TECHNICAL ASSESSMENT

Of the wastewater treatment system at St. Francis Hospital, Katete, Zambia

BORDA
ZAMBIA

Aubrey Simwambi
simwambi@borda-africa.org

Contents

Content of Tables ... iii

Content of Figures ... iv

1. INTRODUCTION ... 1

1.1 ***St. Francis Hospital Project Background*** ... *1*

1.2 ***BORDA*** ... *1*

1.3 ***The Logie Legacy*** ... *2*

1.4 ***Objectives of the consultancy*** ... *2*

2. SCOPE OF WORKS ... 3

3. METHODOLOGY ... 4

3.1 ***Literature*** ... *4*

3.2 ***Questionnaire*** ... *4*

3.3 ***Site visit and detailed data collection*** ... *4*

3.3.1 Stakeholder meetings and interviews ... 4

3.3.2 Technical meetings, observations and on-site investigations ... 4

4. FINDINGS AND DATA ANALYSIS ... 6

4.1 ***Analysis of on-site investigation data*** ... *6*

4.2 ***General Information about proposed project service area*** ... *7*

4.2.1 Demographic information ... 7

4.2.2 Geographical and topographical data ... 7

4.3 ***Water and Sanitation*** ... *7*

4.4 ***Hospital Service numbers*** ... *9*

4.5 ***Waste water infrastructure*** ... *9*

4.6 ***Local resources*** ... *10*

4.7 ***Energy Information*** ... *10*

4.8 ***Solid Waste Information*** ... *11*

4.9 ***Treated Water Reuse Potential*** ... *11*

4.10 ***Sanitation Facilities*** ... *11*

4.11 ***Impressions of on-site investigations*** ... *13*

4.12 ***Waste water production*** ... *15*

4.12.1 Hospital ... 15

4.12.2 Households and nursing school ... 16

4.13 ***Proposed system positions*** ... *16*

4.13.1 Network 1: Hospital and housing unit A ... 17

4.13.2 Network 2: Housing unit B ... 18

4.13.3 Network 3: Housing unit C and Hospital Workshop ... 19

4.13.4 **Network option 4: Combination of B and C** 20
4.13.5 **Network option 5: Combination A, B and C** 20

5. TREATMENT SYSTEM DESIGN 22

5.1 ***Review of available treatment technologies*** *22*
5.1.1 Preliminary Treatment 22
5.1.2 Primary Treatment 22
5.1.3 **Secondary Treatment** 23
5.1.4 Advanced Secondary Treatment 25

5.2 ***By Product reuse*** *26*

5.3 ***Considered treatment options*** *27*
5.3.1 **Applicable and Recommended treatment modules** 27

5.4 ***Assessment of requirements*** *29*

5.5 ***Implementation costs per unit per treatment area*** *31*

5.6 ***System Implementation Scenario's*** *34*

5.7 ***Levelised cost of treatment*** *36*

5.8 ***Design scenario assessment and ranking*** *37*

6. OPERATIONS & MAINTENANCE 39

6.1 ***Operational tasks*** *39*

6.2 ***Maintenance tasks*** *39*

6.3 ***O&M costs*** *39*

7. CONCLUSIONS 40

8. References 41

Appendix: .... A

Hospital and Housing Area A piping costs .... *A*

Housing Area B piping costs .... *B*

Housing Area C piping costs .... *C*

Housing Area B&C piping costs .... *D*

Housing Area A&B&C piping costs .... *E*

Content of Tables

Table 4-1: Current water supply and waste water treatment observations 6
Table 4-2: Average number of monthly patients 9
Table 4-3: Quantity of sanitation facilities per hospital building 11
Table 4-4: Daily hospital wards waste water generation potential 15
Table 4-5: Daily OPD waste water generation potential 15
Table 4-6: Current hospital waste water generation potential 16
Table 4-7: Housing community waste water production potential 16
Table 4-8: Sewer network configuration options. 16
Table 4-9: Waste water generation rates for sewer network 1 18
Table 4-10: Waste water generation potential for network 2 19
Table 4-11: Waste water generation potential for area C 19
Table 4-12: Waste water production potential for Network option 4 20
Table 4-13: Waste water generation potential for the hospital and hospital community 21
Table 5-1: Treatment system combinations 28
Table 5-2: Ranking system 29
Table 5-3: Technical ranking requirements 29
Table 5-4: Maintenance ranking requirements 30
Table 5-5:Economic ranking requirements 30
Table 5-6: System 1 facility costs in ZMW 31
Table 5-7: System 2 facility costs in ZMW 31
Table 5-8: System 3 facility costs 32
Table 5-9:System setup 4 facility costs 32
Table 5-10: System setup 5 facility costs 33
Table 5-11: Treatment system implementation costs for hospital and household area A 33
Table 5-12:Treatment system implementation costs for area B 33
Table 5-13:Treatment system C implementation costs 34
Table 5-14: total implementation cost for separate system implementation 34
Table 5-15: Implementation costs for system 1 and combination of system 2 and 3 35
Table 5-16: Implementation costs for a combined system 35
Table 5-17: O&M costs and project design lifespan 36
Table 5-18: Levelised cost of system implementations per person and per cubic meter of treated waste 36
Table 5-19: Design scenario ranking requirements 37
Table 5-20: Design ranking scores 37
Table 5-21: Design scenario weighting 38

Content of Figures

Figure 4-1: Site Francis aerial view and surrounding communities and picture site 13
Figure.4-2: Site 1 waste disposal area and infiltration test.. 13
Figure 4-3: Picture site 2-blocked overflowing sewer manhole; incinerator.. 14
Figure 4-4: Dry non-sewer receiving manhole with solid waste... 14
Figure 4-5: Picture site 3; Suitable site for implementation of a unit for household area B 14
Figure 4-6: Sewer network 1 covering hospital and household area A 17
Figure 4-7: Sewer network 2 covering household area B... 18
Figure 4-8: Sewer network 3 covering household area C... 19
Figure 4-9: Network option 4; Combination of network area B and C 20
Figure 4-10: Network option 5; combination of networks A, B and C 21
Figure 5-1: Biogas digester (Courtesy of BORDA) 23
Figure 5-2: Primary settler (Courtesy of BORDA)... 23
Figure 5-3: Anaerobic baffle reactor (Courtesy of BORDA) 24
Figure 5-4: Planted gravel bed (Courtesy of BORDA) 24
Figure 5-5: Polishing pond (Courtesy of BORDA)... 25
Figure 5-6: Vertical sand filter.. 25
Figure 5-7: Vortex 26
Figure 5-8: Treatment facility configurations 27

1. INTRODUCTION

1.1 St. Francis Hospital Project Background

St. Francis Hospital (SFH) is a church-administered hospital, situated in Katete district of Eastern Zambia. The hospital was established in 1947 as an Anglican hospital. In 1986, the Anglican Church partnered with the Catholic Church to jointly manage the hospital. The hospital also receives financial aid from the Government of the Republic of Zambia under the Ministry of Health and it also receives support from overseas groups.

St. Francis hospital is known for good service provision and thus has built a reputable corporate image over decades in patients care. The hospital serves both local and international patients both as out patients and in-patient referrals. Patients travel long distances to seek medical attention from St. Francis hospital and some patients' by-pass other major medical institutions to come to the Hospital. The serving of many areas gives the hospital a higher admission and visitation rate than designed. The hospital also houses a recognised nursing and midwifery training school on its premises.

From September 2016 to September 2017, the hospital served 120,230 people and also received specialist referrals from hospitals in the Eastern Province and neighbouring Mozambique.

The hospital reported[1] plans to expand by increasing the capacity of the current wards and construction of new wards to accommodate the increasing hospital service requirements and visitation loads. Works to expand the maternity and commissioning of the Eye OPD were found underway.

For water and sanitation, the hospital has about eight boreholes pumping water to a central water storage and reticulation tank which serves the hospital and the surrounding hospital community. Water is pumped to the tank for an approximated 16hours.

Grey water from the bathrooms and hand wash sinks is disposed through underground infiltration through the soak pits whilst the black water is treated in septic tanks and disposed through soak pits. Old septic tanks never emptied in a very long time have hardened sludge and some have been bypassed to sewer lines conveying sewage to the outside of the hospital where two septic tanks exist that are leading the effluent into the seasonal river. The conveyance system sometimes blocks and the technical team unblocks them. The hospital sewer has two sewer lines running on the west and east side of the hospital. The workers housing also has their water treated on site with the use of septic tanks and soakaways individually and shared depending on the proximity of the houses and the treatment facilities.

1.2 BORDA

Since 2009 Bremen Overseas Research and Development Association (BORDA) has concentrated on development-oriented cooperation projects and services in the field of Basic Needs Services (BNS) by contributing to worldwide knowledge exchange and transfer. Within eight years various projects in Zambia, operating within the context of social-structure reform, are geared towards the development and dissemination of sustainable, decentralized service models with the intent of improving the supply of Basic Needs Services.

[1] based on the conversation with the hospital administration

BORDA is a specialist organization active in the fields of poverty alleviation, sustainable protection of natural resources and the strengthening of social structures. The mission of BORDA is to improve the living conditions of disadvantaged communities and to keep the environment intact through the expansion of Basic Needs Services in the areas of decentralised sanitation, water and energy supply as well as waste water and solid waste disposal.

In line with the government mandate BORDA aim to support efforts for liveable and inclusive cities in Zambia, starting with the provision of inclusive sanitation solutions to the unserved, peri-urban areas where access is low. BORDA also work to strengthen standardisation, harmonisation and regulation for onsite sanitation, including waste water management. With the influence of traditional and civic leader, we continue to engage communities to encourage their participation in improving sanitation.

1.3 The Logie Legacy

'The Logie Legacy', is a charity organisation (www.logielegacy.com) with a long-standing project partnership with St Francis Hospital. 'The Logie Legacy' have funded an ambitious 'Water for Life' project to improve the water supply and distribution network at St. Francis and sanitation was to be their next focus of activity. In discussions with the hospital management about the need to address sanitation issues in the hospital, the organisation represented by Mr Chris Faldon from Scotland, UK contacted BORDA in July 2016 to talk about sustainable and holistic waste water management solutions. These informal talks and subsequent communications led to a follow up visit to BORDA in June 2017 where BORDA were formally contracted to conduct a technical assessment for the hospital and surrounding communities.

1.4 Objectives of the consultancy

The objective of the consultancy was to conduct a comprehensive technical and social assessment for the provision of waste water treatment solutions for St. Francis Hospital and the surrounding tertiary and housing community. The aim of the technical assessment was to help better understand the sanitation problems faced at the Hospital and recommend the best biological treatment practices and approaches to eliminate the challenges.

An on-site investigation and detailed data collect was conducted at the hospital in October 2017 with a goal to derive the most appropriate alternatives for waste water treatment solutions in a holistic and integrated sustainable manner. The assessment was based on and included on-site data collection and investigations in order to clarify design parameters, facility locations, operations and maintenance requirements of the proposed treatment units and human and material resource availability. The data collected was then used to develop an appropriate water, sanitation and energy concept for the hospital and the surrounding community.

2. SCOPE OF WORKS

The scope of works for the consultancy included and was not limited to the following:

- Conduct on-site assessment of water and sanitation conditions of the hospital in close consultation with the administrative and technical team.
- Propose different scenarios on the quantity of treatment systems required by the hospital to ease operation and maintenance. The location should provide easy access to the technical team as well as take into consideration an appropriate reticulation system for the wastewater and by products.
- Propose Conceptual designs including site layout for wastewater treatment, water recycling and/or biogas utilization solutions.
- Provide a proposal on the location of the treatment facilities.
- Recommend and develop the design of the wastewater treatment system. The design should consider the following:
    - Ensure less blockages of the waste water conveyance system
    - Treatment of waste water before disposal
    - Environmental protection, including proper disposal of waste water
    - Resource reuse of the waste water treatment by-products
    - Low operational and maintenance costs
    - Inexpensive construction
- Detail the estimated capital costs of the treatment solutions.

3. METHODOLOGY

The focal point of the methodology was to collect data to be used in the assessment of existing sanitation facilities, observe technical sanitation practices, and estimate waste water generation to assist in the derivation of an integrative sanitation approach for the hospital. Water supply and sanitation services information was collected through questionnaires on water supply, toilet user interfaces and numbers, and related waste water treatment facilities. The data was also collected through literature review, individual observations and interviews during the site visits.

3.1 Literature

Literature on the hospital sanitation systems was obtained from the hospital stakeholders. The sourced literature from Mirco Keller documented the sanitation condition of the hospital and general operations and maintenance of the facilities (Keller, 2012).

3.2 Questionnaire

A survey questionnaire was formulated to guide on the type of data that was required for an informed location of treatment facilities, required quantities and volumes and related costs, possible operations and maintenance management models and to get a first understanding of the hospital. The questionnaire consisted of questions in 5 different topics which were:

- Demographic data
- Water supply and sanitation
- Treatment facilities
- Energy assessment
- Needs assessment – laundry area and grey water production areas

The questionnaire also addressed concerns such as people responsible for maintenance, household waste water facilities, average household sizes, etc.

3.3 Site visit and detailed data collection

The BORDA team then carried out site visits for data collection and the data was collected using the following methods.

3.3.1 Stakeholder meetings and interviews

Separate stakeholder meetings and interviews were held with various members of the hospital; management, administrative, technical and environmental department. The meetings were held to establish interest levels from the aforementioned in relation to the project

3.3.2 Technical meetings, observations and on-site investigations

A hospital mapping and transient walks with group discussions with the technical team were held. The site investigations were done in order to collect various data that gave an overview of the key needs and challenges in the hospital in relation to water supply and sanitation. The walk was guided by the technical lead representatives who also pinpointed water and sanitation related issues. The data collected during the transient walk included and was not limited to the following:

- Number of sanitation facilities:

The number of sanitation facilities were counted and their current usefulness was documented. The facilities recorded included, toilet facilities, hand washing facilities, shower facilities, treatment facilities and disposal units.

- Geographical and Topographical data:

The geographical and topographical data of the area was collected and assessed. Information such as water resources and waste water facilities, height profiles of points of interest in the hospital area, site access roads, drainages and sizes.

- Local Resources data:

Local resources in the area and its surroundings were assessed for availability and suitability to be engaged in the project planning, implementation and operations stages.

- Infrastructure data:

Current and planned infrastructure development data was gathered. This together with the availability of land for future development was assessed to help in the proper project layout.

4. FINDINGS AND DATA ANALYSIS

Meeting the waste water treatment needs was the main criteria for integrated and sustainable waste water treatment facilities. Collected data was analysed to come up with information to lead to needed treatment facilities and by-products reuse options.

4.1 Analysis of on-site investigation data

The main observations of water supply, sanitation and energy system and conclusions are summarised in table 4-1. Pictures giving an impression of the observations are found in the following chapter.

Table 4-1: Current water supply and waste water treatment observations

Observation	Recommendation
Sewer blockages were found along the sewer lines in a neglected state as no one seemed to be bothered	J Maintenance of sewer lines should be emphasised and prioritized
Septic tanks out of the hospital premises were found overflowing as they were blocked and one was found broken	J Septic tanks and soakaways should be serviced
Solid waste was found in treatment units	J Sensitization needs to be made on the management of solid waste in the toilets J Placards of what to throw and not to throw in the toilets can be hung on toilet doors
Some septic tanks in the hospital were found not to be working and have been by-passed by sewer lines taking the sewage to the outside septic tanks	J Non-functioning septic tanks should be sanitized and decommissioned
Two water tanks were found not working	J The water tanks should be maintained and monitored
Many water losses were observed and reported through hand basin, toilets and showers left running and leaking pipes respectively.	J Care should always be taken of water and the community should be sensitized on the conservation of the resource J Periodic controls of the water supply infrastructure
Misuse of sanitation facilities by users as some toilets were found dirty	J Create awareness through announcements, posters etc as some patients come from areas with no flushing toilet experiences hence they could throw anything inside the toilets ranging from bottles, plastic bags, nappies, etc. J Frequent control checks
Blockages along the sewer line were observed together with overflowing septic tanks	J Maintenance should be emphasised to promote public health and safety

4.2 General Information about proposed project service area

4.2.1 Demographic information

St. Francis hospital community consists of approximately 140 households, a guest lodge and a nursing college with dormitories. The main hospital blocks consist of 13 wards, a canteen, mortuary, and 6 administrative offices.

St Francis Hospital was projected to serve a local population of over 200,000 people. The hospital has 378 beds in nine ward buildings separated into adult medical (male and female), paediatric, maternity and surgical (male and female – including gynaecology) wards. The hospital also has a labour Ward with some average of 2000 deliveries each year and a basic Special Care Baby Unit. It has a Zambian staff of 400 and also has overseas workers who compensate the national shortage of clinical staff.

It is estimated that around 850 people are always in the hospital community. Additionally, the hospital community has a school for grade 1-12 and also has 150 households with a household size of between three to five people.

4.2.2 Geographical and topographical data

St. Francis hospital is located 84 km from the provincial headquarters (Chipata) and has a seasonal stream running at the peripheral of the site. Though the Eastern Province of Zambia is generally characterised with hilly landscapes, and the hospital sitting on the side of the mountains, the landscape of the Hospital sits on an almost flat terrain with a gradual slope towards a seasonal stream.

It has a generally clear site with gum tree characterising the tree population, and it has relatively porous gravel soils.

Site topographic and geographic data was obtained and soil porosity experiments done on two out of three locations to understand the porosity of the soil:

- Location 1 in the north of the St Francis Hospital; A high quantity of wastewater is already guided to this area making conveyance of the wastewater to any additional system easier. The location of the outside septic tanks is in a depression area with a gradual gradient enhancing a natural flow force. The treated effluent diverts effortlessly into a seasonal river.
- Location 2 is between the Nursing College and the garden to the west of the main hospital block; the area also flows with a natural gradient and the treated water could be used for irrigation at the garden area or a tree plantation.
- Location 3 soil porosity was not measured but the area has the lowest point for the whole hospital topography and has a vast land space

4.3 Water and Sanitation

The source of fresh water supply in the institution is groundwater pumped from boreholes spread across the institution land. The hospital has sunk 8 boreholes that are located within a 70m radius of the main hospital wards. The water is retrieved from ground aquifers through pumps and stored in 10m^3 overhead tanks spread across the hospital. The borehole yield in this area has been reported to be generally high and until now, there has never been a problem of water shortage. A total of 7 storage tanks have been installed with 5 fully functioning well. The water production and consumption were not measured at the hospital as there are no installed water meters. Nonetheless, water consumption was estimated at 500m^3 per month based on pump activities. The water pumps are run throughout the day and rested at night only. This is done to counteract the abrasion of the pumps. This practice raises concerns to management due to the rate of tear and wear of the pumps.

The over running of the pumps throughout the day was attributed to observed water losses within the reticulation system evident in water pipe leakages and negligent use of the resource by the workers and the patients. Hose pipes and water traps were observed left running with no care. Water leakages through pipes were attributed to the presence of worn out pipes as the pipes have neither been changed nor maintained since installation during construction of the institution hence they have developed cracks that allow significant amounts of water to ooze out.

Despite the water losses, the hospital does not commonly experience water shortages though the losses lead to low distribution pressures which limits supply to several buildings. In cases when the water pumps are under maintenance works or are faulty, water is stored in the hospital overhead tanks and rationed out accordingly. Pipes as well as the waste water pipes are seen as a big issue and as a relevant issue to share. Technical problems were however highlighted by the increasing rates of water leakages and breaking down of pipes due to high pressure and over working respectively. A major 'Water for Life' project funded by donors from Scotland is nearing completion and will see a major overhaul of the mains distribution network.

The hospital waste water is treated by on-site treatment facilities comprising of septic tanks and soak pits that are located in the vicinity of the hospital grounds. The hospital septic managed effluent is disposed to a seasonal stream on the northern periphery of the hospital premises. In many instances, the treatment facilities become blocked and spill semi-treated and untreated waste water over the hospital grounds. This is mainly because the on-site treatment facilities are old and have been poorly serviced and maintained. This poses a threat to the ground water aquifers from which hospital fresh waters are drawn. The fresh water aquifers are further threatened by household sanitation facilities which are very close to the borehole areas as households in the hospital community also use septic tanks and soak pits located within their compounds. A number of households could be connected to one septic tank and soak pit depending on the household arrays and ground terrain whilst some other houses have individual systems.

As settle-able solids in septic tanks settle at the bottom and eventually solidify if the tank is not frequently serviced by desludging it, the solidified sludge reduces treatment volume and treatment efficiency of the units in due course. In cases where the septic tank fills up and the waste clogs the soaking unit, a new septic tank is constructed and the former is by-passed. The disposal of partially treated and untreated waste in the hospital grounds and housing compounds and the reported water leakages creates a public health hazard as waste water could flow into fresh water pipes through minute leaks at times of low pressure and be piped to consumption points, therefore threatening public and hospital safety from faecal diseases. This further threatens the existence of the hospital as any faecal disease outbreak could lead to the closure of the institution. The construction of new treatment facilities whenever old ones fills up also pose public safety hazards around the hospital and the housing units as the old ones are not properly decommissioned by sanitizing and burying them. This practice leads to shortage of safe empty places in the hospital grounds and housing compounds where people can safely inhabit. Therefore, there is need for a solution by which the waste can be taken away from the community and the borehole areas to safeguard public health and safety.

4.4 Hospital Service numbers

Information about the ward admissions, ward bed admissions, ward bed days and the number of visitors of the Out-Patient Department (OPD) for the last year were shared with the BORDA team.

Table 4-2 shows the average past year's monthly visitor numbers with the OPD having an average of 9248. The highest record of average ward admissions and ward bed days per month was in the Bethlehem building with the lowest record of ward admissions, ward beds available and ward bed days being in the Special Care Baby Unit (SCBU).

Table 4-2: Average number of monthly patients

Building	OPD Attendances[2]	Ward Admissions[3]	Ward Beds Available[4]	Ward Bed Days[5]
Bethlehem	-	341	50	2125
Waiter's Shelter	-	-	35	
York	-	158	31	656
Kizito	-	179	44	752
Mukasa	-	119	48	913
Saint Augustine	-	136	40	622
Saint Monica	-	145	40	576
Mbusa	-	181	72	934
Special Care Baby Unit	-	68	18	511
Total	9248	1331	378	9049

4.5 Waste water infrastructure

The user interfaces found at the hospital were both dry and wet toilets in the form of pit latrines and flush toilets (full flush and pour flush) respectively with the wet systems being predominantly over 94%.

The treatment of the waste water from the flush toilets is done by septic tanks and soakaways both in the hospital and the housing community. Soakaways are applied when it comes to the treatment and disposal of grey water from hand wash sinks and the laundry area. Septic tanks are used as primary treatment for black water and soakaways are used for the treatment of greywater and effluent from some of the septic tanks. The treatment in the septic tank is achieved through settling and anaerobic processes in the watertight tank, causing a reduction in solids and organics volumes. Soakaways are porous walled chambers that allow water to slowly soak into the ground, dissipating into the groundwater. There are over 33 septic tanks for around 80 black water pipes and over 100 soakaways for around 160 greywater pipes. The soakaways act as disposal units for the grey water and treated

[2] The OPD is the section of the hospital where patients are provided medical consultations and other allied services. This department does not offer admission services.

[3] Ward admissions describe the number of registered patients in the ward.

[4] Ward Beds available is the number of beds that are present in the ward.

[5] The duration of the patient's stay is shown by the ward bed days.

black water. The separated grey and black water system is a reason for the quantity of chambers that are spread in and around the hospital area.

The Pit Latrines in the hospital area were reported to be buried every time they filled up but the septic tanks were de-sludged by the use of vacuum trucks whenever they filled up. The emptied sludge is taken to the municipal sludge stabilisation ponds located 6 kilometres away. Generally, the desired waste water system for the hospital was reported to be water-borne systems with full flush toilets. Therefore, the institution is in the process of phasing out the pit latrines by burying all filled pits and never digging new ones to replace them.

The current waste water disposal system is poorly maintained and badly managed as some sewer manholes and inspection chambers were found blocked and the septic tanks treating waste water from the hospital were found spooling with waste water and disposing it into the seasonal river stream. The maintenance department was reported to be responsible for work to deal with blockages, flooding and overflowing of septic tanks and soakaways. A number of septic tanks were reported to be not feasible to be emptied due to the solidity of the contents. Therefore, new tanks have been constructed to replace unserviceable ones and the full ones have been disconnected from the system.

The redesigned sanitation system should be a solution for the current and future waste water treatment system. The quantity of septic tanks and soakaways is seen as a problem that is expected to be managed by the new treatment system. The maintenance of the existing treatment system has been less because of the high quantity of septic tanks but low number of qualified waste water plumbers. Solid waste was found in some settlers of the treatment units and it was assumed that the solid waste entered the system through not fully covered and open chambers and also through user interfaces as some people patients flush solid waste into the system. The solid waste thrown into the system increased the risk of blockages.

The design of the new system should address the mentioned problems, that is, quantity of septic tanks, leakages in the pipelines and solid waste in the system. Additional the redesigned system could be helpful as it will produce biogas to compensate some of the high energy demand in the kitchen.

4.6 Local resources

Assessment of local resources in the area and its surroundings was done and the availability and suitability to be engaged in the project planning, implementation and operations stages. Construction blocks, cement, steel other hardware materials could be found in Katete and Chipata throughout the year whilst bricks, sand and construction gravel can be found within the community. The availability of bricks is subject to the weather in terms of rainy and dry seasons.

Unskilled and semi-skilled labour is also abundantly available within the community whilst a shortage exists locally of skilled tradesmen.

4.7 Energy Information

Energy at the hospital is a vital component to functionalities such as running ward and office equipment, heating and lighting. The hospital has a kitchen with industrial electric pots and the kitchen offers daily cooked meals for approximately 230 patients. Furthermore, electricity is used for lighting of the entire hospital community, together with machinery in the theatres.

The hospital has a generator that works as a back- up electricity supply. In certain cases, the generator set has continuously run for one week (i.e. during a time the main grid is faulty or under maintenance) as there cannot be a time when the hospital does not have electricity. The fuel consumption of the back-up generator, when in use, is around 20 litres per hour and the hospital is paying around 16,000 Kwacha per month towards electricity supply from the main grid

4.8 Solid Waste Information

The hospital administration reported that the institution produces approximately 550 – 630 tonnes of solid waste per month. The produced solid waste is collected three times a week from the production points except for biological waste which is collected every day. The hazardous and biological waste is collected and treated separately from the rest of the waste that is generated through incineration or disposal respectively. The capacity of the incinerator at St. Francis hospital was reportedly to be small but with high maintenance costs.

Reported biological waste is material that contains or has been contaminated by a biological agent e.g. after birth placenta, amputations, etc. The biological waste is dumped into a lined pit 126 m^3 (4m x 4m x 8m) big. When the pit is filled up, it is buried and the biological waste will be dumped in a newly created pit. The rest of the solid waste is dumped at a disposal bay. The bay has a volume of 1.875 m^3 (25m x 15m x 5m) and is around 1 km away from the hospital. It is also buried when it is filled.

4.9 Treated Water Reuse Potential

Treated waste water and sludge are the major outputs of the redesigned treatment system. The treated water could be discharged into the seasonal river in the north of the hospital. Otherwise it could be infiltrated into the ground. A high potential of the treated water is seen in the reuse for landscaping and agriculture (gardening). This would create a more liveable and healthier environment. The produced sludge could be disposed in the existing stabilization ponds that are located around 6km away from the hospital.

4.10 Sanitation Facilities

The hospital has 19 buildings with a total of 63 flush, 4 pit latrines, 130 hand basins and 32 showers. Toilets are in every building except the Laundry and the Kitchen. A summary of toilets in the institution buildings is table 4.3

Table 4-3: Quantity of sanitation facilities per hospital building

Building	Toilet	Hand basin	Shower
St.Augustine and Monica	5	5	4
Kizitho and Mukasa	6	8	5
York	5	6	4
OPD/ Old Mbusa	7	33	-
B. Oliver	4	4	-
Mbusa	8	4	6
Bethlehem	12	36	4
Theatre	2	6	2

Laboratory	3	4	1
Kitchen	-	3	1
Workshop	1	-	1
Laundry	-	-	1
Records	1	1	-
St Lukes	3	7	-
EYE OPD	2	4	1
EYE Theatre/ EYE	2	4	1
Pharmacy	1	3	-
Store	2 Latrine	-	-
Morgue	1 + 2 Latrine	2	1
Total	63 +4 Latrines	130	32

The OPD has which a highest number of daily attendees has 33 hand washing basins with every treatment unit having at least one hand basin. Bethlehem ward has the most toilets (12) and hand basins (36). The conditions of the toilets, hand basin and showers in the Bethlehem ward have been analysed as follows:

- One of the 12 toilets is not used, one was found leaking and two are not working.
- Three of the 36 hand basins were leaking.
- Four of the hand basins that are located in the patient room have running water permanently due to faulty plumbing.
- Three well working showers are available and one is leaking.

The York building has five toilets, six hand basins and four showers which are currently not in use.

4.11 Impressions of on-site investigations

The following google earth image of St. Francis Hospital and community shows where the pictures of this chapter are taken including the viewing perspective.

Figure 4-1: Site Francis aerial view and surrounding communities and picture site

Figure.4-2: Site 1 waste disposal area and infiltration test

Figure 4-3: Picture site 2-blocked overflowing sewer manhole; incinerator

Figure 4-4: Dry non-sewer receiving manhole with solid waste

Figure 4-5: Picture site 3; Suitable site for implementation of a unit for household area B

4.12 Waste water production

The waste water produced in the hospital is segregated into grey and black water. The grey water has grey water treatment units in form of settlers for kitchen and laundry units and soak pits for hand wash basins.

Treatment units for the housing units are in form of septic tanks and soak pits. The waste water production per calculated per portioned area is as explained below.

4.12.1 Hospital

The median urine generation volumes from the characteristics of urine and faeces (Rose et al, 2015) was 1.42 l/cap/day with a urination rates of 8 times. The median faecal generation was 126g/cap/day with a stool rate of twice per day. The calculated ward occupancy rates of the hospital produced waste consumption rates as in the table 4-4 below.

Table 4-4: Daily hospital wards waste water generation potential

CURRENT WASTE WATER SITUATION										
Daily Wastewater Generation										
BLACK WATER										
Ward	**Daily Ward Occupancy**	**Fecal waste generation [g/day]**	**Urine generation [L/day]**	**Flush water consumption [L/day]**	**Waste water production [L/day]**		**Fecal generation [g/day]**	**Urine generation [L/day]**	**Flush water consumption [L/day]**	**Waste water production [L/day]**
	Average Daily Ward Occupancy					Maximum Daily Ward Occupancy				
St Monica	19	2394	26.98	1368	1394.98	27	3402	38.34	1944	1982.34
St Augustine	21	2646	29.82	1512	1541.82	28	3528	39.76	2016	2055.76
Mbusa	31	3906	44	2232	2276	50	6300	71	3600	3671
Mukasa	30	3780	43	2160	2203	38	4788	54	2736	2790
Kizito	25	3150	36	1800	1836	32	4032	45	2304	2349
Bethlehem and Waiter's shelter	70	8820	99	5040	5139	109	13734	155	7848	8003
York	22	2772	31	1584	1615	27	3402	38	1944	1982
SCBU	17	2142	24	1224	1248	25	3150	36	1800	1836
TOTAL	**235**	**29610**	**334**	**16920**	**17254**	336	**42336**	**477**	**24192**	**24669**

The outpatient department waste water generation rates are shown 4.5. The production was calculated from a stool production ratio of 0.1 and 0.3 for urine per person.

Table 4-5: Daily OPD waste water generation potential

CURRENT WASTE WATER SITUATION Daily Wastewater Generation BLACK WATER										
Daily OPD Attendances		Fecal generation [g/day]	Urine generation [L/day]	Flush water consumption[L/day]	Waste water production [L/day]		Fecal generation [g/day]	Urine generation [L/day]	Flush water consumption[L/day]	Waste water production [L/day]
	Average Daily OPD Attendances					Maximum Daily OPD Attendances				
New	80	1008	34	1728	1762	104	1304	44	2236	2280
Revisits	225	2829	96	4849	6707	268	3373	114	5782	8176
TOTAL	**304**	**3837**	**130**	**6577**	**6707**	371	**4677**	**158**	**8018**	**8176**

The average and maximum waste water production from the hospital factoring in workers in the institution is summarised in the table 4.6.

Table 4-6: Current hospital waste water generation potential

CURRENT WASTE WATER SITUATION									
Daily Average Wastewater Generation					Daily Maximum Wastewater Generation				
BLACK WATER					BLACK WATER				
	Fecal generation [g/day]	Urine generation [L/day]	Flush water consumption[L/day]	Waste water production [L/day]		Fecal generation [g/day]	Urine generation [L/day]	Flush water consumption[L/day]	Waste water production [L/day]
Average Ward Occupancy	29610	334	16920	17254	Maximum Ward Occupancy	42336	477	24192	24669
Average OPD Attendances	3837	130	6577	6707	Maximum OPD Attendances	4677	158	8018	8176
Staff	20160	213	10800	11013	Staff	20160	213	10800	11013
Total	**53607**	**676**	**34297**	**34973**	**Total**	**67173**	**848**	**43010**	**43858**

4.12.2 Households and nursing school

Resident household members with an approximate urination rates of 6.4 times assuming an 80% probability of urinating at home and an average household size of 5 people per house.

The waste water generation of the household areas as in figure 4.1 are summarised in table 4.7.

Table 4-7: Housing community waste water production potential

CURRENT WASTE WATER SITUATION						
Daily Wastewater Generation						
BLACK WATER						
Housing	**No. Of Houses**	**No. of People per House**	**Fecal generation [g/day]**	**Urine generation [L/day]**	**Flush water consumption [L/day}**	**Waste water production [L/day]**
Housing A	57	5	35910	324	16416	16740
Housing B	29	5	9135	165	8352	8517
HousingC	27	5	17010	153	7776	7929
Hospital Lodge		15	1890	21	864	885

4.13 Proposed system positions

The geographic data and infrastructure data revealed three areas in the vicinity of the hospital and community where waste water treatment facilities could be installed. The identified sites favour easy waste water flow with the option of making use of natural flows and by product reuse.

The conclusions from this analysis as well as geographic advantages and disadvantages are summarised in the following table:

Table 4-8: Sewer network configuration options.

Network	Distance	Height difference	Attributes
Network 1: A combination of household area A and the hospital sewer line	The total sewer line distance is over 2 kilometers	The height difference between the highest and lowest point in the sewer line is 7 meters with the lowest point being the at the northern point of the hospital	- Three intermediate settlers to be installed along the sewer line - The slope of the topography is an average 2% - Construction can be made progressively starting with the hospital unit - Hospital pipelines are already existing - Patients visitors boarding house can have renewable energy for cooking - Incinerator can have biogas for use and save fuel costs

Network 2: A sewer line serving the household area B on the western part of the hospital and the nursing school	The sewer line length is 1.2 kilometers long	The height difference between the highest and lowest point is 8 meters with the lowest point being on the western part of the hospital near the garden	- Two intermediate settlers to be installed - Greater treated waste water reuse potential - School kitchen and nursing boarding house can use the gas
Network 3: Serves the households on the north-western part of the hospital	The sewer distance is approximately 800 meters long	The elevation difference is 12 meters deep	- Intermediate settlers not necessary - Higher concentration of households - Biogas can only be used at some of the households
Network combination 4: Combination of sewer network 2&3	The total sewer line length is approximately 2.6 kilometers long	The height difference between the highest and lowest points is 17 meters	- Intermediate settlers not necessary - Higher concentration of households - Biogas can only be used at some of the households
Network combination 5: An array of a treatment unit that serves the whole hospital and the housing units	The total network sewer line network is 0ver 6 kilometers	The height difference between the highest and lowest points is 17 meters	- Intermediate settlers be incorporated in along the sewer line - The system combining unit A, B and C and implementing one treatment unit at the northern part of hospital housing units

4.13.1 Network 1: Hospital and housing unit A

Figure 4-6: Sewer network 1 covering hospital and household area A

Network 1 in figure 4.6 serves the household area A together with the hospital. The household area serves 57 households and the hospital lodge. The treatment unit is positioned at the northern end outside of the hospital fence and near the existing the septic tanks and the seasonal river as it is the lowest topographical point of the areas.

The total black water production is approximately 53 cubic meters with approximately 35 cubic meters being produced from the hospital. Intermediate waste water settlers are proposed to be installed along the sewer lines for solid waste trapping and creation of solid free sewer. The approximated sewer line length is 2 kilometres long.

The biogas from the intermediate settlers at the household could be piped to the boarding house for cooking and the biogas at the morgue could be piped to the incinerator to fuel burning of the heat for the waste.

Table 4-9: Waste water generation rates for sewer network 1

Unit A						
	Number of Households	Number of people	Faecal generation [g/day]	Urine generation [L/day]	Flush water consumption [L/day]	Waste water production [L/day]
Hospital		600	53,607	676	34,297	34,973
Housing A	57	295	37,800	345	17,280	17,625
Hospital Lodge		15	1,890	21	864	885
Total	57	910	91,407	1,021	51,577	52,598

4.13.2 Network 2: Housing unit B

Figure 4-7: Sewer network 2 covering household area B

Network 2 in figure 4.7 serves household area B and the nursing school. The household area serves over 29 households and nursing school with a combined population of 345 people. The treatment unit is on the western point of the area adjacent to the hospital garden.

The black water production is approximated around 15.9 cubic meters. Intermediate waste water settlers are proposed to be installed along the sewer lines for solid waste trapping and creation of solid free sewer. The approximated sewer line length is 1 kilometre.

The biogas from the settlers could be used for cooking at the nursing boarding house.

Table 4-10: Waste water generation potential for network 2

Unit B						
	Number of Households	Number of people	Faecal generation [g/day]	Urine generation [L/day]	Flush water consumption [L/day]	Waste water production [L/day]
Nursing school		200	12,600	142	7,200	7,342
Housing B	29	145	9,135	165	8,352	8,517
Total	29	345	21,735	307	15,552	15,859

4.13.3 Network 3: Housing unit C and Hospital Workshop

Network 3 in figure 4.8 serves the household area C which serves over 27 households and the hospital workshop. The treatment unit is positioned at the northern end outside of the area lowest topographical point of the areas.

The total black water production is approximately 8 cubic meters. The approximated sewer line length is 800 meters long.

Figure 4-8: Sewer network 3 covering household area C

Table 4-11: Waste water generation potential for area C

Unit C						
	Number of Households	Number of people	Faecal generation [g/day]	Urine generation [L/day]	Flush water consumption [L/day]	Waste water production [L/day]
Housing C	27	135	17,010	153	7,776	7,929

4.13.4 Network option 4: Combination of B and C

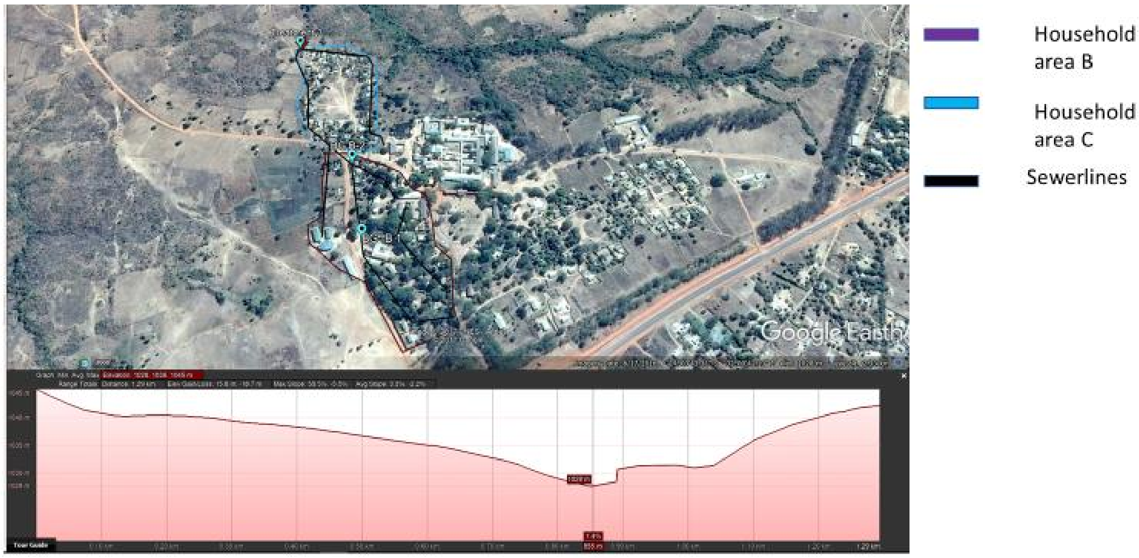


Figure 4-9: Network option 4; Combination of network area B and C

Network option 4 in figure 4.9 serves a combination of network area B and C. The network combination seeks to serve 56 households and the nursing school. The treatment unit is positioned at the northern end of the area as it has the lowest topography.

The total black water production is approximately 32 cubic. Intermediate waste water settlers are proposed to be installed along the sewer lines on the southern point for solid waste trapping and creation of solid free sewer. The approximated sewer line length is 2 kilometres long.

Table 4-12: Waste water production potential for Network option 4

UNIT B&C						
	Number of Households	Number of people	Faecal generation [g/day]	Urine generation [L/day]	Fresh water consumption [L/day]	Waste water production [L/day]
Nursing school		200	12,600	142	7,200	7,342
Housing B	29	145	35,910	324	16,416	16,740
Housing C	27	135	17,010	153	7,776	7,929
Total	56	480	65,520	619	31,392	32,011

4.13.5 Network option 5: Combination A, B and C

Network option 5 is a combination of all the networks in the hospital. The treatment unit is positioned at the northern end of household area C as it is the lowest topographical point of the areas.

The total black water production is approximately 77 cubic. Intermediate waste water settlers are proposed to be installed along the sewer lines for solid waste trapping and creation of solid free sewer. The approximated sewer line length is 6 kilometres long.

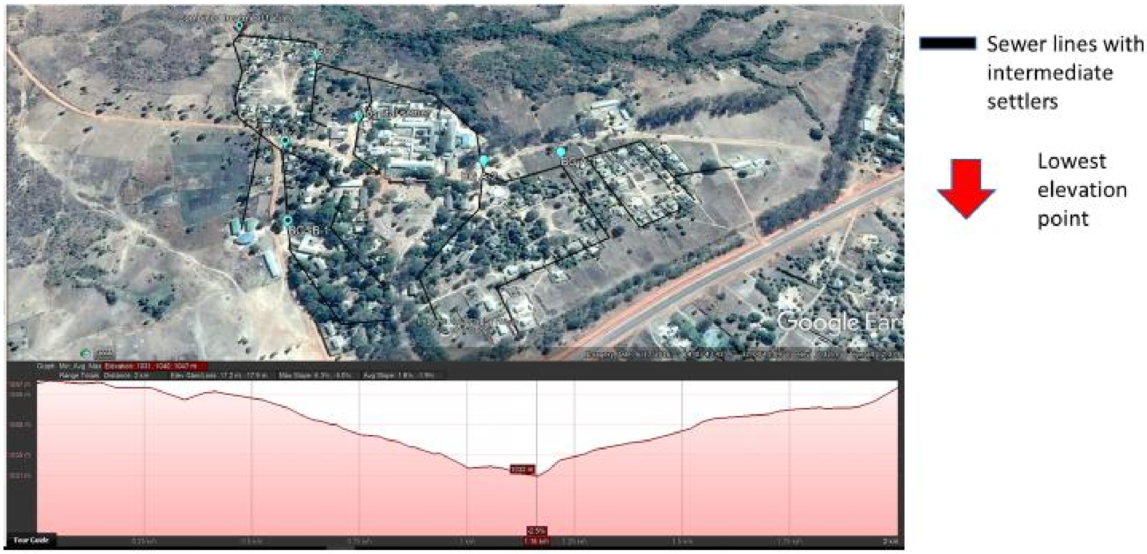


Figure 4-10: Network option 5; combination of networks A, B and C

Table 4-13: Waste water generation potential for the hospital and hospital community

UNIT A, B & C						
	Number of Households	Number of people	Faecal generation [g/day]	Urine generation [L/day]	Fresh water consumption [L/day]	Waste water production [L/day]
Hospital		600	53,607	676	34,297	34,973
Housing A	57	295	37,800	345	17,280	17,625
Hospital Lodge		15	1,890	21	864	885
Housing B	29	145	9,135	165	8,352	8,517
Nursing school		200	12,600	142	7,200	7,342
Housing C	27	135	17,010	153	7,776	7,929
Total	113	1,390	115,032	1,349	67,993	77,271

5. TREATMENT SYSTEM DESIGN

5.1 Review of available treatment technologies

Different technologies are applied in biological waste water treatment solutions. The applied technologies depend on the treatment objectives and the end use. The three types of applied technologies are 'established', 'transferring' and 'innovative' technologies. Established technologies are technologies that have been in use for a very long time and they have been developed on a higher level due to operations and maintenance experience. Transferring technologies are technologies that have been developed for other waste but are being adapted for waste water. Operations and maintenance have to be redefined for transferring technologies as the characteristics and parameters are different from the waste developed for. Innovative technologies are technologies that are still under research and scaling up.

Technologies to be applied should depend on the treatment objectives which could be solid liquid separation, sludge stabilisation, nutrient management and pathogen inactivation. Established waste water technologies for waste water include settling thickening tanks, planted drying beds, and unplanted drying beds and composting. Transferring waste water technologies include anaerobic biogas digesters, anaerobic baffled reactors, incineration, lime treatment and composting. Innovative technologies include pyrolysis, pelletizing, fly larvae composting and ammonia treatment.

5.1.1 Preliminary Treatment

Preliminary treatment facilities could be defined as technologies that are applied at the receiving station. Waste water preliminary treatment is done in the process of screening inorganic waste oils that comes with the sludge.

5.1.1.1 Grease trap

Waste water from kitchens, bathrooms and laundry rooms sometimes contains oils and greases. The oils and fats contain elements which hinder biological treatment of waste water. Grease traps can be in form of small chambered manholes or primary settlers. Grease traps can also be incorporated in treatment units by the use of T-joints when connecting one facility to the other.

5.1.2 Primary Treatment

Dewatering (liquid-solid separation) is one of the most important treatment processes in waste water treatment of which gravity is probably the most commonly employed method of liquid – solid separation. Gravity can achieve the separation of suspended particles and unbound water. Particles that are heavier than water settle out under quiescent conditions at rates based on size of particles, suspended solids concentration, and flocculation. The four types of settling mechanisms include discrete particle, flocculent, hindered, and compression.

Discrete particle settling occurs in lower concentration waste streams when particles settle out individually without reacting with other particles. Flocculent settling occurs when particles join together and merge, increasing their mass and settling velocity. This is important for smaller particles that are held together through Van der Waals force, resulting in increased settling velocities.

5.1.2.1 Biogas Digester/Settlers

The biogas digester is designed as a split globe, made by bricks and built into the ground. Its primary function is to separate the solid and liquid forms of the incoming wastewater as well as to biologically digest the organic solids. The digestion process takes place without oxygen input, under anaerobic conditions, and creates biogas which can be used for cooking, lighting and heating. Biogas digesters are constructed most of the time exclusively using brick-work and built in sizes of minimum 6 m³ to up to 200 m³ due to the dome structure. Biogas digesters have been implemented in FS projects where gas trapping and use is of interest.

Biogas digesters are efficient in solid stabilisation and achieve a COD treatment efficiency of over 70%. The sludge entering the treatment facility should be sand free as it complicates the maintenance of the facility. Periodic removal of stabilised sludge should also be ensured so that a compact layer of sludge difficult to remove does not develop at the bottom.

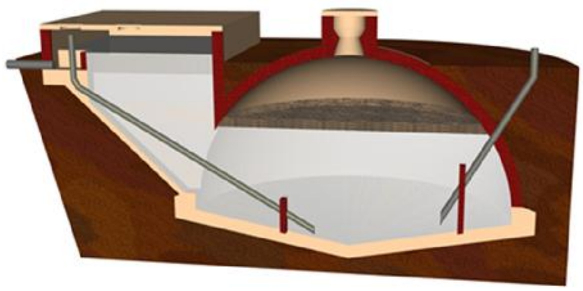


Figure 5-1: Biogas digester (Courtesy of BORDA)

5.1.2.2 Settler

The settler separates scum and large particles which can settle to the bottom, while protecting the post-connected treatment stages. The settler will be fed with wastewater pumped up through the lift station. It pre-treats dissolved and particulate wastewater components through sedimentation and bio-degradation. Utilizing a hydraulic retention time of 1.5 – 2 hours, referring to the peak-flow, up to 30 – 40% of the organic load measured as COD is removed.

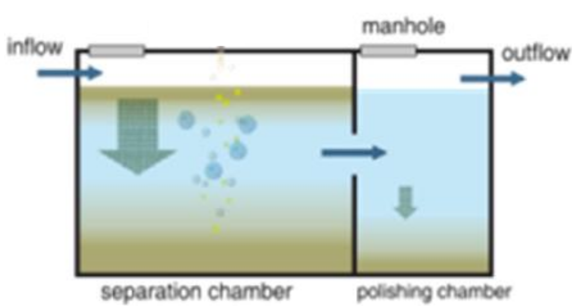


Figure 5-2: Primary settler (Courtesy of BORDA)

5.1.3 Secondary Treatment

Secondary treatment facilities treat the effluent from primary treatment units in the treatment of solids and COD and pathogens. The most commonly used secondary treatment units for waste water treatment include, Anaerobic Baffled Reactors (ABR's), Anaerobic Filters (AF's) and sludge drying beds.

5.1.3.1 Anaerobic Baffled Reactor (ABR)

The ABR serves as the core secondary treatment stage of anaerobic treatment. Up to 60% of the organic load (measured in BOD and COD) coming from the settler can be eliminated through sedimentation and bio-degradation. The up and down flow characteristics of this plug-flow reactor establishes an environment whereby the dissolved and particulate organic matter comes into contact and is biodegraded by the microorganisms forming an activated sludge layer on the bottom of each reactor chamber. This process takes place without aeration and mixing under anaerobic condition and therefore does not require external energy. Distributing the inflow over the entire width of the ABR and maintaining a maximum flow velocity of 0.5-1 m/h are crucial hydraulic design and operation requirements.

In order to avoid storm water intrusion, the ABR should be raised at least 1 m above ground level. This provides additional slope to discharge the ABR effluent into the polishing pond/wetland by gravity flow.

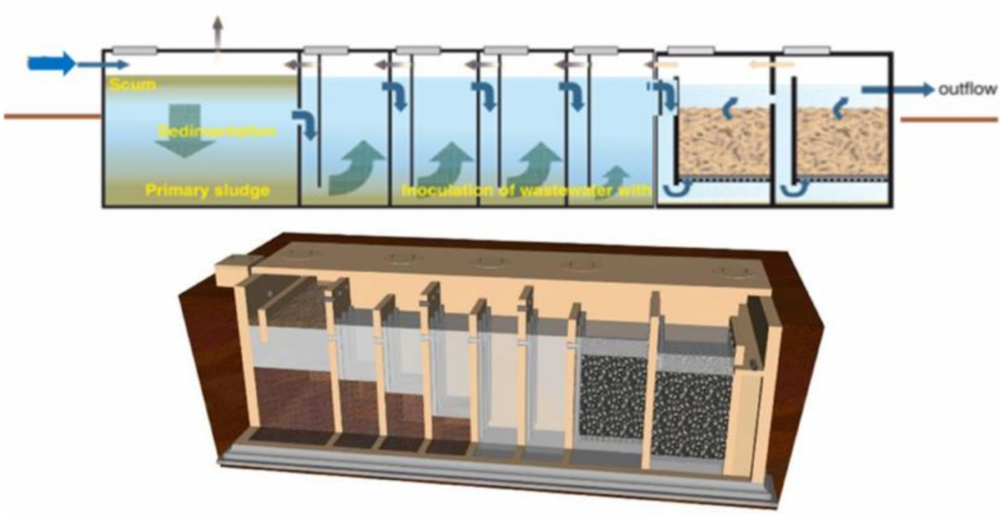


Figure 5-3: Anaerobic baffle reactor (Courtesy of BORDA)

5.1.3.2 Planted Gravel Filter (PGF)

Planted Gravel Filter is a constructed wetland which is the pre-treatment and water distribution stage of the tertiary treatment of Unit III. Its core function within the DEWATS Cluster concept is to distribute the effluent equally and create natural aeration before the treated effluent enters polishing pond. It is suitable for wastewater with a low percentage of suspended solids which have been removed through previous primary and secondary treatment. It also serves a treatment function depending on the size and design parameters, primarily through biological conversion, physical filtration and chemical absorption. The PGF is made of planted filter bodies consisting of graded gravel. The bottom slope is 1% and the flow direction is mainly horizontal. The main plants used in this filter bed are Canas indica, Reed juncus, Papyrus, Phragmites and Arunda donax. The plant selection is mainly based on their ability to grow on wastewater and have their roots go deep and spread wide. Plants transport oxygen via their roots into the ground. However, in the present DEWATS design the use of plants is only to act as catalysts rather than actually be a treatment medium. BOD reduction rate is between 75 - 90% and pathogen removal is over 95% depending on the systems size and design. The operation and maintenance of the system are simple. The spatial requirements for construction are compensated through landscaping.

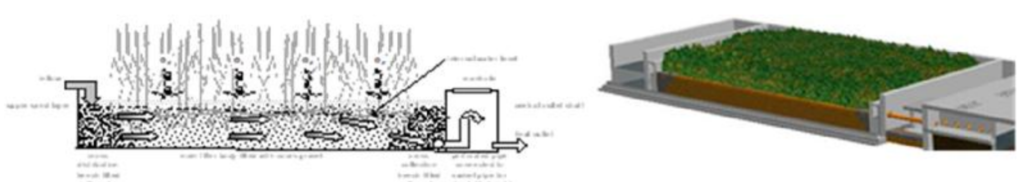


Figure 5-4: Planted gravel bed (Courtesy of BORDA)

5.1.4 Advanced Secondary Treatment

Advanced secondary treatment facilities polish off the treated waste water in readiness for reuse or disposal. Advanced treatment units treat waste water by the use of ultra-violet rays, plants and gravity. These include polishing ponds,

5.1.4.1 Polishing Pond

The polishing pond is the tertiary treatment stage primarily designed to eliminate up to 80-90% of the nutrients (measured as total nitrogen and phosphorous) and up to 99% of the pathogens in the treated effluent from the secondary treatment stage.

Determining the most appropriate tertiary treatment stages involves comparing compact treatment systems requiring energy vs. spatially larger areas utilizing natural treatment i.e. polishing ponds. In many contexts, it is recommended to utilize existing ponds/wetlands and to engineer and operate them as polishing ponds as the tertiary wastewater treatment stage. This serves a dual purpose of protecting these important wetland ecosystems and provides positive overall impacts on water resource management as well as giving them a control function within sustainable urban drainage systems.

Design recommendations for these ponds state that the effluent of the AF should be distributed in a small constructed wetland zone prior to the actual wetland, to ensure equal distribution and natural aeration before entering the pond. The ponds need to provide a minimum hydraulic retention time of 10 days, referring to a daily and maximum wastewater inflow volume, or to a dilution ratio of 1:10.

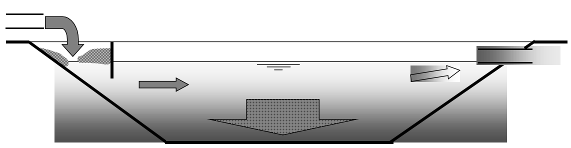


Figure 5-5: Polishing pond (Courtesy of BORDA)

5.1.4.2 Vertical Sand Filter

The vertical sand filter has a treatment efficiency between 90-99% by vertically directing the effluent through course sand which promotes the dissolution of oxygen into the water. Vertical sand filters treat waste water in terms of Cod but also help in the removal of nutrients from the effluent.

However, the facilities require batch feeding intervals which means mechanisms need to be implemented to ensure proper operations.

Figure 5-6: Vertical sand filter

5.1.4.3 Vortex

The vortex is the unit which uses the principle of the tornado in increasing dissolved oxygen content in the waste water before reuse or disposal. The unit works with low energy input and can perfectly fit where a planted gravel nor vertical sand filter cannot fit. The vortex can be incorporated in the polishing pond hence increasing the treatment efficiencies of the waste water

However, operation of the vortex requires the flow of water at high pressure to the tubes hence a pressurising mechanism is required in order to create the swirl in the tube.

Figure 5-7: Vortex

5.2 By Product reuse

Waste water treatment products range from biogas, sludge used as soil conditioner and effluent water. Waste water products have economic value and the use of the products ensures sustainability of the waste water operation.

Biogas

Depending on the type of primary treatment applied, biogas can be recovered as a by-product for reuse if a biogas digester is used as treatment module. The biogas can be used as a fuel for heating purposes depending on the amount of biogas produced and captured in the dome. The volume of biogas produced will depend on the volume of sludge fed into the treatment facilities and the properties of the sludge such as BOD concentrations, PH and temperature.

Treated sludge as soil conditioner

Sludge from the treatment units can be used as soil conditioner for use in gardens, grass lawns and farms as it has high nutrient concentrations. The sludge can be processed by crushing big sludge pieces into small ones and packaged for selling

Treated sludge as biofuel

Sludge collected from waste water facilities can be used as a fuel in combustion plants due to its combustible properties. The calorific value of the sludge will depend on the sand and grit content as well as the moisture percentage.

Treated effluent water

Treated effluent water is the water that has been treated by the treatment modules. Treated waste water can be disposed or reused depending on the treatment levels. The water can be used for road construction, forest irrigation and some sub-surface irrigation.

5.3 Considered treatment options

5.3.1 Applicable and Recommended treatment modules

The analysis from the site investigations and questionnaires gave indications of design incorporations for different treatment options. The considered modules for the treatment plant are as follows:

Conveyance

The conveyance system for St. Francis hospital is a shallow bore sewer network using 6” pipes. The pipes should be laid with a slope of 1-2% gradient. Inspection chambers should be installed along the network at every sewer pipe connection point or at points where the gradient needs to change

Preliminary

The network from the kitchen and laundry units needs to be installed with grease traps to trap greases and also help in the trapping of sand and grit coming from the showers

Primary treatment

Primary treatment facilities will be implemented along the conveyance network and before the major treatment plant. The primary treatment facilities implemented along the conveyance network will act as intermediate settlers to trap solid waste and create a solid free sewer network and produce biogas for use at heat energy requiring facilities in the vicinities. A final primary treatment facility will also be implemented before the secondary treatment plant for final solid trapping and only allow pre-treated water with dissolved solids to go through the treatment plant.

Secondary treatment

The anaerobic baffled reactor and the Anaerobic filters will be implemented at treatment facilities after primary treatment facilities to treat the waste water from primary treatment facilities.

Advanced secondary treatment

The advanced secondary treatment unit to be installed at the treatment plant shall be the planted gravel filter placed at the far end of the treatment plant near the disposal or reuse point. The module shall be placed away from human contact zones for safety.

Reuse/disposal

The disposal option considered is in the seasonal river where the existing septic tanks discharge and the reuse option is the use of underground irrigation of fruit trees with the use of French drains. The waste water treatment and reuse configuration is as in figure 5-8.

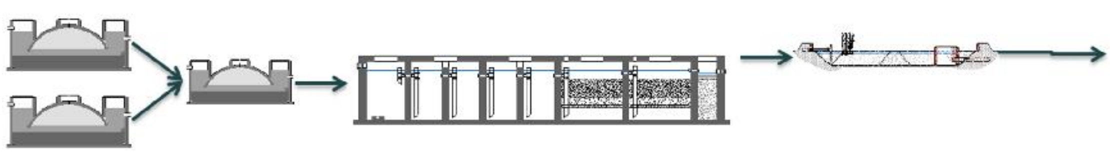


Figure 5-8: Treatment facility configurations

Various technical options and considerations were devised to come up with various suitable and measurables options as tabulated in the morphologic box below:

Table 5-1: Treatment system combinations

Design aspect	Option 1: Three separate treatment units A, B & C	Option 2: Two treatment units' A and B&C	Option 3: One Treatment Unit combined
Waste water flow and gradient	A- High flows specially from the hospital B- Low water flows from the household but high-water flows in the morning C- Low as in B	A-High B-Low	C -High flow volumes in one areas but with medium flow rates on a constant rate
intermediate settlers along pipeline	A-3 intermediate settlers two on the households and one near the morgue B-1 to 2 C-non	A-3 intermediate settlers B-1 to 2	A-3 intermediate settlers B-1 to 2
Frequency of blockages	Low	Low	low
Maintenance requirements	Low	medium	medium
Biogas use options	A-Nursing school hostel, hospital lab and incinerator B-Nursing school kitchen C-Two households	A-Nursing school hostel, hospital lab and incinerator B-Nursing school kitchen C-Two households	A-Nursing school hostel, hospital lab and incinerator B-Nursing school kitchen C-Two households
Treated waste water reuse options	A-New vine yard B-New vine yard C-new vineyard	A-New vine yard C-New vine yard	A-New vine yard
Treated waste water disposal	A-Seasonal stream B-New treated waste water flow C-seasonal stream	A-Seasonal stream C-seasonal stream	C-seasonal stream

5.4 Assessment of requirements

The requirements of the treatment options were sub-divided in technical and financial/economic requirements. In addition, the requirements were ranked according to their importance. The rankings used were as follows:

Table 5-2: Ranking system

Marks	Requirements ranking
4	Mandatory
3	Very important
2	Important
1	Convenient
0	Unnecessary

5.4.1.1 Technical requirements

The technical requirements and parameters considered for the designs were assessed and ranked according to the specifications of importance. The results are tabulated in table 5.3:

Table 5-3: Technical ranking requirements

No.	Requirement	Assessment parameters	Ranking (Importance)
1	Durability	Less human/machine traffic	3
2	Topographic position	Easy flow of waste water	3
3	Easily accessible	Ergonomic treatment position For different waste water flows	1
4	Reuse position	Waste water reuse position	`2
		Biogas Reuse position	
5	Low maintenance	Minimal number of pipes, fittings, valves etc.	2
		Less blockages	
6	Safety	Less human contact	3
7	Stability	Less likely to be disturbed by machine movement	3

5.4.1.2 Maintenance requirements

Table 5-4: Maintenance ranking requirements

No.	Requirement	Assessment parameters	Ranking (Importance)
1	Accessibility	Easily accessible by the maintenance team	3
2	Desludging	Easy to de-sludge during maintenance	4
3	Disposal	Easy disposal of desludged waste	3

5.4.1.3 Financial/ economic requirements

Some essential financial/ economic requirements (management cost and self-sustainability) cannot be assessed through the design, but rather through the operational framework. The table below summarises the financial/ economic requirements and their respective importance.

Table 5-5:Economic ranking requirements

No.	Requirement	Assessment parameter	Ranking (Importance)
1	Low implementation costs	Low material costs	2
		Low labour costs	
		Low transport costs	
2	Low operational costs	Minimal labour costs on operations	3
		No operational materials (consumables) needed	
3	Low maintenance costs	Minimal labour costs on maintenance	4
		Minimal maintenance materials needed	

5.5 Implementation costs per unit per treatment area

Implementation cost estimations for design scenarios

Cost estimates broken down into budget categories were prepared for the respective design components, such as different system setup and treatment facilities.

System 1: Area A

Table 5-6: System 1 facility costs in ZMW

Component	Materials & Tools (ZMW)	Labour (ZMW)	Transport(ZMW)	Site super-vision(ZMW)	Admin & misc. (ZMW)	Sum (ZMW*)
Intermediate digester costs	10,000	8,000	5,000	5,000	5,000	33,000
Main Biogas digester	12,000	10,000	5,000	5,000	5,000	37,000
Biological treatment facility (ABR)	190,000	110,000	15,000	30,000	20,000	365,000
Planted Gravel Filter	30,000	10,000	10,000	10,000	5,000	65,000

System 2: Area B

Table 5-7: System 2 facility costs in ZMW

Component	Materials & Tools (ZMW)	Labour (ZMW)	Transport(ZMW)	Site super-vision(ZMW)	Admin & misc. (ZMW)	Sum (ZMW*)
Intermediate digesters	10,000	8,000	5,000	5,000	5,000	33,000
Biogas digester	12,000	10,000	5,000	5,000	5,000	37,000
Biological treatment facility (ABR)	70,000	30,000	10,000	10,000	5,000	125,000
Planted Gravel Filter	20,000	10,000	10,000	10,000	5,000	55,000

*10 ZMW=1 USD

System 3: Area C

Table 5-8: System 3 facility costs

Component	Materials & Tools (ZMW)	Labour (ZMW)	Transport(ZMW)	Site super-vision (ZMW)	Admin & misc. (ZMW)	Sum (ZMW*)
Intermediate digesters	10,000	8,000	5,000	5,000	5,000	33,000
Biogas digester	12,000	10,000	5,000	5,000	5,000	37,000
Biological treatment facility (ABR)	60,000	15,000	5,000	20,000	2,000	92,000
Planted Gravel Filter	20,000	10,000	8,000	8,000	4,000	50,000

Combination B &C

Table 5-9:System setup 4 facility costs

Component	Materials & Tools (ZMW)	Labour (ZMW)	Transport(ZMW)	Site super-vision (ZMW)	Admin & misc. (ZMW)	Sum (ZMW)
Intermediate digester cots	10,000	8,000	5,000	5,000	5,000	33,000
Biogas digester	12,000	10,000	5,000	5,000	5,000	37,000
Biological treatment facility (ABR)	190,000	110,000	15,000	30,000	20,000	365,000
Planted Gravel Filter	30,000	10,000	10,000	10,000	5,000	65,000

*10 ZMW=1 USD

System combination A, B & C

Table 5-10: System setup 5 facility costs

Component	Materials & Tools (ZMW)	Labour (ZMW)	Transport(ZMW)	Site super-vision (ZMW)	Admin & misc. (ZMW)	Sum (ZMW)	Materials & Tools (ZMW*)
Intermediate digester costs	10,000	8,000	5,000	5,000		5,000	33,000
Biogas digester	12,000	10,000	5,000	5,000		5,000	37,000
Biological treatment facility (ABR)	290,000	130,000	30,000	40,000		30,000	52,000
Planted Gravel Filter	40,000	15,000	15,000	10,000		5,000	75,000

Treatment system components implementation per area

Table 5-11: Treatment system implementation costs for hospital and household area A

	System A				
Facility	#	Volume (each) M3	Amount	Implementation costs	Subtotal costs (ZMW*)
Intermediate digester costs	3	16	33,000	99,000	99,000
Big digester	1	22	37,000	37,000	37,000
Biological treatment facility (ABR)	1	54	365,000	365,000	365,000
Planted Gravel Filter	1				65,000
Total					566,000

Table 5-12:Treatment system implementation costs for area B

	System B				
Facility	#	Volume (each)	Amount	Implementation costs	Subtotal costs (ZMW)
Intermediate digester costs	1	16	33,000		33,000
Big digester	1	22	37,000		37,000
Biological treatment facility (ABR)	1	20	125,000		125,000
Planted Gravel Filter	1		55,000		55,000

Total					250,000

*

Table 5-13:Treatment system C implementation costs

	System C				
Facility	#	Volume (each)	Amount	Implementation costs	Subtotal costs (ZMW)
Intermediate digester costs					
Big digester	1	16	33,000	33,000	33,000
Biological treatment facility (ABR)	1	16	92,000	92,000	92,000
Planted Gravel Filter	1		50,000	50,000	50,000
Total					175,000

5.6 System Implementation Scenario's

Scenario 1: Separate systems for area A, B and C

Table 5-14: total implementation cost for separate system implementation

	System 1				
Facility	#	Volume (each)	Amount	Implementation costs	Subtotal costs (ZMW)
intermediate digesters small digesters	4	16	33,000	132,000	132,000
Big digester A	1	22	37,000	37,000	37,000
Big digester B	1	22	37,000	37,000	37,000
Big digester C	1	16	33,000	37,000	33,000
Biological treatment facility (ABR) A	1	54	365,000	365,000	365,000
Biological treatment facility (ABR) B	1	20	125,000	125,000	125,000
Biological treatment facility (ABR) C	1	16	92,000	92,000	92,000
Planted Gravel Filter A	1		65,000	65,000	65,000
Planted Gravel Filter B	1		55,000	55,000	55,000
Planted Gravel Filter C	1		50,000	50,000	50,000
Total					991,000

The investment costs per person for the system setup is 712 ZMW.

Scenario 2: Separate systems for area A, and B&C combined

Table 5-15: Implementation costs for system 1 and combination of system 2 and 3

	Scenario 2				
Facility	#	Volume (each)	Amount	Implementation costs	Subtotal costs (ZMW)
Intermediate digesters small digesters	5	16	33,000	132,000	165,000
Big digester A	1	22	37,000	37,000	37,000
Big digester B&C	1	30	40,000	40,000	40,000
Biological treatment facility (ABR) A	1	54	365,000	365,000	365,000
Biological treatment facility (ABR) B&C	1	23	310,000	310,000	170,000
Planted Gravel Filter A	1		65,000	65,000	65,000
Planted Gravel Filter B&C	1		80,000	80,000	80,000
Total					922,000

The investment costs per person for the setup is 663 ZMW.

Scenario 3: Combined system

Table 5-16: Implementation costs for a combined system

	Scenario 3				
Facility	#	Volume (each)	Amount	Implementation costs	Subtotal costs (ZMW)
Intermediate digesters small digesters	6	16	33,000	132000	198,000
Big digester	1	30	40,000	40000	40,000
Biological treatment facility (ABR) B&C	1	32	520,000	520,000	520000
Planted Gravel Filter A	1		65,000	65,000	90,000
Total					848,000

The investment costs per person for the setup is 610 ZMW.

5.7 Levelised cost of treatment

The levelised cost of waste water treatment was calculated for the different waste water treatment options using the approach below.

$$D \quad i\iota = \frac{C}{Li}$$

$$O\&M\ c\iota = (N \quad o \quad o \quad) * M \quad hl\iota\ s\iota * \frac{12\ m \quad hs}{y} * ti \quad s\iota \quad o \quad the\ u$$

The levelised cost of treatment was then computed with the formula

$$L\iota = \frac{D \quad + O\&M}{w \quad t\iota}$$

and

$$L\iota = \frac{D \quad + O\&M}{P \quad s\iota}$$

The items considered for the costs were:

Table 5-17: O&M costs and project design lifespan

Item	Amount
Sanitation workers Salary	2,500
No. of workers	2
Time spent on sanitation	20%
Money spent on sanitation per year	12,000
Auxiliaries	600
O&M cost per year	12,600
Lifespan years	30

With an estimated life span greater than 30 years, the depreciation of the units is tabulated below:

Table 5-18: Levelised cost of system implementations per person and per cubic meter of treated waste

Scenario	System setup	Implementation cost	Depreciation	O&M costs	No. People	Treated wastewater	Levelised cost ZMW/ person	Levelised cost ZMW/m3
1	A	566,000	18,867	4,200	910	53	25	435
	B	250,000	8,333	4,200	345	16	36	783
	C	175,000	5,833	4,200	135	8	74	1254
	A, B, C	991,000	33,033	12,600	1390	77	33	593
2	A	566,000	18,867	6,300	910	53	28	475
	B&C	356,000	11,867	6,300	480	32	38	568
	A, B&C	922,000	30,733	12,600	1390	77	31	563
3	A, B & C	848,000	28,267	12,600	1390	77	29	531

The implementation of a combined treatment facility has a low levelised cost of water treatment with a separated system setup having the highest costs.

5.8 Design scenario assessment and ranking

The initial three design scenarios were assessed and ranked according to the technical, maintenance and economic system requirements. Each requirement is marked according to its degree of fulfilment by the respective design scenario with scores between 0 (not suitable) and 4 (important). The scores for each category are scaled to 100% as maximum score.

Table 5-19: Design scenario ranking requirements

Marks	Requirements ranking
4	Mandatory
3	Very important
2	Important
1	Convenient
0	Not important

The total score for each scenario is calculated by weighing the technical and the operations and maintenance requirements with 40% each and economic requirements with 20%. Technical requirements are weighed higher, because of the diversity and number of requirements compared to the other categories and because of the limited assess-ability of the economic requirements without taking the management framework into account.

Table 5-20: Design ranking scores

No.	Technical requirement	Assessment parameters	Importance	Option 1	Option 2	Option 3
1	Durability	Less human/machine traffic	3	3	4	4
2	Topographic position	Easy flow of waste water	4	3	3	3
3	Easily accessible	Ergonomic treatment position	3	2	2	2
		For different waste water flows	3	3	3	3
4	Reuse position	Waste water reuse position	3	3	3	3
		Biogas Reuse position	4	2	3	4
5	Low maintenance	Minimal number of pipes, fittings, valves etc.	2	3	3	3
		Less blockages	3	4	3	3
6	Safety	Less human contact	3	3	4	4

7	Stability	Less likely to be disturbed by machine movement	4	3	4	4
Score				58%	59%	68%
No.		Assessment parameters	Importance	Option 1	Option 2	option 3
1	Accessibility	Easily accessible by the maintenance team	2	2	3	4
2	Desludging	Easy to de-sludge during maintenance	3	3	3	3
3	Disposal	Easy disposal of desludged waste	4	2	3	3
Score				58%	75%	83%
No	Financial/ economic requirements	Assessment parameters	Importance	Option 1	Option 2	option 3
1	Low implementation costs	Low material costs	3	2	3	4
		Low labour costs	3	3	3	4
		Low transport costs	3	2	2	2
		Minimal labour costs on operations	4	1	2	3
2	Low operational costs	No operational materials (consumables) needed	1	2	2	2
3	Low maintenance costs	Minimal labour costs on maintenance	4	2	3	3
		Minimal maintenance materials needed	3	3	3	3
Score				52%	48%	67%

Table 5-21: Design scenario weighting

Category	Weight	Scenario 1	Scenario 2	Scenario 3
Technical	40%	23%	24%	27%
Maintenance	40%	23%	30%	33%
Financial	20%	10%	10%	13%
	100%	57%	63%	74%

Scenario 3 which involves the implementation of one unit for waste water treatment at the North-Western point of the hospital land scored the highest point technically, operations and maintenance and financially.

6. OPERATIONS & MAINTENANCE

6.1 Operational tasks

The designed treatment facilities for St. Francis Hospital requires essential and unsophisticated execution of O&M tasks for successful system implementation that should be carried out on a daily/weekly basis. O&M responsibilities for O&M personnel need to be defined, shared and taken up accordingly by the existing operations and maintenance team. The identified operational tasks include tasks directly related to the systems operations (e.g. gas use, manhole cleaning, planted gravel filter cleaning, etc.). Lack of execution of these minute operational tasks can lead to a drop in the treatment efficiencies of the systems which might be further lead the unacceptance by the community.

6.2 Maintenance tasks

The identified system maintenance crucial for long-term system functioning requires operations such as cleaning of surrounding, desludging and backwashing of treatment facilities and repair of system failures.

Proper preventive maintenance measures minimise reactive maintenance which might be detrimental to the system. Preventive maintenance tasks need to be carried out periodically depending on system requirements (e.g. daily, weekly, monthly, yearly). Lack of execution of maintenance tasks might lead to excessive repair and replacement costs and can lead to system breakdowns that might further lead to a non-conducive environment and abandonment of the system.

6.3 O&M costs

Operational costs

The identified costs after system implementation mostly only involves salaries for caretakers and as tasks will not be changed but lessened, O&M costs of sanitation facilities remain the same.

Maintenance costs

As the designed system does not involve intricate parts, the maintenance costs only involve periodical (depending on system setup, execution of O&M tasks and incidents of vandalism) non-replacement of expendable parts.

Periodical system maintenance such as treatment system de-sludging and backwashing of treatment facilities was also valued at K 1000 per month (depending on system setup).

7. CONCLUSIONS

Following bullet points summarise conclusions and recommendations concerning design and system setup aspects

- At least one treatment facility necessary is required for the hospital and surrounding areas. Implementation of the facilities could be progressively done depending on the availability of resources even though option three was favoured as it had high technical, maintenance and economic scores.
- Implementation of a bigger treatment facility to accommodate all the black water at one location will reduce implementation costs as it has a low investment cost per person and per cubic meter of waste to be treated.
- Natural waste water flow is feasible in all the areas with a gradient of not less than 1% hence no external energy is required for conveyance of the waste water to treatment facilities.
- The implementation of waste water treatment systems on the northern points of the hospital lands reduces the risk of fresh water contamination as the boreholes are situated on the higher points of the hospital land
- Grey water settlers should be left for grey water as existing and some grey water tanks need to be maintained. The treated grey water from the settlers can be used for irrigation of crops near the hospital
- Fruit tree vineyards could be implemented to produce fruits for the patients and supplement their daily dietary needs
- Biogas could be recovered from intermediate settlers which could be used at the following points:
    - Nursing boarding house for the facility in household area A
    - Incinerator for the unit near the mortuary
    - In the lab for the main unit next to the treat plant in area A
    - Nursing boarding house for the units in area B
    - Some households in area C for the unit in area C

  Approximately, 27 cubic meters of gas is expected to be produced from the treatment facilities

8. References

C. ROSE, A. P. (2015). *The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology* (Vol. 45).

Keller, M. (2012). *Situation analysis and recommendation of options for an improved wastewater disposal system at Saint Francis Hospital in Zambia.* Loughborough: WEDC.

Appendix:

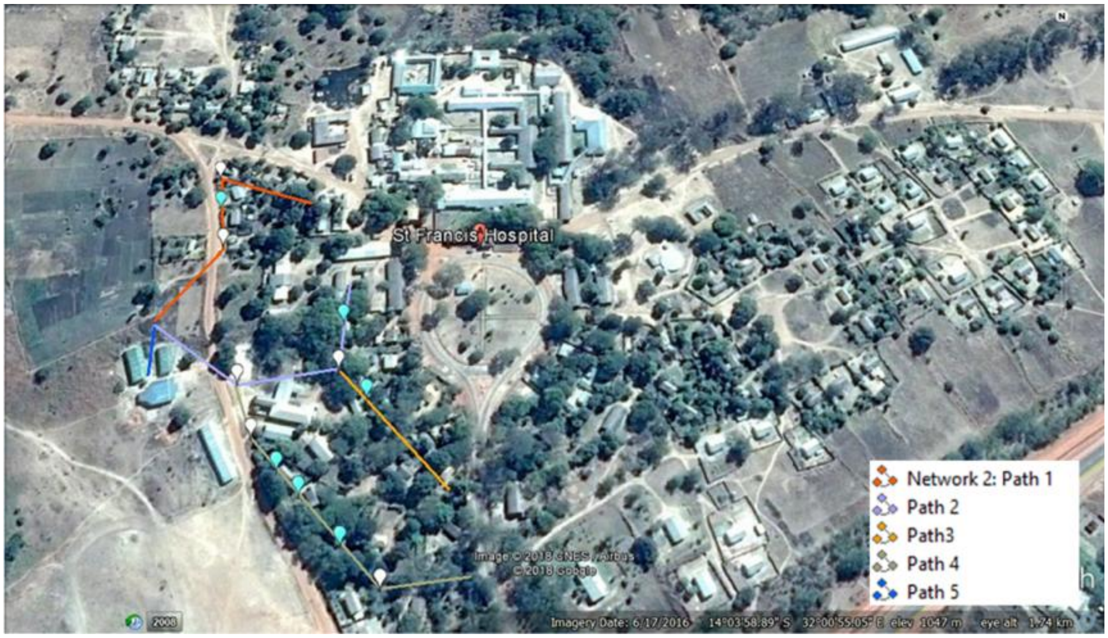
Hospital and Housing Area A piping costs

Appendix Figure 1: Pipe Layout for Housing Area A

Appendix Table 1: Plumbing Cost for Hospital and Housing Area A

Acquisition and Installation	Total Quantity Required	Unit	Price per unit (ZMW)	Applied prices (ZMW)
160mm PVC pipe thickness 3,0 mm, length 6 m	4413	m	33.33	147085
160 mm PVC T-junctions with rubber seal	61	Piece	75	4575
Excavation	3089.1	m^3	6.5	20079
Installation	-	-	-	7583
Transportation	-	km	-	15166
Contingencies:	Excavation @ 5%			1004
	Transportation @ 10%			1517
	Installation @ 12%			910
Total				197919
Administrative Costs				5000
Engineering Fee @12.5% flat rate				24740
Total Engineering Fee				29740
Engineering Fee per meter	4413	m	52	-
			TOTAL COST	**227659**

Housing Area B piping costs



Appendix Figure 2: Pipe Layout for Housing Area B

Appendix Table 2: Plumbing Cost for Housing Area B

Acquisition and Installation	Total Quantity Required	Unit	Price per unit (ZMW)	Applied prices (ZMW)
160mm PVC pipe thickness 3,0 mm, length 6 m	1807	m	33.33	60227
160 mm PVC T-junctions with rubber seal	29	Piece	75	2175
Excavation	632.45	m^3	6.5	4111
Installation	-	-	-	3120
Transportation	-	km	-	6240
Contingencies:	Excavation @ 5%			206
	Transportation @ 10%			624
	Installation @ 12%			374
Total				77078
Administrative costs				5000
Engineering Fee @12.5% flat rate				9635
Total Engineering Fee				14635
Engineering Fee per meter	1807	m	51	-
			TOTAL COST	**91712**

Housing Area C piping costs

Appendix Figure 3: Pipe Layout for Housing Area C

Appendix Table 3: Plumbing Cost for Housing Area C

Acquisition and Installation	Total Quantity Required	Unit	Price per unit (ZMW)	Applied prices (ZMW)
160mm PVC pipe thickness 3,0 mm, length 6 m	1112	m	33.33	37063
160 mm PVC T-junctions with rubber seal	27	Piece	75	2025
Excavation	389.2	m^3	6.5	2530
Installation	-	-	-	1954
Transportation	-	km	-	3909
Contingencies:	Excavation @ 5%			126
	Transportation @ 10%			391
	Installation @ 12%			235
Total				48233
Administrative costs				5000
Engineering Fee @12.5% flat rate				6029
Total Engineering Fee				11029
Engineering Fee per meter	1112	m	53	-
			TOTAL COST	**59262**

Housing Area B&C piping costs

Appendix Figure 4: Pipe Layout for Housing Area B&C Combined

Appendix Table 4: Plumbing Cost for Housing Area B&C Combined

Acquisition and Installation	Total Quantity Required	Unit	Price per unit (ZMW)	Applied prices (ZMW)
160mm PVC pipe thickness 3,0 mm, length 6 m	3101	m	33.33	103356
160 mm PVC T-junctions with rubber seal	56	Piece	75	4200
Excavation	1085.35	m^3	6.5	7055
Installation	-	-	-	5378
Transportation	-	km	-	10756
Contingencies:	Excavation @ 5%			353
	Transportation @ 10%			1076
	Installation @ 12%			645
Total				**132818**
Administrative costs				5000
Engineering Fee @12.5% flat rate				16602
Total Engineering Fee				21602
Engineering Fee per meter	3101	m	50	-
			TOTAL COST	**154420**

Housing Area A&B&C piping costs

Appendix Figure 5: Pipe Layout for Housing Area A&B&C Combined

Appendix Table 5: Plumbing Cost for Housing Area A&B&C Combined

Acquisition and Installation	Total Quantity Required	Unit	Price per unit (ZMW)	Applied prices (ZMW)
160mm PVC pipe thickness 3,0 mm, length 6 m	7633	m	33.33	254408
160 mm PVC T-junctions with rubber seal	117	Piece	75	8775
Excavation	2671.55	m^3	6.5	17365
Installation	-	-	-	13159
Transportation	-	km	-	26318
Contingencies:	Excavation @ 5%			868
	Transportation @ 10%			2632
	Installation @ 12%			1579
Total				325105
Administrative costs				5000
Engineering Fee @12.5% flat rate				40638
Total Engineering Fee				45638
Engineering Fee per meter	7633	m	49	-
			TOTAL COST	**370743**