# Wastewater Treatment and Management of Fecal Sludge in Mozambique: Current Situation, Challenges and Perspectives

Case Study – City of Beira

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Thesis to obtain the Master of Science Degree in

## Environmental Engineering

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**July 2017**

# Wastewater Treatment and Management of Fecal Sludge in Mozambique: Current Situation, Challenges and Perspectives

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## ABSTRACT

A WWTP consists of a set of treatment facilities and equipment, for further use of the effluent in compatible uses, or simply to be discharged into receiving waters with a level of pollution appropriate to their current or subsequent uses.

The dissertation refers to Mozambique situation and has as main objectives to analyze the concrete situation of the sanitation and in particular the treatment of waste water. A critical analysis of the legislation is carried out. The general process of wastewater and fecal sludge management is also discussed and the application to a case study is presented: the WWTP of the city of Beira.

Finally, the main challenges and perspectives for the near future are identified. Thus, the legal and institutional framework of the water and sanitation sectors is addressed and some wastewater treatment techniques are described.

A description of the most commonly used decentralized sanitation systems in Mozambique is also presented. An analysis is carried out on the sanitation and treatment of wastewater in Maputo city (Infulene WWTP) and in the rest of the country. It also describes the stages of fecal sludge management (collection / emptying / transport / treatment and final disposal), the recovery of fecal sludge and the main impacts associated with management.

The case study of the city of Beira is developed, making a general analysis about the respective performance over the three years under study.

Finally, the main challenges and prospects of wastewater treatment and fecal sludge management in the country are presented, followed by a synthesis, conclusions and perspectives.

**Key-words:** Decentralized sanitation systems; Fecal sludge management; Mozambique; Wastewater Treatment Plant (WWTP);

# 1. INTRODUCTION

The need for sanitation is very relevant globally for the health and well-being of mankind. The demographic explosion, as well as the rural exodus and the search for more opportunities for young people, which has been observed in recent decades in developing countries such as Mozambique, means that the increase in the demand for sanitation systems Improve the need to develop new infrastructures. It is desirable that new sewage treatment systems be installed as well as promote the proper management of fecal sludge in the case of dry cleaning in order to promote an improvement of the sanitation system, taking into account existing sanitary systems.

### Objectives of the work

In the scope of this dissertation, it is intended:

i) analyze the concrete situation of Mozambique in terms of collection and treatment of wastewater, including critical analysis of legislation,
ii) to define in general terms fecal management practices in Mozambique,
iii) to develop a "case study" applied to the city of Beira, evaluating the performance of the Wastewater Treatment Plant (WWTP), and
iv) identify the main challenges and future prospects of the sector in Mozambique.

# 2. GENERAL SITUATION OF SANITATION IN MOZAMBIQUE

In Africa, water, sanitation and hygiene are vital components for sustainable development and for poverty reduction. The absence of these causes the main cause of malaria, diarrhea and cholera. Today political leaders and industry experts have created new momentum in these important areas in order to advance progress.

In Mozambique, access to safe drinking water and adequate sanitation remains one of the greatest challenges to be overcome. In fact, about 90% of deaths from diarrhea and cholera are related to lack of adequate sanitation. In recent years, Mozambique has continued to have a very high infant mortality rate for the same reasons (UNICEF, 2013).

Historical data from censuses and demographic projections show an exponential growth trend, with respect to the population evolution of Mozambique. According to INE, the population was at least 25 million, with the majority of the population living in rural areas; that is, up to 2010, 68.4% lived in the rural area and 31.6% in the urban area. The largest concentration of the population in the age group 0-14 years represents more than 45% of the total population in 2014 (INE, 2013 - 2014).

The predominant climate is tropical humid, with a dry season that in the center and north ranges from four to six months. On the other hand, the southern region presents a dry tropical climate with a dry season that extends for six to nine months, throughout the year.

Mozambique is a very vulnerable country in the face of climatic conditions, with regard to natural disasters such as cyclones (bordering one of the most active tropical cyclones), floods and droughts, thus increasing the risk of diseases with negative impacts on the social well-being.

Mozambique is a country where the majority of the population lives on less than a dollar a day; It is noteworthy that recent data indicate that more than half of the population are children. Despite the country's needs, it continues to attract large investors into its vast reserves of natural gas and coal (UNICEF). Agriculture and fishing are the main economic activities in the national territory.

Despite having natural resources such as coal, natural gas and minerals, industries in these sectors are still developing and will have to accelerate growth in order to secure the most potential employment market and develop the country's economy.

## 3. TECHNOLOGICAL WASTEWATER TREATMENT SOLUTIONS

### 3.1. Theoretical framework

Wastewater is water from industrial activities, residential areas (domestic activities), service areas, commercial facilities and rainwater drainage system networks, i.e. all waters that are rejected as a result of their use for various purposes and contain pollutants capable of causing negative environmental impacts if they are discharged directly into the environment.

Wastewater treatment technology solutions must be chosen taking into account the following requirements:

1) The investment costs involved in the installation,
2) The operation,
3) Maintenance,
4) Simplicity,
5) Sustainability of the treatment facility,
6) The characteristics and availability of space,
7) The type of climate,
8) The requirement in terms of resources of skilled labor, energy, water, reagents, equipment and specialized technical personnel.

It is also necessary to know the quality of the effluent to be treated, depending on the quality parameters to be defined, as a function of the receiving medium (Arceivala, 2008).

### 3.2. Centralized treatment technologies

#### 3.2.1. General aspects

Centralized treatment technologies are infrastructures with the capacity to treat waste water from several settlements in only one treatment area.

### 3.2.2. Activated sludge (suspended biomass)

Activated sludge or suspended biomass treatment process is a wastewater treatment technique that is perhaps the most used in developed countries. This process can be performed in three main stages of treatment. In the first phase, the dissolved organic matter and colloidal in the residual water is degraded (through bacterial action) in the aeration tank or oxidation ditch under aerobic conditions. In the second stage, the mixture undergoes a decantation process and the sludge accumulated in the bottom of the decanter is removed for further treatment. In the third and last stage the process of recirculating the remaining sludge takes place to maintain the biological degradation process of the system

### 3.2.3. Trickling filters (fixed biomass)

Trickling filters / biological filters or treatment process by fixed biomass are filters filled with stones or filters of rough filling or gravel (of plastic material or of ceramic type especially adapted for the purpose), to which are added decanters where it occurs the separation of the solid phase and the liquid phase; the process of degradation of organic matter is made by the microorganisms responsible for the biological process.

### 3.2.4. Pond Systems

Lagoon or pond systems (stabilization ponds) consist of treatment in lagoons, without the need for mechanical intervention. The lagoons are classified in aerobic, anaerobic, maturation and facultative, depending on the characteristics of degradation of the organic matter; regarding the nature of the effluent, the systems may be primary or secondary (Sousa, 1981). It is the most widely used treatment systems in developing countries, because it is one of the techniques that require the least investment and maintenance costs.

### 3.2.5. Treatment of waste water in soil

Soil treatment consists of the treatment of the waste water by the soil itself, or by plants through the physical, chemical and biological processes. Compared to other conventional treatment techniques, this depends much more on the local characteristics (climate, geology, topography, physico-chemical, soil hydraulics and qualitative and quantitative surface water and underlying aquifers) and on the area where the treatment is to be carried out (Matos, 1985a).

### 3.2.6. Constructed wetlands

The constructed wetlands incorporate ponds capable of developing abundant macrophytes, which promote the oxidation process of the organic matter present in the wastewater. The ponds are usually installed following a primary decantation treatment in a sewage tank or Imhoff tank to remove suspended solids.

## 3.3. Decentralized treatment technologies

Decentralized treatment technologies are small-scale technologies, including collection, treatment and discharge of wastewater. They allow the management of wastewater in the vicinity of the production sites, and there is no need for a collection and transport network for distant treatment plants and are

suitable for treating flows between 1 and 500 $m^3$ / day (Sasse, 1998). This type of technology is most commonly used in developing countries.

### 3.4. Wastewater treatment in Maputo City

#### 3.4.1. General Aspects

Maputo City is the capital and largest city of Mozambique. It is located in Maputo Bay, in the extreme south of the country, near the border with South Africa and the border with Swaziland.

#### 3.4.2. Sanitation of Maputo City

The most applied sanitation system in the city of Maputo is of the latrines type, although in the city center (cement city), it has a network of wastewater and rainwater collectors.

#### 3.4.3. Drainage and sanitation systems in Maputo city

The network is mostly run upstream, in the gravitational sense, with only two lift stations leading a portion of the wastewater to the WWTP in the Infulene valley. The remaining wastewater is directed to the Bay of Maputo, through several emissaries, namely in the neighborhoods of Ponta Vermelha, Polana and Baixa da Cidade (Engidro, Hidra, Aquapor, 2015).

#### 3.4.4. Infulene Wastewater Treatment Plant

The WWTP of Infulene is located in the city of Maputo, in the valley of the Infulene, near the Garden District. Infulene's treatment system has limited capacity since it was originally designed to serve 90 000 inhabitants. Currently, it is not operating at full capacity, because two lift stations carrying a significant part of the wastewater are not operating.

#### 3.4.5. Results of the Infulene WWTP

In order to determine the mean daily flow rate at the Infulene WWTP, a master's thesis from Eduardo Mondlane University, campaigns were carried out in July 2014, with measurements of both the water heights and the flow velocity at the entrance site.

#### 3.4.6. Infulene WWTP performance evaluation

The evaluation of the performance of the Infulene wastewater treatment plant was carried out at the level of pollutant removal efficiency by collecting waste water samples upstream and downstream of the pond, as well as collecting sludge samples at discharge points In the WWTP. The WWTP performs poorly, which is critical for the subsequent use of the treated water, even in the case of small tributaries (Engidro, Hidra, Aquapor, 2015).

### 3.5. Treatment of wastewater in other regions of the country

The remaining regions of the country, except for Songo and Beira, do not currently have a WWTP. Treatment of sewage is done by septic and latrine septic tanks.

### 3.6. Wastewater Treatment Plants

The compact WWTPs or ECOTANQUES were created to treat domestic sewage of dwellings or small population clusters, with equivalent populations from 5 to 700 inhabitants.

## 4. MANAGEMENT OF FECAL SLUDGE IN MOZAMBIQUE

### 4.1. Theoretical framework

According to the report of the Municipal Council for Water Regulation (CRA), 2015, the study of the definition and organization of sanitation and fecal management services was initiated, providing for the establishment of tariffs for these services.

### 4.2. Fecal Sludge Management Stages

Since the most used sanitation in Mozambique is of the decentralized type, it is necessary to emphasize the great importance and necessity of fecal management in the country. In the case of Maputo City it is estimated that more than 80% of the population live in peri urban areas and depends on solutions of localized sanitation, which makes fecal sludge management indispensable (Engidro, Hidra, Aquapor, 2015).

In Mozambique, emptying services are mostly carried out by small private operators, from manual emptying machines to small enterprises that combine the emptying and transport of sludge; there are also tank trucks and clean septic tanks, operated by the municipal council. Most services are done overnight to ease problems with the neighborhood. In extreme situations (more constant), manual emptying is the only possible procedure given the characteristic and location of latrines or pits to be emptied (Barroso et al., 2015).

The biggest challenge is the lack of adequate services for the emptying of latrines and septic tanks, due to the difficulty of access roads to the entrance of collection trucks. In these areas, the collection is done by small-scale informal services and buried in the customer's yard, dumped in the sewage system or garbage containers, endangering public health (Barroso et al., 2015).

### 4.3. Fecal sludge reuse

Properly treated sludge can be used in agriculture or urban gardens (as fertilizers), can be used in industry (such as construction materials, fuel or fertilizers), soil application (as soil correctives) and as solid fuels.

### 4.4. Impacts associated with the environment, health and fecal sludge management.

The main impacts associated with the environment are the pollution of ambient air, aquatic environments and soils.

Water resources are particularly relevant because they are the source of water consumption, especially in Mozambique, which results from the direct uptake of surface water or local aquifers, without it having been subjected to treatment for human consumption.

Fecal management impacts on public health stem from improper management of sludge, i.e. direct and indirect contact (e.g. through the consumption of food with pathogenic microorganisms), improper and inappropriate discharges, and the reuse process of fecal sludge. Undue discharges into semi-abandoned areas also occur in the poorest and densely populated areas, where vulnerable communities are exposed to severe contamination.

## 5. CASE STUDY – CITY OF BEIRA

In terms of sanitation, the **city of Beira** has faced great difficulties due to the lack of adequate sanitation related to the unavailability of financing for the improvement of local sanitation systems and due to its vulnerability in terms of infrastructures and their geographical location. Thus, this case study will make it possible to characterize the degree of improvement in the sanitation of the city, as well as to emphasize the importance and necessity of expansion of infrastructures (WWTP), for the rest of the country, since this is the first and largest WWTP in addition to the Infulene WWTP.

The operational performance of the WWTP will be evaluated, taking into account:
I) The current design of the WWTP,
Ii) The quality of the treated effluent,
Iii) The efficiency of removal of contaminants.

### 5.1. Characterization of the city of Beira

Due to the morphological characteristic of the city, whenever precipitation occurs or during high tide period, surface runoff becomes deficient due to the low slope of the land, which causes much of the city to be flooded during these times of the year. In the rainy season water cannot flow into the sea due to the flat geography of the city; the drainage system is composed of lift stations that pump rainwater to reduce the possibility of flooding.

#### 5.1.1. Climate and precipitation

The climate is tropical humid, savanna rainy, characterized by high and humid temperatures during the summer, with prevailing winds of the Eastern and Southeast front, which causes the city to be subject to both cyclones seasonal and periodic droughts in a cycle of three years, suffering, therefore, from serious problems of floods.

#### 5.2.2. Evolution of the population

The growth of the population is influenced by the relatively intense immigration processes that have occurred in the last 10 years;

#### 5.2.3. Economy of the city of Beira

In the city, most of the population lives in commerce and the port, which moves cargo. There is also a container terminal. It is between two transport corridors (connecting to Zimbabwe by road and rail and

facilitates access from the mainland to the coast). The port has played an important role in the transaction of national and international merchandise.

### 5.3. Sanitation of the city of Beira

Most of the city is less than 10 meters above mean sea level. The flat nature of the terrain implies that most of the city is flooded during rainy periods. This flood problem is most pronounced in areas of disordered occupation, which generally coincides with the lower parts of the city. Sanitation systems, such as septic tanks and latrines, face major problems due to the high level of water table. These systems generate a high level of contamination of groundwater. In fact, the treatment that should occur in the systems does not normally occur due to the saturation of the soils.

According to the 2007 data, in city of Beira only 12.8% of households had conventional sanitation inside the dwelling (connected to the sanitation network), of which 6.7% were conventional houses and 6.2% were Compound apartments in lots of two or more floors; The rest of the city consists of other types of housing where conventional sanitation is not considered (RGPH, 2007).

#### 5.3.1. Data on water supply and consumption in the city of Beira

From the flow rates and the capitation values, it was possible to estimate the number of the population with water coverage supplied by the FIPAG Services of the city of Beira. Also from these Services, it was possible to know that only about 12% of the city's population during these three years had the water system connected to the home, so it was possible to calculate the number of the population with water connected to the home. Finally, it was possible to calculate the value of the flows, of the population with water connected to the home.

### 5.4. Rainwater drainage network of the city of Beira

As for the drainage of rainwater, the urban or structured area of the city (of which the Pioneers, Esturro, Mananga, Matacuane, Chaimite, Ponta-Gêa, Chipangara, Macurungo and Macuti Which is served by a classic drainage network of buried collectors, totaling about 57 km of collectors, with independent exits or discharge points for the Indian Ocean through the Púngué Estuary.

### 5.5. Wastewater Treatment Plant of the city of Beira

The wastewater treatment plant in **city of Beira** is located in the Munhava neighborhood, on the edge of the Púngué River estuary. It is currently considered the largest WWTP in the country.

Currently the WWTP employs 20 workers, who are divided according to the performance of their functions: 2 electricians; 2 mechanics; 9 operators; 2 laboratory agents; 4 gardeners and 1 cleaning agent.

#### 5.5.1. Design of the WWTP of the city of Beira

The type of wastewater treatment technology used in the city of Beira is high rate trickling filters, which use the filter medium and the process is preceded by an UASB reactor.

### 5.5.2. Main stages of the operation of the WWTP of the city of Beira

The wastewater treatment is divided into two parts: liquid phase and the solid phase. The liquid phase can be subdivided into the following treatment steps: pretreatment, primary, secondary and tertiary. The purpose of the treatment is to meet the requirements of the discharge license in order to be discharged into the receiving environment. The treatment of the solid phase corresponds to the treatment of the solids removed in the liquid phase of the waste water. It may also be necessary to add odor treatment as a result of degradation of organic matter in wastewater and release of compounds with aggressive odors (Simões et al., 2008).

The sludge produced at the city of Beira WWTP is subjected to anaerobic digestion for a period of about three months in the UASB anaerobic reactor; then this fecal sludge is discharged in sand-bottom tanks, where they are then subjected to the dehydration process in order to reduce the amount of water and facilitate its transport to the drying beds.

After drying the sludge is removed manually from the drying beds and stored for a few months for subsequent use as agricultural fertilizer, as these are rich in nutrients (phosphorus, nitrogen and calcium); can also be used as soil pH correctors because they are alkaline.

## 5.6. Results of the performance of the WWTP of the city of Beira

In the present study, we will only analyze the evaluation of the operational performance of the WWTP.
The evaluation of the performance of a WWTP is a process by which management identifies the extent to which the functioning of the WWTP contributes to meeting the objectives defined in order to achieve the organization's results (effectiveness, reliability and sustainability of these services). It should not be understood as an instrument of control but rather as a means of obtaining a more effective knowledge of performance in an objective and rigorous way, providing continuous improvement of its performance.

### 5.6.1. Analysis of the flows of the WWTP of the city of Beira

It is verified that the flow that reaches the WWTP has been decreasing over the years under study, questioning the efficiency of the WWTP.

However, this can be due to the poor conservation of the domestic wastewater network, which does not allow great progress, since the sewerage network has been degrading day-after-day because it is very old (dating back to 1950). When someone stated that "it has been rehabilitated", in fact only about 1/3 of the total needed has been intervened.

In addition, the flow to the WWTP is influenced by the supply of water to the home, which has been subject to frequent restrictions in recent years. Sometimes there is no water supply for two and three consecutive days.

With these sanitation problems, upstream of the WWTP, many sewage that would have to be reached also get lost along the way (infiltration), negatively affecting the operative image of the WWTP.

In addition to this, operating failures, reflected in electricity failures, as well as the lack of fuel to supply the alternative electric generator, result in failure of the flow registers (the flowmeter does not record the values since it is an electronic device).

After verifying that the values of flows that arrive in the WWTP are much lower than those of the project, and considering that the flow can be influenced by the climatic factors, it was possible to relate the variation of the flow that arrives at the WWTP, with the rainfall over the three years.

### 5.6.2. Analysis of the performance and efficiency of the WWTP

The performance of a biological treatment system is influenced both by the physical-chemical characteristics of the effluent to be treated as well as by environmental and operational factors. The samples were collected at the entrance and exit of the effluent at the WWTP. The analysis were carried out in the WWTP laboratory, by collecting several samples periodically throughout the year, to allow a more rigorous evaluation to be made considering the different seasons of the year (dry and rainy season), which may influence the operation of the WWTP.

### 5.6.3. Quality of treated effluent

According to the services of the **city of Beira**, there is no analysis of Fecal and Total Coliforms in the laboratory of the WWTP due lack of equipment for this type of analysis.

Observing the results of the performance of the WWTP, it does not reach the expected efficiency. What can be concluded is that the system will be influenced by the temperature, the characteristics of the effluent, the flow rate at the inlet of the decanters, because it is important that the decanter feed is carried out continuously and without oscillations occurring.

## 6. CHALLENGES AND PERESPECTIVES OF THE RESIDUAL WATERS TREATMENT AND MANAGEMENT OF FECAL SLUDGE IN MOZAMBIQUE

### 6.1. Challenges associated with wastewater treatment and fecal sludge management

One of the main constraints related to wastewater in Mozambique is the lack of infrastructures for its collection and treatment. That is, the country only has three public WWTPs (Beira, Maputo and Songo). Only the parts of "cement cities" are it has collector networks. In addition to the lack of adequate infrastructures, existing ones have serious maintenance problems due to financial inadequacy. Although in some areas such as Maputo / Matola and Beira / Dondo, there are some sources of revenue (such as the rate of sanitation and cleaning of septic tanks in the water bill), the values obtained are not sufficient to support maintenance costs.

The following main challenges can be identified:

- At Infulene WWTP, the operation is related to the difficulty of cleaning the sludge in the lagoons, particularly the extraction of the sludge from the anaerobic lagoons and a convenient final disposal. It

is also convenient to limit public access to them by placing a protective fence (Engidro, Hidra, Aquapor, 2015);

• In the case of the in the city of Beira WTTP, it was verified the poor conservation of the network of domestic wastewater collectors because it is very old and due to the poor intervention (only 1/3 rehabilitated);

• The fecal management cycle in the country has faced several difficulties from collecting to final disposal of sludge, due to the lack of equipment for this purpose, which leads to the postponement of the emptying operation, using very little Manual dewatering (Engidro, Hidra, Aquapor, 2015);

• The collection of fecal sludge from septic tanks and latrines faces major difficulties in terms of the risk of collapse of latrine wells, difficulty in accessing collecting sites, lack of knowledge of the location of access Collection points and the difficulty of extracting dry sludge in dry latrine wells (Engidro, Hidra, Aquapor, 2015);

• In the case of the city of Maputo, one of the main challenges lies in the collection and transportation of sludge, that is, at long distances to the Infulene wastewater treatment plant, and the high transportation costs result in the unlawful discharge of sludge into nearby unoccupied areas of origin (Engidro, Hidra, Aquapor, 2015);

• Decentralized systems that could be adequate solutions are not part of municipal sanitation plans;

• The involvement of citizens in the decision-making process is relevant given the need for their cooperation in the reduction and exploitation of infrastructures at neighborhood level;

• People living in extreme poverty, remote rural areas or informal urban settlements need to be included in the process of involvement. It is also essential to involve women as they account for most of the health effects of non-management of safe disposal of human waste.

It is necessary to create a means to operationalize the principle that sanitation is the responsibility of all, ensuring the participation of all in order to ensure effective sustainability. A national system of evaluation and certification of communities free from open fecal should also be established.

## 7. SUMMARY AND CONCLUSIONS

In support of the development of the present study, one can conclude that: the level of water supply and sanitation in Mozambique remains one of the most challenging problems to overcome in the coming decades. Hence these challenges were included in Agenda 2030.

In terms of wastewater treatment, Mozambique only has three public WWTPs, which reveals a very small number of infrastructures taking into account the size of the country, with most of the infrastructures still to be built. The present dissertation intends to be a contribution to the analysis of

this sub-sector of the waters and in particular for the area of the treatment of residual waters.

After evaluating the operation of the WWTP of Infulene, it was concluded that the site of the WWTP was neglected, with weed proliferation and without any restriction regarding access to the facilities (Engidro, Hidra, Aquapor, 2015).

Regarding the WWTP of the city of Beira, this being one of the first studies to be carried out since the beginning of its operation, several difficulties arose due to the deficiency in the information supply and the lack of clarity of the responsible ones.

Clearly, there is a need for more process control, requiring greater care and attention:

(i) in the flow record, during the monitoring of the WWTP, and
(ii) in the laboratory during the development of the parameters control processes (COD, $BOD_5$ and SST).

As final suggestion, I would like to mention that currently it looks like that it is not a priority to build a second treatment line of the city of Beira WWTP, but rather to invest in network expansion, improvement of the existing drainage networks for wastewater and rainwater, as well as in drainage so that the wastewater can be directed in perfect conditions. In particular, considering the wastewater network, it will be desirable that these can reach the WWTP in perfect condition (in its totality), so that with the increase of the flow rate, it will improve its performance.

Due to the limitations that the country presents in specialized human resources for the area of wastewater treatment and fecal management, it will be advisable to use simple sustainable technological solutions, adaptable to the national reality.

That is, solutions that fit the limitation of specialized human resources, the need to avoid significant charges with imported energy, water, reagents, materials and equipment, preferring to treat wastewater by ponding, biological filtration or beds of macrophytes.

Low-energy systems should be used.

It should be invested in sewage treatment plants, as a matter of urgency, since a large part of the sanitation practiced in the country is of the dry sanitation type.

It should be invested in laboratories, in order to ensure greater safety in the results obtained in the treatment of waste water.

As there are no microbiological analyzes, it is possible to control the effluent quality through the crops that are irrigated by the WWTP.

As Mozambique legislation is limited in terms of defining the limits of microbiological control, rather than just using international law, it is necessary to adapt this legislation to the national reality.

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