# LOW COST ON-SITE SANITATION

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## ABSTRACT

To ensure improved sanitation of 75% of the world's population is one of the Millennium Developing Goals (MDG). Nevertheless, sanitation levels remain far from the intended. There is still an overwhelming percentage of the world's population that lacks access to improved sanitation, the need for action to tackle this problem is urgent. The present decision model, based on flowcharts, aims to help defining the sanitation system in its entirely and allows a straightforward understanding of the main variables that must be taken into account when designing a low-cost, on-site sanitation system. Its focus is on small villages, up to 250 inhabitants, with a maximum density of 200hab/ha. It is believed that this decision support system could be a significant help for stakeholders when choosing appropriate methods for the implementation of improved sanitation in developing countries, particularly for the Portuguese speaking countries.

**Keywords:** On-site, low-cost; sanitation, MDG, PALOP, decision model; developing countries.

## INTRODUCTION

To plan an on-site sanitation system is a complex matter and should always be focused on the population's needs and wishes. As a result, a good understanding of the population's culture, beliefs and the physical constraints connected to the development site are crucial. The present paper is focused on how these constraints; either physical or behavioural may affect the system's design.

However, it is crucial to understand the deep impacts that the lack of appropriate sanitation can have on society and the specificities of the reality on developing countries. This paper is intended for the rural and disperse periurban context of developing countries, in particular for villages that have no more than 250 inhabitants and its housing density is limited to 200 inhabitants per hectare. The motivation behind this paper lies on the scarcity of information on this matter accessible in Portuguese language. This dissertation results as a thorough research on the most recent and important documents on on-site sanitation and aims to help on the decision making process of developing these systems for Portuguese speakers.

## THE NEED FOR SANITATION ON DEVELOPING COUNTRIES

The lack of sanitation is a problem that affects one third of the world's population. Although there has been international action on this matter, the continuous growth of the number of people that do not have access to a safe and clean toilet on their daily basis shows that these efforts have not been enough. Sanitation may be defined as the establishment of facilities and services that guarantee the safe disposal of urine and faeces. These are essential for the maintenance of hygienic conditions that play a major role in public health and human wellbeing (WHO, 2013).

On developed countries, sanitation revolves around centralized treatment, with complete wastewater treatment plants, and clean water supply for every household. This reality could not be further away from the existing one on developing countries. The cost of centralized treatment is very high and unlikely feasible option for these communities, especially in the rural and periurban context. Furthermore, in most of these countries, especially in sub-Saharan Africa, water is scarce and people do not have access to safe drinking water inside their homes. Thus, the concept the toilet has to be adapted to this reality (Black, et al., 2008).

## Sanitation as a disease barrier

Humans have always had the urge to separate their daily lives from excreta, this results from the fact that human faeces carry extremely high doses of pathogenic material that pose serious threats to human health. Therefore, sanitation comes as the first barrier to the dissemination of diseases. Along with food security, personal hygiene and safe drinking water, sanitation comes as a major motor for public health. The most common way of contamination is the faecal-oral route. Contamination may occur in many different situations; these may be related to soiled hands, handling ~~of~~ contaminated objects, disease transmission vectors (insects or rodents) and contaminated water or food. Thus, sanitation, acts as the first barrier between pathogens and the new host (Wagner, et al., 1958).

## Millennium Development Goals (MDG) and the sanitation ladder

For some decades~~,~~ sanitation has been on the international community agenda. However, if comparing to drinking water, sanitation has~~,~~ received less attention for a long time. The United Nations (UN) presented the eight MDG in 2000. However, only in 2002, during the World Summit for Sustainable Development, sanitation was incorporated as a part of the 7$^{th}$ MDG, which has as objective to ensure environmental sustainability. This goal aims to halve the number of people without access to improved sanitation until 2015; this means that by that time, 75% of the world's population should have access to improved sanitation (UN Millennium Project, 2005).

The deadline to reach these goals is drawing near and the progress on this sanitation benchmark still seems far from attainable. By 2011, there were 45 countries where half of the population did not have access to improved sanitation; most of these countries are located in sub-Saharan Africa. Presently, the aim is to eradicate completely open defecation by 2025 (WHO/UNICEF, 2013).

Access to decent sanitation has major impacts on population's quality of life; therefore, sanitation affects in very important ways all of the other MDGs.

Improved sanitation is defined by the sanitation ladder developed by the Joint Monitoring Program (JMP) of UNICEF and the World Health Organization (WHO). It aims to act as an indicator of the development of the access to sustainable sanitation on developing countries. This ladder has four rungs from Unimproved Sanitation (open defecation, unimproved, shared) to Improved Sanitation; the ascent on these rungs requires increasing investment and technical knowledge. Nevertheless, this monitoring tool may lead to some inaccurate data about the sanitation situation (Kvarnström, et al., 2011). On this paper only technologies present on the Improved Sanitation rung will be considered.

### The sanitation situation on PALOP

This paper has a focus on the African Portuguese speaking countries (PALOP): Angola, Mozambique, Guinea-Bissau, Sao Tome and Principe and Cape Verde. The UN lists all of these countries, except Cape Verde, as some of the least developed countries in the world, with most of their population living below the poverty line (WHO/UNICEF, 2013). Over the last five decades, these countries have witnessed an extreme increase in urban population, of around 40 times (Black, et al., 2008). Within this scenario, the existing wastewater systems are unable to respond to such a quick population rise, most of cities inhabitants do not have access to decent toilet facilities, that is, when there is any.

In these countries, open defecation is still a very common practice, mostly in rural areas. Since 1995 until 2011, the country that has shown a bigger progress in terms of access to improved sanitation is Angola, with an increase of 37%. On the other hand, Guinea-Bissau has the poorest development with only 11%. All of these countries have the biggest part of their population in urban centres, with the exception of Mozambique, where only 31% of its people live in cities. Of the PALOP, Mozambique is the country with the poorest sanitary conditions, in rural areas only 9% of the population has access to improved sanitation. In terms of open defecation, for 55% of the population is still the only option. However, Sao Tome and Principe is the country where this practice is more common, at 55% (WHO/UNICEF, 2013).

In light with previously mentioned, it becomes clear that the need for intervention in these countries is crucial and the governments need to take action if they intend to get closer to attaining the sanitation MDG. Hence, it becomes imperative that information on how to tackle this problem is widely known, Which is indeed the main goal of the objective of this paper.

## ON-SITE SANITATION FOR SMALL HOUSING CLUSTERS

On-site sanitation means that excrete is dealt with where it is deposited (Franceys, et al., 1992). Furthermore, it is considered that the system should always be installed on land that is owned by the community, otherwise the cost associated with its acquisition will add up to the system's price. Out of this paper's scope are matters that deal with the management of these systems and the specificities of public toilet services.

A sanitation system should always comply on means of collecting and storing excrete, and possibly black and greywater along with it, there might be the need of transportation but treatment is always deemed as necessary. Any system should always have all of these components. Ignoring any of them does not solve the sanitary problem; it simply displaces it somewhere else. On-site systems should always have the following characteristics (ISO, 2013):

- It should satisfy the user's needs;
- It's utilisation, maintenance and construction should be simple and low-cost;
- It should include facilities that guarantee the right treatment of the produced residue.

## Different types of users and excreta accumulation

The ways to deal with personal hygiene vary greatly depending on the cultures. Sanitation systems should always aim to respect these traditions. For instance, some cultures prefer sitting while defecating while others find squatting more natural. The materials with which the anal cleansing is done are also highly variable; they can range from paper or corncobs to water (Franceys, et al., 1992). This kind of information is relevant when choosing between different sanitation techniques, some dry sanitation options may not be compatible with wet materials, such as the *ecological latrine* where faeces can be dehydrated and in this case moist content should be kept to a minimum.

Faeces and urine have highly variable characteristics according to the different ways of life. The quantity and pathogenic content excreted per individual depends on the existing access to water, climate, diet, age and sex. Knowing these quantities is necessary when dimensioning pits and it is highly recommended to obtain precise values for each case. If this is not possible then some indicative values are presented on Table 1.

**Table 1: Amount of faeces and urine excreted daily per person depending on the kind of diet and climate. Adapted from Franceys, et al. (1992).**

| Diet and climate | Urine (l/person/day) | Faeces (g/person/day) |
|---|---|---|
| **Protein diet and temperate climate** | 1,2 | 120 |
| **Vegetarian diet in a tropical climate** | 1,0 | 400 |

However, more aspects are deemed necessary for the determination of the volume of excrete during storage. The process of decomposition of excreta starts as soon as it is deposited and after some time it becomes a stable matter without unpleasant odour. This process is due to the action of bacteria and fungi, this may occur under aerobic or anaerobic conditions.

**Table 2: Sludge accumulation rate, litres per person per year. Adapted from (Franceys, et al., 1992)**

| | Sludge accumulation rate (l/person/year) |
|---|---|
| **Waste retained under water and cleansing materials are degradable** | 40 |
| **Waste retained under water and cleansing materials are non-degradable** | 60 |
| **Waste retained on dry conditions and cleansing materials are degradable** | 60 |
| **Waste retained on dry conditions and cleansing materials are non-degradable** | 90 |

In addition to the mentioned degradation processes, decomposition also implies a volume reduction, the very accumulation of excreta leads to compaction. Additionally, besides the type of anal cleaning material used, the storage volume also depends on whether decomposition takes place under water or not. Under water decomposition leads to greater volume losses. Table 2 depicts indicative storage accumulation rates, these values take into consideration all the above mentioned variables.

## Excreta reuse in agriculture

Currently much of agriculture is dependent on the use of chemical fertilizers to improve productivity of the fields. Through the reuse of nutrients in excreta, sanitation systems can help reduce the expense associated with the purchase of these products.

The products of sanitation systems can be urine and materials with a similar appearance to natural soil (compost or humus), these have a high quantity of nutrients in their composition, and their addition to soils improves productivity leads to a better yield. Therefore, the reuse of excreta can help ensuring a better food supply for the community (Morgan, 2007). Moreover, this reutilisation may improve local economy. On one hand, compost and urine can be a product of trade that may become a source of additional income to the families. On the other hand, better quality products may be sold more easily and thus instigating agriculture (WaterAid Moçambique, 2001).

There are differences between the composition of urine and faeces. Nutrients are found in greater quantity in urine but faeces have the largest percentage of organic material (WHO, 2006). Besides its different compositions, there are further differences between urine and faeces related to their storage time and treatment. For instance, faeces need a longer treatment when compared to urine. Furthermore, populations usually have a better acceptance of the reutilization of urine (WaterAid Moçambique, 2001).

One other product of this type of systems is biogas; it is produced during the digestion of faecal sludge and can be utilised as cleaner energy alternative. This means biogas can be used for cooking, lighting and heating (Tilley , et al., 2008).

# SANITATION SYSTEMS

When planning a sanitation system it is necessary to take into account the reality of the community that will use these structures and services. The sanitation systems considered can be divided into five different elements. This division creates a greater number of options as to guarantee that the chosen solution fits the site's conditions on the best possible way. The five elements are: (i) user interface, (ii) collection & primary treatment, (iii) emptying & transport, (iv) complementary treatment and (v) final destination.

The **user interface** is the means by which people access the sanitation system, this includes the various types of toilet. Followed by the collection, which encompasses the collection and isolation of the "excreta" from the population, ultimately leading to a reduction of the risk of spreading pathogens and therefore guaranteeing a primary treatment. The latter eliminates most of the transmission vectors. Nevertheless, storage technologies need emptying and therefore, it is necessary to provide an **emptying** and **transport** service to the **complementary treatment** site, where faecal sludge is transformed into an innocuous material. The last phase of the system is the **final destination** and its purpose is to ensure the safe use and disposal of products resulting from the treatment of excreta in a way that it is not harmful to the environment or to public health.

According to the average water consumption levels existing on developing countries, 20 to 30 l/person/day as suggested by the WHO (2006), three different types of systems are considered. These systems are presented along with the water consumption levels that ensure their proper functioning

### Dry Systems - Water consumption under 20 l/person/day

Dry systems are typically used in rural areas with low population density and water scarcity. The water distribution is usually done through standpipes or hand-dug wells. In these cases the treatment of greywater if it is considered, is done separately. Beside excreta, these structures can be filled with other types of waste such as dung or cooking waste. Each household must have its own toilet.

In these systems, treatment is accomplished by natural decomposition processes, which take place during long storage periods. The whole treatment can be ensured in hand-dug pits. After two years of storage the organic matter that has been deposited is stabilized and sanitized. , and can be used as a soil fertiliser.

### Transition Systems - Water consumption between 20 and 60 l/person/day

These systems are appropriate when water is more readily available; therefore, the water consumption is higher than the considered for dry systems. However, it still is not enough to consider a water-based system. In this case, the water distribution is done typically through taps located at houses' backyard. Similarly to dry systems, on transition systems only blackwater is considered. In most cases, greywater is treated separately. These kind of systems will need, on most occasions, complementary treatment for the faecal sludge and the effluent; this means that a proper emptying and transport system should be guaranteed between systems' components.

### Water Systems - Water consumption over 60 l/person/day.

All of the technologies in this system are water-based and, therefore, for their proper treatment water distribution must be domiciliary. In these systems the use of cistern flush toilets is advisable and greywater is treated along with blackwater, making this the most expensive option. All water systems must have two complementary treatments: one for the faecal sludge and another for the effluent that is produced during collection and primary treatment.

## DECISION SUPPORT SYSTEM

When choosing an on-site sanitation system there are many important factors that should be taken into account: socioeconomic situation, culture, financial, technological and institutional (Franceys, et al., 1992). Furthermore, these systems should be well adapted to the local conditions and must be prepared to adjust to environmental changes. Prior to the decision process, the village should be completely characterised in terms of its situation towards sanitation. Some estimates on how the village will develop over the next decades are also necessary; all the technologies should have a lifespan of at least 5 to 10 years (Monvois, et al., 2010). The population's preferences must be considered at all times, as well as cultural beliefs and taboos. The system only has a positive impact on public health and improves people's lives if it is correctly used.

The selection model proposed by the author is divided into five phases: (i) selecting the type of system, (ii) choosing the technology for *Collection & Primary Treatment*, (iii) choosing the method of *Emptying & Transport*, (iv) choosing the technology for *Complementary Treatment* and (v) the confirmation of *Final Destination*. Each decision phase, for each type of system, is guided by a flowchart and decisions are made according to the soil's characteristics and users preferences. This decision model is does not contain specific information about the system's cost. Construction, operation and maintenance costs are very variable; they depend on the system's final design, the availability of certain materials, and labour costs. Although there are some studies on cost prediction methods, such as the one developed by BRETTL (2013), further research on this topic is needed.

As a demonstration of the flowcharts developed, only dry systems are presented. This type of system was chosen for this abstract as they are constituted by the least expensive technologies and meet more frequently the existing conditions on rural and disperse periurban settings of developing countries. Figure 1 comprehends the flowchart that aids the choice of the *Collection & Primary Treatment*. Soil conditions are extremely important for the feasibility of these systems, the existence of shallow rock formations, the soil's permeability, the knowledge of the groundwater level and the likelihood of flooding in the area, are crucial. The possibilities for user interface are the dry toilet, the urine diversion dry toilet (UDDT) and the urinal. These last two facilitate the collection and, consequently, the reutilization of urine.

Firstly, the soils permeability is one of the main influencing factors as most of these sanitation techniques require the infiltration of wastewater. The percolation of water through the soil guarantees pathogenic elimination as the soil granular matrix acts as a filter (Tilley , et al., 2008). Secondly, the excavation of rocky soils becomes a difficult task without mechanical equipment that is hard to attain on rural areas of developing countries, also these kind of soils are not permeable. Thirdly, the groundwater position is key, a high groundwater level may pose a threat to public health as it can easily become contaminated by pathogens. Therefore, it should always be at least 3m below the bottom of the technology. Finally, flooding may jeopardize the integrity of the pits, putting public health at risk due to the dispersion of faecal matter (Tilley , et al., 2008; Monvois, et al., 2010). The technologies considered are the single simple pit, the single ventilated improved pit (VIP), the *fossa alterna* and the ecological latrine. Only the latter is compatible with areas where excavation/infiltration is not possible or that are prone to flooding.

Additionally, the available space for the construction of multiple pits and the acceptance of reutilization of the sanitation products are important for this technological choice. It is recommended that these systems utilize some kind of technology to deal with greywater that is generated by food preparation, other types of domestic chores or personal hygiene. This is important as stale water is the habitat of mosquitoes that spread diseases such as malaria or dengue (Huuhtanen, et al., 2009). Therefore, on Figure 1 each sanitation technology is accompanied by an infiltration technique. If reutilization of the materials is desired, dry sanitation systems are always dependent of manual *Emptying & Transport*. Due to the earth-like consistency of the product, techniques that utilize vacuum for suction are impracticable.

After selecting the *Collection & Primary Treatment* technology, the reader should examine the flowchart on Figure 2 for information on *Complementary Treatment*. Most *Collection & Primary Treatment* technologies do not need further treatment, only single pits (single VIP pit or the simple pit) that will be reutilized need this treatment. In this case, exists the opportunity of treating other organic residue, such as domestic waste, alongside with the faecal matter, on co-composting sites. However, if communities do not desire this type of treatment then the option should be planted drying beds.

Figure 3 is the last flowchart of this guide and its aim is to confirm the *Final Destination* of the products generated throughout the utilization of the system. Single pits may be deactivated or their content may be deposited on a landfill. The treated effluent from landfill filters may be reused for irrigation or discharge on mass waters, whereas soak pits recharge the aquifers. The compost resulting from co-composting, *fossa alterna* or ecological latrine should be reutilized as fertilizer.

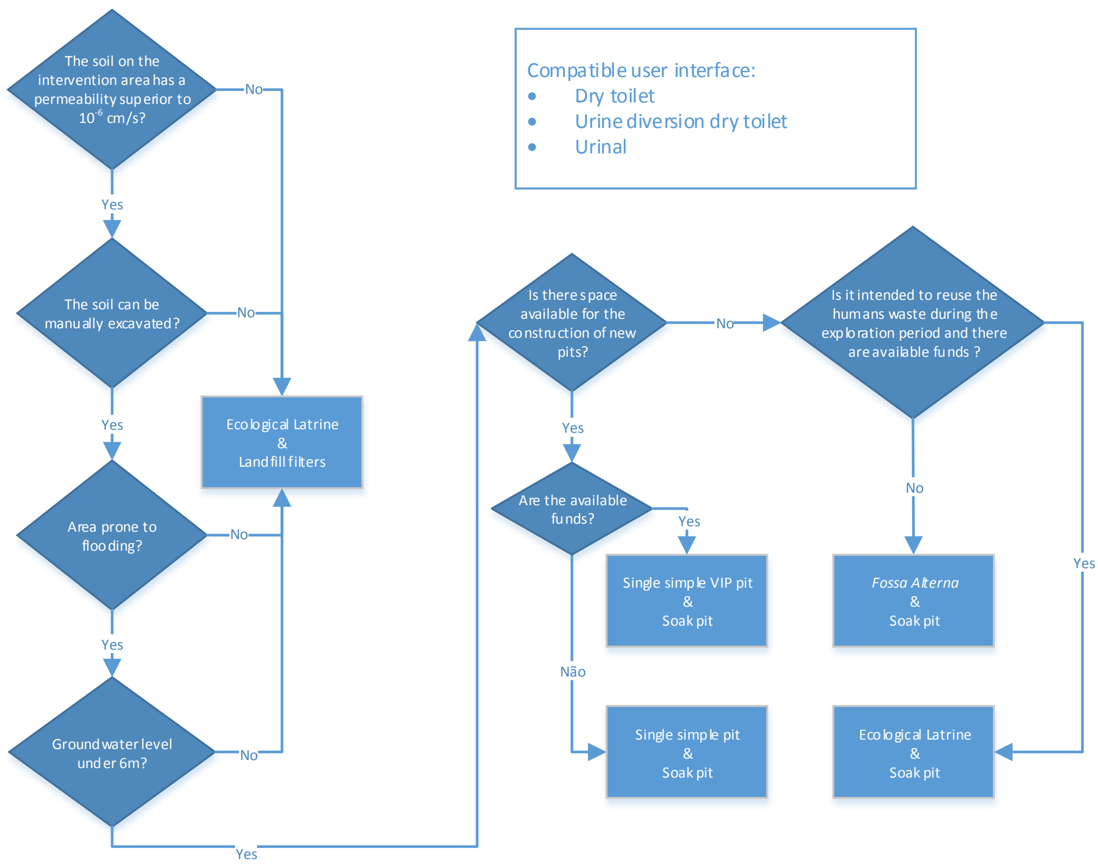


**Figure 1: Setting the Collection & Primary Treatment phase, depending on the physical characteristics of the soil for dry systems. Possible user interface is also identified.**

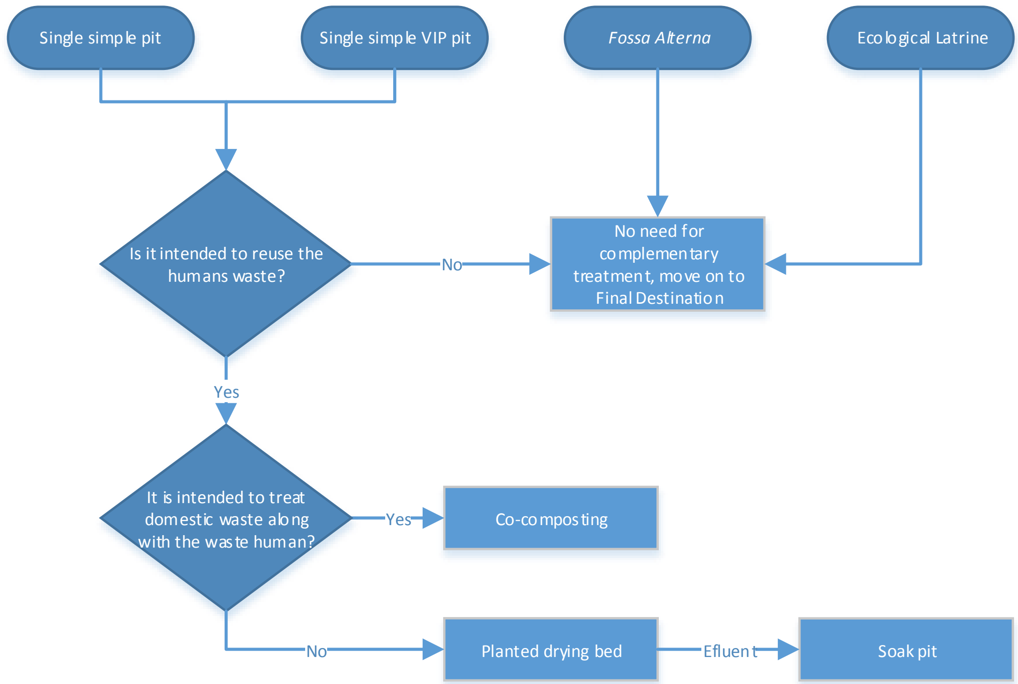


**Figure 2: Setting the Complementary Treatment phase, depending on the previous choices on dry systems.**

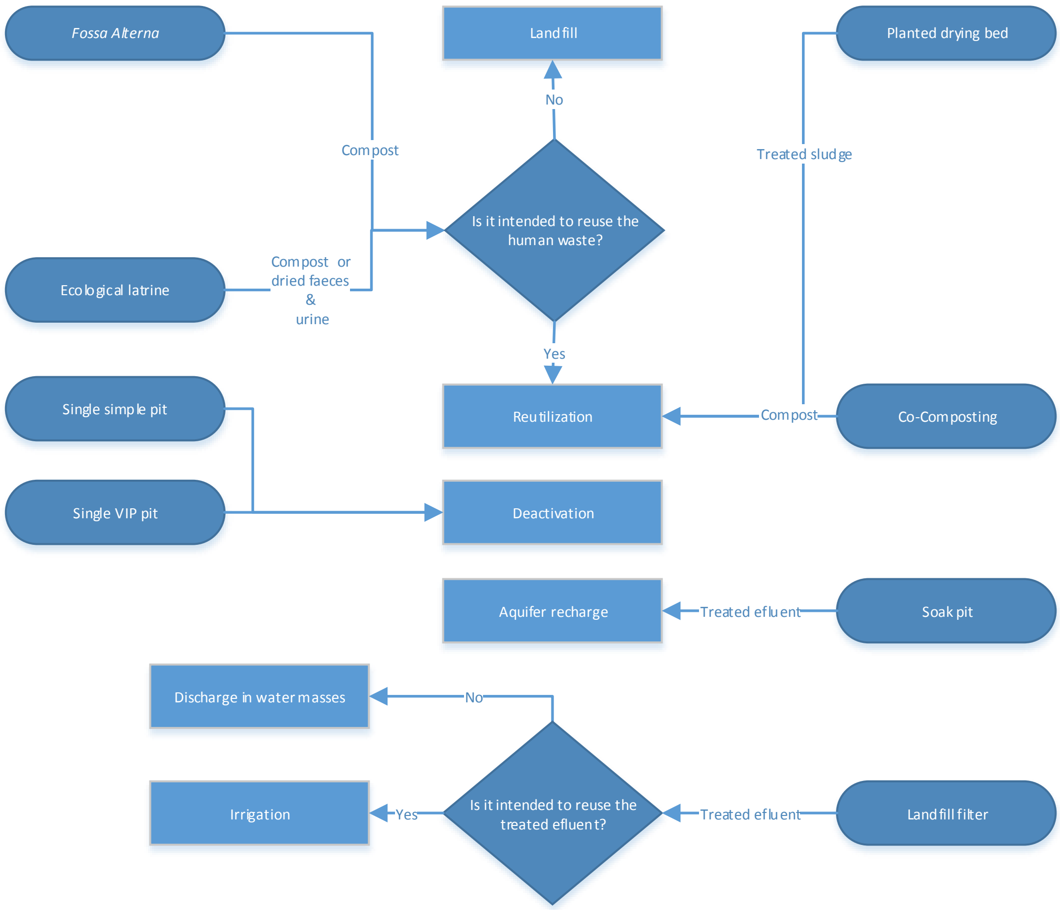


**Figure 3: Confirmation of Final Destination of dry systems' products.**

## CONCLUSION

Ensuring improved sanitation to 75% of the world's population is one of the MDGs. With a little more than a year to its deadline, sanitation levels remain far from the intended. Africa is the continent where the situation is more critical, and the PALOP are no exception. There is still an overwhelming percentage of the world's population that lacks access to improved sanitation. In addition, there are large discrepancies between the urban and rural settings, where open defecation is still widely practiced.

A sanitation system provides clear improvements to public health. Furthermore, it also has profound effects on local economy as people become more productive and even entrepreneurial, due to the improvement of their health. The construction of sanitation may bring business opportunities for the community and can contribute to the productivity of agricultural fields. All these factors contribute to the communities' ability to develop sustainably; economically and socially.

Although simplified, this decision model allows a straightforward understanding of the main variables that must be considered when designing a low-cost, on-site sanitation system.Withal, the author believes these concepts could be a significant help for stakeholders when choosing appropriate methods for the implementation of improved sanitation in developing countries, particularly for the Portuguese speaking countries.

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