325,000	325,000	300,000
Salt, rock e/		5,000	5,000	1,000 r/	1,000 r/	1,000
Scoria e/		240,000	250,000	250,000	250,000	250,000
Soda ash, natural		20,000	20,000	15,000	15,000	15,000
Stone, sand and gravel: e/ 5/						
Construction stone, crushed	thousand tons	750	750	750	1,000	1,000
Dimension stone 6/		38,000	38,000	40,000	130,000	100,000
Limestone	thousand tons	3,215 4/	3,300	3,300	3,400	3,000
Sand 7/	do.	1,600	1,600	1,600	2,500	2,500
Silica sand		6,000	6,000	7,000	7,000	7,000
Tantalite, concentrate (40% Ta_2O_5)		20	20	20	20	20

e/ Estimated. r/ Revised.
1/ Data are for year ending July 7 of the year listed.
2/ In addition to the commodities listed, some lignite, semiprecious gemstones, steel semimanufactures, and talc reportedly were produced, and silver was reportedly contained in gold ingots from the Lege Dembi Mine, but information is inadequate to estimate output.
3/ No platinum production was officially reported after 1988. Some artisanal platinum probably continued to be produced, and platinum was also reported by others as being contained in gold ingots from the Lege Dembi Mine, which started up in 1990.
4/ Reported figure.
5/ When reported as volume or pieces, conversions to metric tons are estimated.
6/ Includes marble.
7/ May include gravel.

Table A.4-. Production of mineral commodities in Ethiopia (Mobbs, 1999).

Appendix 5: Calculation of quantity of human faeces excreta produced in dehydration toilets by the population of study for the UPESSA project in the Arat Kilo and Piazza inner city areas.

The amount of fresh faeces that will be produced in 4 months for the total population of 1980 individuals will be 71 280 l, approximating to 2000 inhabitants, the total amount of faeces will be 72 m^3.

Design data

$Mass_{faeces/person}$ (g/d*p)=	300		
$Mass_{faeces/person}$ (kg/d*p)=	0,3		
$Volume_{faeces/person}$ (l/d*p)=	0,3		
Total mass of faeces per month (kg/month)=	0	≅	18 ton/m
Total mass of faeces per 4 months (kg)=	0	≅	72 ton
Total volume of faeces per month (l/month)=	0	≅	18 m^3/m
Total volume of faeces per 4 months (m^3)=	0	≅	72 m^3

It will be assumed that the faeces, due to the free fall, will be broken into pieces, in such a way that the structure will not be maintained. In this way the reduction of volume and weight will be the same. According to Winblad and Simpson-Hébert (2004), the dehydration process reduces the moisture content of the faecal material to less than 25% v/v through evaporation and addition of dry material. Taking as percentage of water volume in faeces of 80 %, it could be defined the following formula for the volume reduction of faeces under dehydration conditions:

$$Faeces\_Vol_{dehydrated} = Faeces\_Vol_{fresh} \cdot \left(water\_\%_{fresh\_faeces} \cdot water\_reduction + Solid\_content_{faeces}\right)$$

$$Faeces\_Vol_{dehydrated} = 72m^3 \cdot (0{,}80 \cdot 0{,}25 + 0{,}20) = 28{,}8m^3$$

Even though the desiccation process reduces the volume of faeces in a 40%, the total volume reduction of the faecal matter to be handled and treated is almost the same as the original, due to the addition of dry material after each defecation. The exact quantity of dry material to be added to the excreta varies. From the data provided for the Vietnamese double-vault toilet and the Ecological Sanitary Unit- Mexico the following estimation of added drying additives could be made:

✓ According to Winblad and Simpson-Hébert (2004), each compartment of the Vietnamese double vault toilet is 80 x 80 x 50 cm, resulting in 0,32 m^3. The first vault can be used for about 4-5 months by a household of 4-6 persons. When it is two-thirds full then it is filled with dry material to the brim. Assuming that the amount of faeces produced by the Vietnamese population is 350 g/d (see table 3.1), 80% of water content in faeces and 25% moisture reduction, the total volume of produced partial desiccated volume in 4 months will be 0,101 m^3, which results in a total amount of additives of 0,110 m^3. There are plenty different desiccating agents that could be used for the dry toilets. However, lime, earth and ashes are the most common. The following table shows the density of the possible drying agents, from which an average of density has been estimated in order to define a bulk density of the additive to be used (934, 7 kg/m^3)

Table A.5- Density of common desiccation agents (Simetric, 2001)

Drying agent	Density (kg/m^3)
Lime, quick, lump	849
Lime, quick, fine	1201
Ash black	540
Ash white	670
Ashed, dry	570-650
Clay, dry, lump	1089
Earth, loam, dry, excavated	1249

Under the assumption exposed above the total amount per person per day to be used in the Vietnamese double vault toilet is 143 g/d ≈ 150 g/d.

Table A.6- Determination of the additive fraction in the Vietnamese double vault toilet.

Country	Filled volume of the chamber (2/3)	Number of persons	Time of filling	Amount of fresh faeces in 4 months	Partial desicated volume in 4 months	Total estimated amount of additives in 4 months	Additive per person per day	
	m^3	-	month	m^3	m^3	m^3	m^3	kg
Vietnam	0,211	6	4	0,252	0,101	0,110	0,00015	0,143

✓ According to Peasey (2000), the Mexican ecological sanitary unit is a prefabricated toilet constructed from high-impact recycled polyethylene, consisting on two chambers as the above explained double vault toilet of Vietnam. According to the author, this design requires ideally the addition of 0,5 kg per user per day of ash, lime and soil in equal proportions. A mixture of 3 parts soil and 1 part lime is also reported to be effective.

For the matter of this project it would be estimated the use of a mixture 50% earth and 50% lime, with a density of (ρ= 1225 kg/m^3), due to the availability of lime and earth in the mineral market of Ethiopia (2500 metric tonnes of lime produced in year 1999) (Mobbs, 1999).

Table A.7- Estimation of Volume of drying agent in 4 months for different quantities

Inhabitants	Amount of drying agent per person	Mass of drying agent	Mass of drying agent in 4 months	Volume of drying agent	Volume of drying agent in 4 months
(-)	(g)	(kg/d)	(kg)	(m^3/d)	(m^3)
2000	150	300	36000	0,24	29,39
	300	600	72000	0,49	58,78
	400	800	96000	0,65	78,37
	500	1000	120000	0,82	97,96

In table A.8 different amounts of drying agent are evaluated. A drying agent amount average of 300 g/p·d will be assumed, in order to ensure the total covering of the surface of the excreta to avoid fly breeding and smell. With this 1:1 proportion of faces and excreta, the total volume of drying agent in 4 months will be 58,78 m^3. The total amount of product to be collected, transported and treated every 4 months is then the addition of 28,8 m^3 of dry faeces and 58,8 m^3 of drying agent, giving a total of 87,6 ≈ 90 m^3 (100,8 tonn).

Appendix 6: Calculations regarding logistics and labour input of the desiccation treatment for products of the dry-toilets.

The following table shows the calculations regarding the logistics of collecting and transport of the dry faecal matter produced in the study area.

Table A.8- Logistics (measure in hours of work) regarding collection and transport

Amount of faecal product every 4 months	m^3	90
Capacity of the Tipper truck	m^3	8
Number of collection trips in 4 months	No	11,25 $\cong$ 12
Time estimated for each emptying	h	8
Time estimated for each drive to the eco-station (both ways)	h	2
Monitoring time of each procedure	h	4
Monitoring of the systems (1 per week)	h	3

Another important factor to be considered is the required amount of dry-agent to be prepared for the study population. The following assumptions were taken:

✓ Capacity of the tipper truck: in order to calculate the number of trips to be performed by the truck to pick up raw material and deliver the agent to the costumer is 8 m^3.

✓ The lime and earth producers or distributors are located in Addis Ababa, being the total collection time in both ways 2 hours.

✓ Every family will be composed of 5 members, each one needing 300 g/d of dry agent.

✓ The tripper truck will be able to carry 390 packages of dry agent at once.

✓ The needed time to mix and package 19600 kg of produce material is 60 hours.

✓ The needed time to deliver 390 packages to consumers is 5 hrs.

The following table shows the results of the logistics of production and distribution of drying agent.

Table A.9- Logistics (measure in hours of work) regarding production and distribution of drying material

Quantity of drying material needed each four months	m^3	60
Quantity of earth needed	m^3	30
Quantity of lime needed	m^3	30
Capacity of the Tipper truck	m^3	8
Number of trips to transport earth from point of selling to eco-estation (delivery)	-	3,75 ≅ 4
Number of trips to transport lime from point of selling to eco-estation (delivery)	-	3,75 ≅ 4
Estimated time in each trip to the raw material producer	h	2
Amount of drying material produced in each delivery	kg	19600
Amount of drying material needed by a family of 5 members in 4 months	kg	180 ≅ 200
Amount of drying material delivered every 2 weeks to each family	kg	25
Number of packages produced per delivery of raw material (25kg)	-	784
Total number of packages to transport to the city in 4 months	-	3136
Maximun number of packages per drive to transport to the city (capacity of the truck)	-	392 ≅ 390
Number of drives to deliver the total amount of drying agent needed in two weeks by the study population	-	8,041 ≅ 9
Number of drives to deliver the total amount of drying agent needed in one month	-	18
Time estimated to mix and pack the drying material needed in 4 months	h	480
Time estimated of transporting, delivering and selling the dry material per month (5h each delivery)	h	90

The following table shows an overview of the staff and time required for each task in hour/months for the primary treatment of dry faeces using the desiccation technology. It will be assumed 8hours/day (160 hours/month) as working day,

Table A.10- Labour input (measure in hours of work) regarding production and distribution of drying material and collecting of dry feaces

	Duty	**Unskilled worker**	**Driver**	**Technician**	**Engineer**
		(h/month)			
Emptying	Emptying "gathering tank"	24,5			
	Transport of dry material		6,125		
	Monitoring and managment of the system			12	
	Monitoring of the empyting procedure			12,25	30
Dry Agent	Transport of raw material		4		
	Preparation of drying material	120		20	
	Transport, selling and distribution	90	90		30
	total hours	235	100	44,25	60
	(person/month)	1,47	0,63	0,28	0,38

An estimation of the investment and operational costs are presented in the following table. The prices are taken from the Master plan of wastewater treatment of the city of Addis Ababa, other are assumed as no information was found (costs of the gathering tanks; costs of soil and lime in Ethiopia).

Appendix 7:The science of composting (from IWMI&SANDEC, 2002)

Composting systems

The technologies chosen for aerobic composting (or co-composting) will depend on the location of the facility the capital available and the amount and type of waste delivered to the site. Two main types of systems are generally distinguished which are: 1) open systems such as windrows and static piles and 2) closed "in-vessel" systems. In-vessel or "reactor" systems can be static or movable closed structures where aeration and moisture is controlled by mechanical means and often requires an external energy supply. Such systems are usually investment intensive and also more expensive to operate and maintain.

"Open" systems are the ones most frequently used in developing countries. They comprise:

• Windrow, heap or pile composting
The material is piled up in heaps or elongated heaps (called windrows). The size of the heaps ensure sufficient heat generation and aeration is ensured by addition of bulky materials, passive or active ventilation or regular turning. Systems with active aeration by blowers are usually referred to as forced aeration systems and when heaps are seldom turned they are referred to as static piles. Leachate control is provided by a sloped and sealed or impervious composting pads (the surface where the heaps are located) with a surrounding drainage system.

• Bin composting
Compared to windrow systems, bin systems are contained by a constructed structure on three or all four sides of the pile. The advantage of this containment is a more efficient use of space. Raw material is filled into these wood, brick or mesh compartments and aeration systems used, are similar to those of the above described windrow systems.

• Trench and pit composting
Trench and pit systems are characterised by heaps which are partly or fully contained under the soil surface. Structuring the heap with bulky material or turning is usually the choice for best aeration, although turning can be cumbersome when the heap is in a deep pit. Leachate control is difficult in trench or pit composting.

Key factors of the composting process

The key factors affecting the biological decomposition processes and/or the resulting compost quality are listed below.

<u>C:N Ratio and other nutrients</u>: The primary nutrients required for microorganism growth are carbon, nitrogen, phosphorus and potassium. Although bacteria also need trace amounts of sulphur, sodium, calcium, magnesium, and iron, these elements are usually present in adequate quantities and do not limit bacterial activity. Carbon and nitrogen are both the most important and the most commonly limiting elements for microbial growth (occasionally phosphorous can also be limiting). The ideal ratio of C to N is between 20-30 :1. When there is too little nitrogen, the microbial population will not grow to its optimum size, and composting will slow down as nitrogen becomes a limiting factor to the growth of microorganisms. Microorganisms are forced

to go through additional cycles of carbon consumption, cell synthesis, decay, etc, in order to burn off the excess carbon as CO_2. In contrast, too much nitrogen allows rapid microbial growth and decomposition, but this can create serious odour problems as oxygen is quickly depleted and anaerobic conditions occur. In addition, some of this excess nitrogen will also be given off as ammonia gas that generates odours while allowing valuable nitrogen to escape. The bioavailability of carbon also needs to be taken into account when considering the C/N ratio. This is commonly an issue with carbon materials, which are often derived from wood and other lignified plant materials, as increased lignin content reduces biodegradability. Thus a C/N ratio of 30 where carbon has high lignin content would be too low for ideal composting as the carbon is not easily available for microbial activity. Mixing various feedstocks of different C/N ratios allows a control of the total C/N ratio. Some raw materials are high in carbon others high in nitrogen. In practice, the ideal combination of different feedstock types can be determined by experimentation and experience. Generally one can classify "green" high nitrogen materials and "brown" high carbon materials which in a simple recipe mixture can be mixed together in equal volumes. Examples for "green" materials are fresh grass clippings, manure, garden plants, or kitchen scraps; "brown" materials are dried leaves and plants, branches, and woody materials.

Moisture*:* Maintaining adequate moisture content in the composting pile is important, as humidity is required by microorganisms for optimal degradation. Moisture also dissipates heat and serves as a medium to transport critical nutrients. Moisture content between 40 to 60 percent by weight throughout the pile is ideal. Higher moisture levels slow the decomposition process and promote anaerobic degradation because air spaces in the pile are filled with water and can not be supplied with oxygen. Moisture levels less than 40 percent cause the microorganisms to slow their activities and become dormant or die. Moisture can be easily added during turning by sprinkling water or a mixture of urine and water in a mixing ratio of 1:4 as urine enhances the growth of the microorganisms. For best control of moisture, composting in piles covered by a roofed structure is ideal. If in an open area, at times with excessive rains, the waste pile can be made as steep as possible and be covered with a tarpaulin, plastic sheeting or gunny-bags to reduce water infiltration. In times of excessive heat and drought, the same coverings can serve to reduce evaporation. The optimal moisture level is achieved when the composting material feels damp to the touch; that is, when a few drops of liquid are released while squeezing a handful of material strongly. You can also test for moisture level content by putting a bundle of straw in the heap. If after five minutes, it feels clammy, then the moisture level is good; if still dry after five minutes, the moisture level is too low. Water droplets on the straw indicate that the heap is too wet for successful composting. Moisture content and coarseness of material are closely interrelated in terms of displacement of air in the pores by water, promotion of aggregation and lowering of the structural strength of the material.

Particle size*:* The surface area of the organic material exposed to microorganisms is another factor in determining the rate of composting. Waste material shredded, chipped, or otherwise reduced in size can be degraded more rapidly. This is significant especially with slow degradable woody materials. However, care must be taken to avoid compacting the materials by too small material sizes, as this reduces the porosity of the pile and possible air circulation. The optimum particle size ranges between 25 and 75mm (1 and 3-inches). GTZ recommends chopping all materials to be composted to the length of about 5-10cm. Some authors reported that typical particle sizes should be approximately 1cm for forced aeration composting and 5cm for passive aeration and windrow composting. The physical state and the size of particles affect the moisture content and the composting process. The coarser the material the higher the moisture content should be. A consistent particle size ensures a homogenous composting process and facilitates the further treatment of the compost.

Aeration***:*** The air contained in the interstitial spaces of the composting mass at the beginning of the microbial oxidative activity varies in composition. The carbon dioxide content gradually increases and the oxygen level decreases. When the oxygen level falls below 10%, anaerobic microorganisms begin to exceed the aerobic ones. Fermentation and anaerobic processes take over. This implies that the aerobic microorganisms must have constant supply of fresh air to maintain their metabolic activities unaltered. The oxygen needed for composting is not only needed for aerobic metabolism and respiration by the microorganisms but also for oxidising various organic molecules present in the mass. Oxygen consumption during composting is directly proportional to microbial activity; therefore there is a direct relationship between oxygen consumption, temperature and aeration. The greater the aeration rates the more rapid the rate of degradation. Aeration provides the necessary aerobic conditions for rapid odourless free decomposition and for destruction of pathogenic organisms by heat. The most common way for aerating the compost heap cheaply in the developing country is by turning. Active aeration refers to methods which actively blow air through the compost pile. Passive aeration takes advantage of the natural diffusion of air through the pile enhanced by ventilation structures such as perforated pipes in the pile, openings in the walls of composting bins and of course the particle size and structure of the raw materials in the heap. If air supply in the pile is limited, anaerobic conditions occur; thus producing methane gas and malodorous compounds such as hydrogen sulfide gas and ammonia. The consumption of oxygen is greatest during the early stages and gradually decreases as the com posting process continues to maturity.

Temperature***:*** In windrows which have been prepared according to the "rules of the art", i.e. with adequate porosity, humidity, and C:N ratio, and exhibiting a minimal size to provide sufficient "body" for insulation (1x1x1 meters), thermophilic temperatures develop independently of ambient temperatures. Heat is generated in aerobic decomposition as a result of the microbial activity in the pile as the aerobic degradation of organic material is an exothermic process. As the temperature of the pile increases, different groups of organisms become active. With adequate levels of oxygen, moisture, carbon, and nitrogen, compost piles can heat up to temperatures in excess of 65 degrees Celsius. Higher temperatures begin to limit microbial activity. Temperatures above 70 °C are lethal to most soil microorganisms. If windrows don't turn hot, this is a sign of process failure and that windrows were not set up according to the rules of the art. The thermophilic composting process goes through several temperature variations The class of bacteria involved in the degradation process are psychrophilic (5-20 °C), mesophilic (20- 50 °C) and thermophilic (50-70 °C). This diversity is necessary for the stepwise decomposition of the organic substances to stable compost (humic substances and nutrients). Although composting will occur also at lower temperatures, maintaining high temperatures is necessary for rapid composting as it controls the thermo-sensitive human pathogens as well as destroys weed seeds, insect larvae, and potential plant pathogens that may be present in the waste material. After piling the organic material, the temperature rises to 60 – 70 °C within 1-3 days. After several days of active degradation, the process slows down and the temperature remains around 50 – 55 °C. After approximately 30 days the compost process will slow down further and the temperature will drop below 50 °C. The composting process now enters into the maturing phase with low microbiological activity at temperatures around 40 °C. As the compost becomes mature the temperature approaches the ambient temperature conditions.

Turning frequency*:* Usually the greater the turning frequency, the better the chances for uniform and better degradation. For quality control, it is important that all the waste has been through the thermophilic phase. This can be best controlled by regular turning. However, frequent turning may also lead to increased ammonia losses, particularly so during the first few days of thermophilic activities, when temperatures and pH is highest.

pH*:* Organic matter with wide range of pH (between 3 and 11), can be composted. However, good pH values for composting are between 5.5 and 8; and between 4 and 7 for the end product. Whereas bacteria prefer a nearly neutral pH, fungi develop better in a fairly acid environment. In the first moments of the composting process, the pH may drop to around 5 as organic acids are formed, however then microbial ammonification will causes the pH to rise into the range of 8-8.5. Only during maturation, when the ammonium compounds are nitrified to nitrate will the pH sink once more below 8. Thus, a high pH is generally the sign of immature compost.

Nitrogen conservation*:* Like other nutrients (phosphorus, potassium, micronutrients), nitrogen may also be lost through leaching, yet, in contrast to those nutrients, by far the greatest portion is lost through volatilization in the form of ammonia (NH_3) and other nitrogenous gases. These losses have impact on the fertilising value of the compost product, thus influencing crop yield, farm economics and, hence, farmers' livelihood. Ammonia losses are affected by almost all process parameters such as C/N ratio, pH, moisture, aeration, temperature, the chemical form of nitrogen in the feedstock, adsorptive capacity of the composting mixture, and windrow turning frequency. Excessive dryness will enhance NH_3 volatilisation whereas sufficient moisture contents, like those for optimum composting, from 50-70 %, allow to keep the highly soluble ammonia in dissolved state. Excessive aeration and windrow turning enhances loss of ammonia, which escapes more easily when the composting material is exposed to the atmosphere. Hence, an optimum frequency of turning must be found, which balances the need for all parts of a windrow to be subjected to hot degradation with the need to limit nitrogen loss. A similar balance has to be strived for in temperature development. High temperatures of around 60°C - max. 65 °C are desirable to attain good pathogen inactivation, yet long periods of around 70 °C must be avoided as ammonia formation and potential escape increases considerably at this temperature.

Degree of decomposition or compost maturity

Indicators for the degree of decomposition are: the colour and smell, the drop in pile temperature, the degree of self heating capacity, the nitrate-N / ammonium-N ratio, the amount of decomposable and resistant organic matter in the decomposed material, redox potential, and oxygen uptake. In immature composts, when applied on soil, the microbial activity continues and there is a danger of microorganisms competing with the plants for the availability of soil nitrogen (nitrogen block). Immature compost also may contain high levels of organic acids and can damage plant growth when used for agricultural applications.

Appendix 8: Municipal organic solid waste

(Data from IWMI&SANDEC, 2002)

The resource potential of mixed municipal solid waste is more variable than for excreta as it depends on the waste composition, which varies considerably from city to city and also among city districts depending on income levels and consumer habits. Low-income countries generate significantly less waste than high- income countries. It is also estimated an average municipal solid waste generation (mixed) between 0.4 - 0.6 kg per capita per day in low-income countries, compared to 0.7 – 1.8 kg/cap and day in high-income countries. Typically in low-income countries the biodegradable fraction is significantly higher (40-85 %) than in high income countries (20-50 %) where municipal waste consists mainly of packaging materials (paper and plastics). Assuming a daily per-capita solid waste generation of 0.5 kg with a 60 % biodegradable fraction, 300 g/cap.day wet organic waste is being generated. Based on an assumption of 50 % water content of this organic fraction, this is equivalent to 150 grams dry organic solids/cap and day. Based on contents on a dry weight basis of 30-40 % carbon (C), 1-2 % nitrogen (N) and 0.4-0.8 % phosphorus (as P), and 1 % potassium (as K), the per-capita nutrient and carbon contributions from the organic fraction of MSW is as indicated in Table A.13. The table shows that municipal organic solid waste although low in nutrients is particularly rich in organic matter can be thus be valued on its soil conditioning potential.

Table A.11.- The fertilization equivalent of municipal soild waste (org.fraction) before waste treatment.

Nutrient	Contribution in kg / cap•year
Nitrogen (as N)	0.55 – 1.1
Phosphorus (as P)	0.2 – 0.4
Potassium (as K)	0.55
Carbon (as C) [1]	16 – 22

[1]indicative of the potential for soil conditioning, normally not designated as a nutrient

For composting purposes, the easily biodegradable fraction is of immediate interest. This includes food waste, vegetables and fruits, and garden wastes (sometimes referred to as yard wastes) such as grass, leaves and small woody materials. Although organic waste materials such as paper and timber may also be composted, they are more resistant to microbial degradation due to their high lignin content. If these materials are included in the composting process, their particle sizes are often reduced beforehand through shredding to allow for quicker decomposition. Based on composition of solid waste of cities of low- and middle income countries (from Algiers, Accra, Alexandria, Cairo, Sao Paolo) easily biodegradable fractions range between 44 and 87 %. (in weight).

Appendix 9: Calculations regarding logistics and labour input of the composting treatment of Scenario A.

The following information contains the basic data needed for the calculations to follow. Density of household, agricultural and market waste is obtained based on results performed by IWMI and SANDEC (2002)

Basic Data

HW: Household waste

Density of HW ρ (kg/m^3)= 533

MAW: Market waste / agricultural waste

Density of MAW ρ (kg/m^3)= 400

DF: Dried Faeces

Ratio DF/OW	DF:SOW $_{volume}$=	1: 2
Mass of Dry faeces	m_{DF} (kg)=	100800
Volume of Dry faeces	V_{DF} (m^3)=	90
Density of DF	ρ (kg/m^3)=	1120

SOW: Solid Organic Waste

SOW=HW+MAW

The following table shows the calculation regarding the amount of household waste and market and agricultural waste needed to run the composting process, as well as the calculation regarding logistics.

Table A.12- Source of organic solid waste /collection for Scenario A

HW production	(kg/per×d)	0,17
Inhabitants	(per)	2000
HW production$_{TOTAL}$	(kg/week) (m^3/week) (kg/month) (m^3/month)	2380 4,4625 10200 19,1
HW produced in 4 months	(m^3)	76,5
SOW needed (2 ×DF)	(m^3)	180
MAW to receive in 4 months	(m^3)	103,5
Weekly MAW received after sorting	(m^3/week)	6,47
Times at month of HW collecting	(-)	4
Estimated time of collection of HW	(h)	5
Time estimated for each drive to the eco-station (both ways)	(h)	2

Following the indications regarding labor input for sorting procedure found in section 5.1.3.1, the next table shows the weekly work needed to sort the solid organic waste.

Table A.13- Sorting of Solid Organic Waste of Scenario A

Amount of HW to be sorted	(m^3/week)	8
Labour imput for HW sorting	(hours/m^3)	10
Estimated time for HW sorting	(hours/week)	80
Amount of MAW to be sorted	(m^3/week)	10
Labour imput for MAW sorting	(hours/m^3)	6
Estimated time for MAW sorting	(hours/week)	60

The following table shows the calculation regarding the design of the windrows, taking into account the amount of solid organic waste delivered by each source, as well as the recommendations regarding faecal sludge / organic matter ratio (1:2), moisture needed (50% weight) and geometry of the pile

Table A.14- Design of the composting windrow and Starting the composting process of Scenario A

Available HW available per week	(m^3/week)	4,5
	(kg/week)	2380
Available MAW available per week	(m^3/week)	6,5
	(kg/week)	2588
Available OSW every week	(m^3/week)	11
	(kg/week)	4968
Amount of dry faeces to compost	(m^3/week)	5,5
	(kg/week)	6121,5
Total material to be composted	(m^3/week)	16,5
	(kg/week)	11089
Large	(m)	6,6
Width	(m)	2,5
Height	(m)	1
Volume of the pile	(m^3)	16,5
Initial water to be irrigated	(m^3)	55
Time needed to set the composting pile (1h/m^3)	(h)	16,5

The following table presents the calculation regarding the monitoring and maintenance of the 8 piles of composting, which would be running every week.

Table A.15- Composting process in Scenario A

Duration of composting period	(weeks)	8
Turning and watering sesion (twice at week first month, once at week second month)	times/pile	12
Time of each turning and watering sesion	(h)	3
Total turning and watering sesions to be perfomed with 8 piles (4 piles twice at week, 4 piles once at week)	times/week	12

Assuming a reduction of 50% volume and 30% weight of organic material, the following table shows the production of compost every 4 months and monthly.

Table A.16- Production of compost in Scenario A

		Every four months	
		Before	**After**
Amount of lime and soil	kg	72000	72000
	m^3	58,78	58,78
Amount of faeces	kg	28800	8640
	m^3	28,8	14,4
Amount of OSW	kg	82200	24660
	m^3	180	90

Total mass (kg)	**Every four months**	105300
Total volume (m^3)		163,18

Total mass (kg)	**Monthly**	26325
Total volume (m^3)		40,8

The following table shows the estimations regarding labour input of the composting procedure for Scenario A taking the following assumptions:

✓ Technician work:
5% of non skilled work for sorting HW and MAW
30% of non skilled work for starting and maintenance of the pile.
1 hour/ week for selling

✓ Engineer work
1% of non skilled work for sorting HW and MAW
10% of non skilled work for starting and maintenance of the pile.
3h/d of management
1hour/ week for selling

Table A.17- Labour input (measure in hours of work) regarding composting process for scenario A

Duty	Unskilled worker	Driver	Technician	Engineer
	(h/month)			
Collection of HW	20			
Transport of HW to eco-station		8		
Sorting HW	320		16	3,2
Sorting MAW	240		12	2,4
Starting the composting pile	66		19,8	6,6
Turning and watering sesion	144		43,2	14,4
Management of composting period (3h/d) - 6 d/week				72
Charging compost to sell	16		4	4
total hours	806	8	95	103
(person/month)	5,04	0,05	0,59	0,64

Appendix 10: Calculations regarding Vermicomposting-Rottenbehälter technology in Scenario B.

The expected amount of faecal product and filtrate is shown in the table A.19, together with the amount of units needed for the study area.

Table A.18- Calculations regarding the flows and the rottenbehälter units needed in the study area.

Housing Unit	Inhabitants (-)	$Mass_{faeces}$ (kg/d)	$Volume_{faeces}$ (m^3/d)	$Volume_{flush\ water}$ (m^3/d)	$Volume_{Filtrate}$ (m^3/d)	$\Delta Volume_{faecal\ cake\ (85\%\ moisture)}$ (m^3/d)	Volume $_{faecal\ cake\ in\ 6\ months}$ (m^3)	Number of units needed (-)	
A	432	129,6	0,1296	2,592	2,2896	0,1728	31,536	10,1	11
B	192	57,6	0,0576	1,152	1,0176	0,0768	14,016	4,5	5
C	96	28,8	0,0288	0,576	0,5088	0,0384	7,008	2,2	3
D	266	79,8	0,0798	1,596	1,4098	0,1064	19,418	6,2	7
E	248	74,4	0,0744	1,488	1,3144	0,0992	18,104	5,8	6
F	42	12,6	0,0126	0,252	0,2226	0,0168	3,066	1,0	2
G	352	105,6	0,1056	2,112	1,8656	0,1408	25,696	8,2	9
H	352	105,6	0,1056	2,112	1,8656	0,1408	25,696	8,2	9
Total	**1980**	**594**	**0,594**	**11,88**	**10,494**	**0,792**	**144,54**		**52**

Design Data:

$Mass_{faeces/person}$ (g/d*p)= 300

$Mass_{faeces/person}$ (kg/d*p)= 0,3

$Volume_{faeces/person}$ (l/d*p)= 0,3

$Volume_{flushing\ water/person}$ (l/d*p)= 6

Volume of the sack (1,25 x 1,25 x 2) (m^3)= 3,125

(*) Security 2 times per day / 2 flushing

Assuming a 30% reduction of volume through the process of Vermicomposting, the following total amount of produced compost are given:

Table A.19- Amount of produced compost.

Volume of substrate (m^3) (30% reduction)	
Initial	**Final**
31,536	22,0752
14,016	9,8112
7,008	4,9056
19,418	13,5926
18,104	12,6728
3,066	2,1462
25,696	17,9872
25,696	17,9872
144,54	**101,178**

The following tables present the logistics and the labour input needed for this scenario.

Table A.20- Logistics regarding Vermicomposting and transportation of compost.

Amount of compost product every 6 months	m^3	101,178
Capacity of the Tipper truck	m^3	8
Number of collection trips in 6 months	No	12,64725 ≅ 13
Time estimated for each emptying	h	8
Time estimated for each drive to the field (both ways)	h	2
Monitoring time of each transportation procedure	h	4
Maintenance of the systems (per week each system)	h	3
Monitoring time of each system (per week)	h	0,5

Table A.21- Labour input (measure in hours of work) regarding the application of vermicomposting.

Duty	**Unskilled worker**	**Driver**	**Technician**	**Engineer**
	(h/month)			
Maintenance of the vermiculture	624		104	104
Emptying and transport of the ready compost	17,3	4,3	4,3	4,3
total hours	641	4	108	108
(person/month)	4,01	0,03	0,68	0,68

Appendix 11: Calculations regarding Anaerobic degradation in Scenario B.

Sizing the digester: The size of the digester is determined on the basis of the chosen retention time RT (30 days) and the daily substrate input Sd (faeces + flushing water): $Vd = Sd \times RT$

In the following table the volume of the digesters are calculated assuming a retention time of 30 days and a security factor of 30%.

Table A.22- Labour input (measure in hours of work) regarding the application of Vermicomposting

Housing Unit	Inhabitants (-)	$Mass_{faeces}$ (kg/d)	$Volume_{faeces}$ (m^3/d)	$Volume_{flush\ water}$ (m^3/d)	$Volume_{Brown\ water}$ (m^3/d)	$Volume_{Brown\ water\ 30\ days}$ (m^3)	Volume of the Digestor (30% security) (m^3)
A	432	129,6	0,1296	2,592	2,7216	81,6	106
B	192	57,6	0,0576	1,152	1,2096	36,3	47
C	96	28,8	0,0288	0,576	0,6048	18,1	24
D	266	79,8	0,0798	1,596	1,6758	50,3	65
E	248	74,4	0,0744	1,488	1,5624	46,9	61
F	42	12,6	0,0126	0,252	0,2646	7,9	10
G	352	105,6	0,1056	2,112	2,2176	66,5	86
H	352	105,6	0,1056	2,112	2,2176	66,5	86
TOTAL					**12,474**	**374,22**	**486**

Design Data:

$Mass_{faeces/person}$ (g/d*p)= 300

$Mass_{faeces/person}$ (kg/d*p)= 0,3

$Volume_{faeces/person}$ (l/d*p)= 0,3

$Volume_{flushing\ water/person}$ (l/d*p)= 6 (*) Security 2 times per day / 2 flushing

Table A.23- Production of biogas and liquid slurry.

Housing Unit	$Mass_{faeces}$ (kg/d)	Biogas Production (m^3/d)	Digested Sludge (ton/d)
A	129,6	7,776	2,7
B	57,6	3,456	1,2
C	28,8	1,728	0,6
D	79,8	4,788	1,7
E	74,4	4,464	1,6
F	12,6	0,756	0,3
G	105,6	6,336	2,2
H	105,6	6,336	2,2
TOTAL		**35,64**	**12,5**

Appendix 12: Calculations regarding human urine management produced by the population of study for the UPESSA project in the Arat Kilo and Piazza inner city areas.

According to the analysis of the chapter 4, the amount of urine per person in Ethiopia is taken as 1,5 l/p·d. The following calculation shows the daily and monthly production of urine in the inner city areas Piazza and Arat Kilo.

Table A.24- Total amount of urine per day and per month

Building Code	Inhabitants (-)	$Volume_{urine}$ (m^3/d)	$Volume_{urine}$ (m^3/month)	$Volume_{tank\ (2\ months\ retention\ time}$ + 20% security factor) (m^3)		Trips to transport (capacity of truck 8 m^3) (-)
A	432	0,648	19,44	38,88	47	6
B	192	0,288	8,64	17,28	21	3
C	96	0,144	4,32	8,64	10	1
D	266	0,399	11,97	23,94	29	4
E	248	0,372	11,16	22,32	27	3
F	42	0,063	1,89	3,78	5	1
G	352	0,528	15,84	31,68	38	5
H	352	0,528	15,84	31,68	38	5
Total		3	90		214	27

Design data

$Volume_{urine/person}$ (l/d)= 1,5

$Volume_{urine/person}$ (m^3/d)= 0,0015

Estimated volume

Total volume of urine per month (m^3/month)= 89,1 ≅ 90

Total volume of urine per year (m^3/y)= 1084,05 ≅ 1100 Amount of N (kg) 7040

Table A.25- Logistics regarding management of urine and transportation to agricultural land

Amount of urine product every 2 months	m^3	180
Capacity of the Vacuum truck	m^3	8
Number of collection trips in 6 months	No	22,5 ≅ 27
Time estimated for each emptying/transfilling	h	8
Time estimated for each drive to the field (both ways)	h	2
Monitoring time of each Empytying/Transportation/Transfilling procedure	h	4
Maintenance of the systems (per week)	h	3
Monitoring time of each system (per week)	h	2

Table A.26- Labour Input for management of urine

Duty	Unskilled worker	Driver	Technician	Engineer
	(h/month)			
Emptying/Transfilling	108		54	54
Transport of the Urine	27	27		
Maintenance of the system	12		8	8
total hours	147	27	54	54
(person/month)	0,92	0,17	0,34	0,34

Appendix 13: Calculation of costs

Table A.27- Calculation of cost for Scenario A

Investment costs							Operational costs									
	Unit	Quantity	Unit price (birr/unit)	Investment birr	Operation (annual %)	Operation (birr/month)	Labour costs	Unit	Quantity	Unit price (birr/unit)	Cost (birr/month)	Material costs	Unit	Quantity	Unit price (birr/unit)	Cost (birr/month)
Gathering Tanks	-	40	1500	60000	1	50	**Engineer**		0,38	1500	563	**Operation and maintenance**	proportional of investment			6512
Tipper truck	-	1	771000	771000	10	6425	**Technician**		0,28	600	166	**Dry agent**	kg/month	19600	0,05	980
Excavation for the construction of 8 ramps	m^3	200	40	8000	1	7	**Unskilled worker**	person/month	1,47	400	587	**Energy (oil + electricity)**	trips	23	30	690
Kit Wheelbarrows + Shovels	-	2	200	400	20	7	**Driver**		0,63	500	313	**Administration**	%	1		82
Drying material storage - Roofed area	m^2	36	800	28800	1	24	**Administration**		10%	600	165					
Sub-total Primary Treatment				**868200**		**6512**	**Sub-total**				**1794**	**Sub-total**				**8264**
Dry faeces storage - Roofed area	m^2	90	800	72000	1	60	**Engineer**		0,64	1500	962	**Operation and maintenance**	proportional of investment			398
SOW reception / sorting - Roofed area	m^2	25	800	20000	1	17	**Technician**		0,59	600	356	**Energy (oil + electricity)**	trips	4	30	120
Composting Area - Roofed area	m^2	255	800	204000	1	170	**Unskilled worker**	person/month	5,04	400	2015	**Administration**	%	1		5
Compost storage - Roofed area	m^2	25	800	20000	1	17	**Driver**		0,05	500	25					
Kit Wheelbarrows + Shovels	-	6	800	4800	20	80	**Administration**		10%	600	379					
Construction of well	-	1	1000	1000	5	4										
Monitoring Equipment	-			3000	20	50										
Sub Total Secondary Treatment				**324800**		**398**	**Sub-total**				**3737**	**Sub-total**				**523**
Total Area required	m^2	750	5	**3750**												
Sub Total				**1196750**												
Allowances (10%)				**119675**												
Design and Supervision (8%)				**95740**												
TOTAL				**1412165**												**14318**

Table A.28- Calculation of cost for Scenario B

Investment costs							Operational costs									
	Unit	Quantity	Unit price (birr/unit)	Investment birr	Operation (annual %)	Operation (birr/month)	Labour costs	Unit	Quantity	Unit price (birr/unit)	Cost (birr/month)	Material costs	Unit	Quantity	Unit price (birr/unit)	Cost (birr/month)
Rottenbehälter unit	-	52	20000	1040000	1	867	Engineer		0,68	1500	1020	Operation and maintenance	proportional of investment			883
Pipe system (250 mm - 5 m perhousehold)	m	200	85	17000	0,5	7	Technician		0,68	600	408	Flushing water	m^3	356	10	3560
Excavation for the construction of 8 ramps	m^3	80	34	2720	1	2	Unskilled worker	person/month	4,01	400	1604	Administration	%	1		44
Kit Wheelbarrows + Shovels	-	2	200	400	20	7	Driver		0,03	500	15	Other (Vermicomposting)				1000
Installation of pipes	m	200	85	17000	-	-	Administration		10%	300	162	Transport of compost to field (Rent and Energy)		2	300	600
Sub-total				**1077120**		**883**	**Sub-total**				**3209**	**Sub-total**				**6087**
Allowances (10%)				**107712**												
Design and Supervision (8%)				**86169,6**												
TOTAL				**1271002**												**9296**

Table A.29- Calculation of cost for management of urine

Investment costs							Operational costs									
	Unit	Quantity	Unit price (birr/unit)	Investment birr	Operation (annual %)	Operation (birr/month)	Labour costs	Unit	Quantity	Unit price (birr/unit)	Cost (birr/month)	Material costs	Unit	Quantity	Unit price (birr/unit)	Cost (birr/month)
Pipe system (150 mm - 10 m perhousehold)	m	400	50	20000	0,5	8	Engineer		0,3375	1500	506	Operation and maintenance	proportional of investment			7120
Installation of pipes	m	400	85	34000	-	-	Technician		0,34	600	203	Energy (oil + electricity)	trips	13	30	390
Storage tanks (total capacity)	m^3	214	120	25680	1	21	Unskilled worker	person/month	0,92	400	368	Administration	%	1		71
Earthworks	m^2	214	40	8560	1	7	Driver		0,17	500	84					
Vacuum Truck	-	1	850000	850000	10	7083	Administration		10%	300	53					
Sub-total				**938240**		**7120**	**Sub-total**				**1213**	**Sub-total**				**7581**
Allowances (10%)				**93824**												
Design and Supervision (8%)				**75059,2**												
TOTAL				**1107123**												**8795**