ASSESSING THE USE OF POLY ALUMINIUM COATED GRANULES FROM WATER TREATMENT SLUDGE TO ENHANCE THE DEWATERING OF FECAL SLUDGE IN SLUDGE DRYING BEDS : A CASE STUDY LUBIGI FECAL SLUDGE AND WASTEWATER TREATMENT PLANT

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S21B32/090

A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

April, 2025

UGANDA CHRISTIAN UNIVERSITY
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ABSTRACT

Lubigi fecal sludge and waste water treatment plant currently operates using non-conventional technology for treatment with drying of fecal sludge by evaporation and percolation. Although the plant has the capacity to manage human excreta from both the onsite and offsite sanitation facilities, there is high solid loading due to the incoming large volumes of waste what exceed the design capacity of the plant and a problem of longer drying periods than intended. There is need for optimum utilisation of the sludge drying beds and the treatment plant all together. This study aimed at assessing the use of water treatment sludge granules coated with poly aluminium chloride from water treatment sludge to enhance dewatering of fecal sludge.

The raw fecal sludge samples were analysed for parameters of pH, electrical conductivity, moisture content and total solids. Water treatment sludge was also characterised using the X-ray fluorescence technique so as to determine whether the content of aluminium oxide present is suitable for the preparation of poly aluminium chloride.

Water treatment sludge granules coated with poly aluminium chloride showed potential in dewatering of fecal sludge with the lowest moisture content of 25.3% and maximum total solids of 74.7% achieved with the 4g/l dosage.

DECLARATION

I, MUHWEZI ANDREW NDAMIRA hereby declare that this is my original work, is not plagiarised and has not been submitted to any institution for any award.

Name: MUHWEZI ANDREW NDAMIRA

Signature: ....

Date: ....

APPROVAL

This is to certify that all the works in this report was done by MUHWEZI ANDREW NDAMIRA and is ready for submission with approval.

Project supervisor: ELEANOR WOZEI (PhD)

Signature: ....

Date: ....

DEDICATION

I dedicate this research work my family which has supported me throughout my academic journey.

ACKNOWLEDGEMENT

I am grateful to the almighty God for granting me life and good health which has enabled me achieve this. I am grateful to my family which has supported me throughout the entire journey financially, emotionally and spiritually.

I would like to thank Professor Eleanor Wozei, my project supervisor for her guidance, encouragement and time she gave up to ensure that this project is successful. Her mentorship has been incredible and instrumental towards the shaping of this research.

I would like to thank the field personnel who have assisted me in carrying out field visits and laboratory analysis. I would like to thank Mr. Baayo Robert, Ms. Irene Adong, Eng. Christopher Kanyesigye, Eng. Phillip Muhumuza of National Water and Sewerage Corporation and Mr. Kasaka Moses of Geochemistry laboratory at Makerer University for providing a conducive environment for fulfilment of objectives of this research.

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CHAPTER 1: INTRODUCTION

1.2 BACKGROUND

Fecal sludge refers to the raw slurry or partially digested semi-solids resulting from a combination of Blackwater and human excreta (Strande, 2014). Management of fecal sludge is an important practice in sanitation maintenance and some of the activities and techniques include storage, collection, transportation, treatment and then disposal. On site facilities such as pit latrines, toilets, pour flash latrines and septic tanks are used in fecal sludge management at household levels (Emmanuel, 2019). In the world today, around 2.7 billion people are estimated to live in areas without proper sanitary facilities. According to the estimate world population of 5 billion people by 2030 (WHO, 2014), around 1 billion of the onsite sanitation facilities will be located in urban areas (Hu et al., 2016) which would increase the amount of fecal sludge generated and thus require management. This provides a big challenge in the effective management of sludge in developing countries for example looking at the Republic of Uganda where over 90% of the population depends on the onsite sanitation facilities which are operated and maintained through empting, transporting and then treatment at the different fecal sludge treatment facilities (Gibson et al., 2018). Looking at Kampala, around 390 m^3/day of fecal sludge is produced with an addition of 150 m^3/day from the neighbouring districts. All this sludge is transported to Lubigi fecal sludge and wastewater treatment plant. This plant operates under the National Water and Sewerage Corporation and is located in Namungoona. It was commissioned in 2014 with a design capacity of 500 m^3/day of wastewater and 400 m^3/day of fecal sludge. For the fecal sludge section, the plant operates at 50% over the design capacity (KCCA, 2020).

Water treatment sludge refers to the residue produced from the water treatment processes of coagulation, flocculation and sedimentation. The Ggaba III water treatment plant produces about 113000 metric tons of water treatment sludge per year (Muhabuzi el al., 2023). The sludge contains aluminium salts such as aluminium hydroxide as the largest component, non-toxic elements and organic matter (Shi et al., 2023). It is considered as waste and it is ever increasing due to treatment of water on a daily basis. Some water treatment plants consider managing the water treatment sludge through disposing it off to the landfills but scientific research has been or is being done to utilise this sludge through sustainable resource management.

1.2 PROBLEM STATEMENT

The Lubigi fecal sludge and waste water treatment plant currently faces a challenge of slow dewatering process of sludge in the drying beds. The sludge currently dries for 6-8 months although the sludge drying beds were designed with a drying period of 1-2 months (site visit, 2024). This is attributed to the stickiness in sludge that makes the solid liquid separation process slow and thus exceeding the design period of 4 weeks (Rost, 2018). The plant has 48 sludge drying beds with with a capacity of 71 m^3. The units are lined with sand filtering membrane on top of the gravel to allow slow sludge dewatering through infiltration (Lindberg, 2018). The remaining semisolid is left to dry for about 4-8 weeks and further stored for 6 months to remove pathogens making it suitable and safe for use (Rost, 2018; Velkushanova et al., 2021). The slow dewatering may also be a result of clogging of the filter beds, particle size of sand and the mix ratios of the sludge (Ngabirano, 2023). There is need to quicken the dewatering process and such that its then disinfected allow safe use for other applications like agriculture, making of fire briquettes. This project aimed at using water treatment sludge granules coated with poly aluminium chloride obtained from water treatment sludge to enhance the dewatering process of fecal sludge in the sludge drying beds at Lubigi Fecal sludge and waste water treatment plant.

1.3 OBJECTIVES OF THE STUDY

1.3.1 Main objective

The main objective of this research study is to access the use of water treatment sludge granules coated with poly aluminium chloride to enhance the dewatering of fecal sludge.

1.3.2 Specific objectives

To determine the parameters of fecal sludge. (Moisture content . pH, electrical conductivity and total solids)

To determine the parameters of water treatment sludge.

To evaluate the enhancement in dewatering of fecal sludge achieved with using water treatment granules coated with poly aluminium chloride.

1.4 Research questions

What are the parameters of fecal sludge at Lubigi fecal sludge and waste water treatment plant?

What are the parameters of water treatment sludge?

How much dewatering of fecal sludge in sludge drying beds can be achieved with the use of water treatment sludge granules coated with Poly aluminium chloride?

1.5 Justification

This study aims at using water treatment sludge granules coated with poly aluminium chloride to enhance the dewatering of fecal sludge in the sludge drying beds. With the increasing challenges in fecal sludge management in developing countries and given the increase in the population increases the generation of fecal sludge. This triggers the need to look into potential ways of reducing the sludge and this could be through decreasing the dewatering time as well as ensuring safe use of this fecal sludge after it has been treated.

Water treatment sludge refers to the residue generated during the water treatment process and this sludge contains not only aluminium compounds but also other non toxic elements and organic matter (Shi et al., 2023). The dried water treatment also contains aluminium based salts and this increases the settling velocity of the solid sludge thus enhancing the dewatering the dewater ability although the properties of this sludge could be improved as the sludge is reacted with poly aluminium chloride. The dried water treatment sludge contains aluminium hydroxide which when reacted with hydrochloric acid dissolves the aluminium salt and removing undissolved solids thus forming a solution containing aluminium chloride.

$$Al(OH)_{3(aq)} + 3HCl_{(aq)} \rightarrow AlCl_{3(aq)} + 3H_2O_{(l)}$$

The solution is further reacted with water to undergo hydrolysis thus forming aluminate species that enhance the formation of poly aluminium chloride. The obtained solution is then reacted with sodium hydroxide in the polymerization process to yield a solution containing poly aluminium chloride (Adamu, 2023)

$$Al(OH)_{3(aq)} + NaOH_{(aq)} \rightarrow Al_n(OH)_mCl_{3n-m\ (aq)} + {}_nNaCl_{(aq)}$$

Poly aluminium chloride produced from the reaction of the water treatment sludge with hydrochloric acid and through the polymerisation process has stable polymer chains which enhance its flocculation and coagulations capabilities. This enables it to effectively bind the suspended solid and colloidal particles into large particles thus facility solid – liquid separation (Jin, 2016). This helps in enhancing the dewatering process. The end product from polymerisation contain sodium chloride which is also a good component to enhance the dewatering of sludge because its efficient in changing the surface charges and viscosity, the calcium ions compress the colloid double layers (Xinhau, 2013).

1.6 Significance of the study

Improving the dewatering process of the fecal sludge reduces the sludge volumes being handled at the plant which serves as a key component for the fecal sludge management. This also provides a better and efficient method for the treatment of sludge in that the risks associated with the pathogens are minimised such that the fecal sludge can be safely used for other uses without compromising the health of the users. This would also address the sustainable development goal number 6 of the United Nations which aims at ensuring proper management of sanitation.

Utilising Poly aluminium chloride from water treatment sludge granules also promotes the sustainable practice in waste water management and resource management (Debasree, 2024).

CHAPTER 2: LITERATURE REVIEW

2.1 Water treatment sludge

Water treatment sludge refers to the by-product from the purification process of drinking water. It is generated from both the sedimentation process, sand filters and the back washing process during the cleaning of the filters. This sludge contains aluminium oxide and other non-toxic elements such as silicon dioxide, calcium oxide, magnesium oxide, iron (III) oxide and sodium oxide (Zhao et al., 2021).

Table 1: Percentage composition of water treatment sludge

components	**Percentage composition**	
	Ahmad et al., 2016	Naayo, 2024
SiO_2	52.78	58.955
Al_2O_3	14.38	38.614
Fe_2O_3	5.2	2.031
CaO	4.39	9.499
K_2O	3.62	0.177
MgO	3.08	-
NaO_2	0.97	-
TiO_2	0.61	-
P_2O_5	0.17	0.403
MnO	0.08	8.71
ZnO	0.01	-
TiO_2	-	0.443

Cr_2O_3	-	0.731
Cl	-	0.051

With the increasing demand for potable water which is due to the rapidly growing world population and the urban expansion has also resulted into the generation and accumulation of large water treatment sludge volume which call for an economical and environmentally sustainable management measures. Currently, a few practices have been developed to manage this waste and these include resource recovery, use of water treatment sludge as an adsorbent for heavy metals as well as the use of this water treatment sludge in brick making (Dassanayake et al., 2015). Water treatment sludge from Ggaba III

2.2 Fecal sludge

Fecal sludge refers to the human waste collected from onsite sanitation facilities such as pit latrines, ventilated improved pit latrines, composting latrines and septic tanks. Waste in the septic tanks decomposes over time and before it is transported to the treatment plant using cesspool emptier trucks to treatment plants (Reno, 2015).

Fecal sludge may be categorised basing on its concentration in categories such as liquid fecal sludge, slurry fecal sludge, semi-solid fecal sludge and solid fecal sludge (Strande, 2021). Fecal sludge may also be further catergorised basing on the methods of treatment and these include digested sludge, primary sludge, mixed sludge and mineral sludge.

2.2.1 Management of fecal sludge in Uganda

Management of fecal sludge in Uganda has been predominantly handled by National Water and Sewerage Corporation, NWSC and Kampala Capital City Authority, KCCA for Kampala along with other stakeholders that are either directly or indirectly involved. KCCA provides environmental certificates and regulates private operators, National Environment Management Authority issues fecal waste transportation licenses while NWSC provides treatment plants (Laker, 2020). Fecal sludge in Kampala is handled and treated at Lubigi fecal sludge and waste water treatment plant which has a fecal sludge treatment capacity of 400m^3/day. According to UNICEF, management of fecal sludge helps reduce risk of waterborne disease outbreaks in communities.

Fecal matter from pit latrines and septic tanks in Kampala is collected and transported to Lubigi fecal sludge and waste water treatment plant where it is treated before use for agricultural practices, research, making of fire briquettes and so on. The main modes of fecal sludge emptying and transportation technologies used in Kampla include mechanised cesspools and semi mechanised gulpers (FSM alliance, 2023).

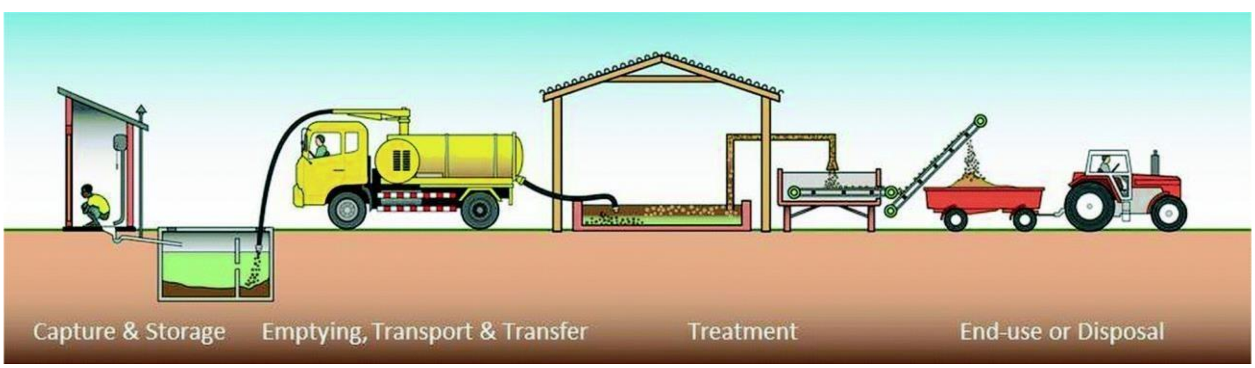


Figure 1 Sanitation service chain (Medland et., 2016)

2.2.2 Waste water and fecal sludge treatment process

The Lubigi fecal sludge and waste water treatment plant handles and treats both waste water and fecal sludge. The plant has a capacity of $5000m^3$/day for waste water and $400m^3$/day for fecal sludge. This waste Is collected and delivered to the plant where it goes through primary, secondary and tertiary treatment.

2.2.3 stages of treatment

Screening

Screening is the removal of solid materials in waste water using fine and course screens. Selection of type of screen to use depends on the septage composition and the requirements of the treatment process (Tayler, 2018). The smaller the size of the spacing with low velocity flow, the higher the efficiency of the plant and regular maintenance is required for removal of trapped solids (Rost, 2018).

8mm screens are used to trap physical contaminants of relatively big size that flow along with waste water. These contaminants include pampers, sanitary pads, leaves, polythene bags, plastic bottles and so on. Removal of these objects helps prevent blockages and clogging id the system. The screens are occasionally cleaned using a rake.

Figure 2 8mm screens at Lubigi

Grit chamber

The grit chamber is used to remove grit particles in waste water that are fine enough to go through the bar screens. Grit includes fine sand soils and gravel. In this chamber, flow is slowed down so as to allow settlement of the particles. Grit that settles at the bottom is routinely removed manually using spades so as to maintain the efficiency of the process.

Grit removal is a basic consideration for plants designed to receive a loading greater than 250m^3/day and plants that use enclosed systems such as anaerobic ponds and sludge drying beds (Niwagaba, 2014). That plant is designed to receive 400m^3/day thus qualifies to have this chamber as part of the treatment processes.

Figure 3 Grit chamber

Sedimentation chamber

The fecal waste from the grit chamber is directed into the sedimentation tank. Lubigi Fecal sludge and waste water treatment plant has two sedimentation chambers which operate in turns that is to say that one chamber is loaded for up to 3 months as the other is being dislodged.

Figure 4 Sedimentation tank

Anaerobic ponds

Anaerobic ponds do not have oxygen except at the top at the air liquid interface. The organic load produces anaerobic conditions that is there is no dissolved oxygen in the pond. These ponds function like open septic tanks and work efficiently in warm climates. The liquid effluent is retained in the ponds for about 4 days and then proceeds to the secondary stage of treatment (Verbyla, 2017).

Figure 5 Aerobic pond

The plant has shallow anaerobic ponds that receive liquid effluent from the sedimentation tanks. The anaerobic bacteria in the ponds breaks down the waste water and decomposes the it thereby forming sludge. The sludge is periodically removed using s dredging system. The anaerobic process results into formation of methane, ammonia and carbon dioxide (Aziza, 2022). These gases are toxic and do not support life of multiple eco systems.

Facultative ponds

Facultative ponds can be classified into primary and secondary facultative ponds where the primary facultative ponds receive raw waste water while the secondary facultative ponds receive settled waste water (Chen et al., 2018). These ponds reduce on the biochemical oxygen demand. Facultative ponds are a combination of aerobic and anaerobic ponds. The top zone has aerobic conditions while there are anaerobic conditions in the lower zones.

Tertiary treatment

This a system of treatment designed for nutrient removal and filtering of waste particles that might damage sensitive ecosystems. The wastewater is passes through additional filtering lagoons to remove the nutrients. Some of the methods usi=ed at this phase include sand filtration which helps remove particulate matter, enhanced biological phosphorous removal where specific bacteria called polyphosphate accumulate organisms that store phosphate in their tissue.

2.2.4 Challenges faced in fecal sludge management.

There is a challenge of rapidly growing population which requires expansion of existing facilities so as to handle fecal sludge and waste generated (Basika, 2024). There is also a challenge of unauthorised stakeholders involved in management of fecal sludge. A survey conducted under the Kampala fecal sludge management project showed that there were 15 trucks and 20tricycles operating yet not legalised to operate (KCCA, 2018).

2.3 Sludge drying beds

These are either open or covered beds that use sand as a filtration medium for sludge from the sedimentation and the anaerobic ponds to allow drying of the sludge. Sludge drying beds are commonly used to dewater sludge due to their affordability compared to the other techniques used.

Figure 6 Sludge drying beds

The sludge drying beds at Lubigi fecal sludge and waste water treatment plant are consistent of the the underlain course aggregates and then fine aggregates on top of which sludge is pumped on the beds. The pumped sludge is left to dry by evaporation and water percolating through the filter media of the bed (Gava, 2021).

2.4 Poly aluminium chloride

Poly aluminium chloride is an inorganic chemical with large polymers and that consists of monomers such as $Al(OH)^{2+}$, $Al(OH)_2$, dimers such as $Al_2(OH)_2{}^{4+}$, and trimer $Al_3(OH)_4{}^{5+}$ (Chen et al., 2018). Poly aluminium chloride is a superior aluminium based coagulant used for particulate matter removal and removal of small particles, heavy metals and precipitation of phosphates. This chemical has the ability to reduce the volatile suspended solids in that it aggregates the sludge flocs causing a more tightly bound extracellular polymeric substances remain in the sludge flocs (Chen et al., 2018).

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter consists of the different series of steps that were taken when conducting data collection, analysis methods and materials that were used in order to achieve the objectives of this study.

3.2 Area of study

In this study, the fecal sludge to be sampled is delivered from cesspool trucks from onsite sanitation facilities. The fecal sludge samples were collected from Lubigi fecal sludge and waste water treatment plant located in Namungoona, Rubaga division in Kampala district. The catch ment area of this facility consists of areas such as Makerere, Katanga, Mulago, Kalerwe, Bwaise and areas along the Northern Bypass (Okasio. A, 2021).

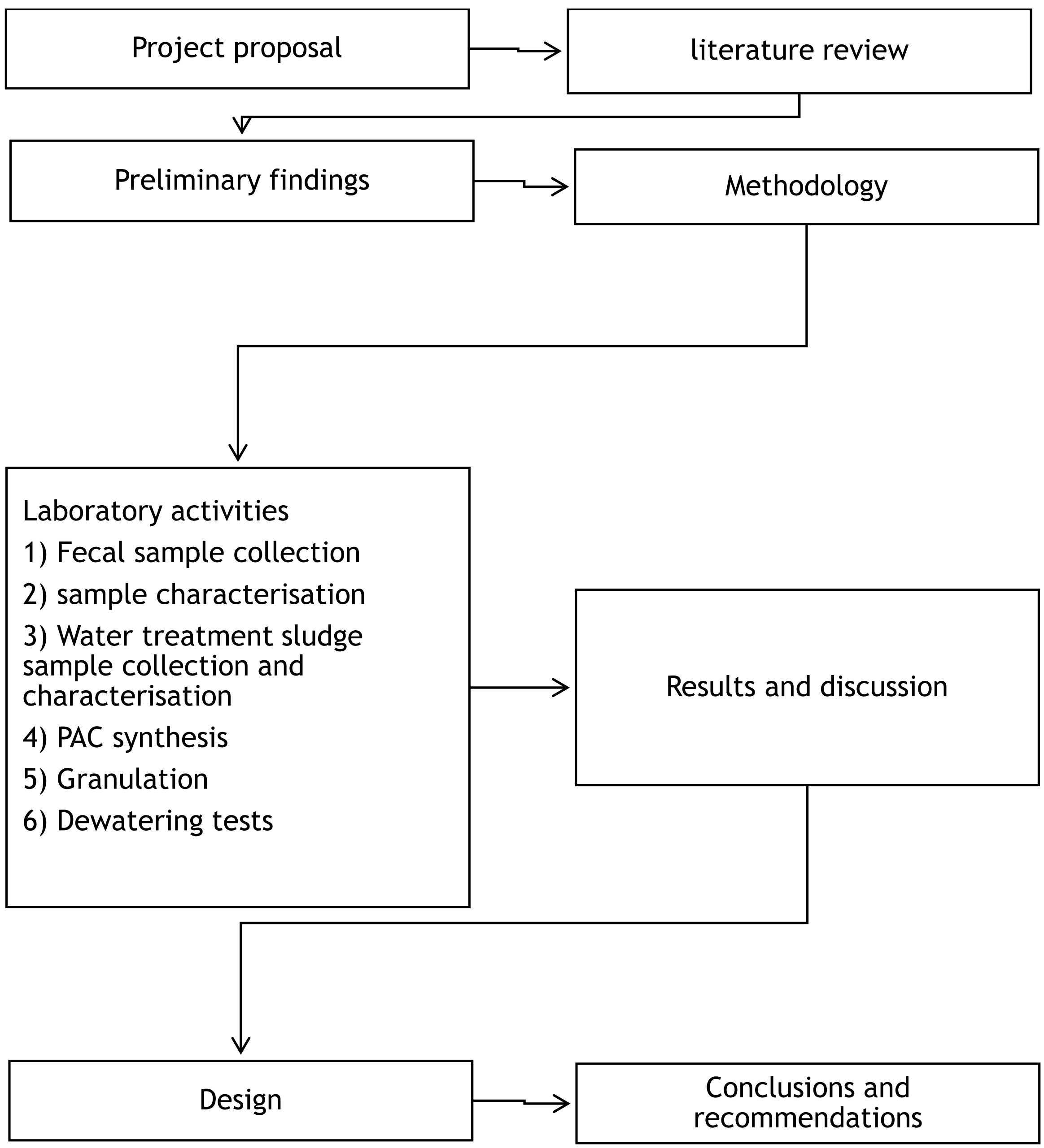
Water treatment sludge that was used to produce poly aluminium chloride was collected from Katosi Drinking Water Treatment Plant. The plant started operations in 2021 and is under National Water and Sewerage Corporation.

3.3 INFORMATION SOURCES

For this research study, the sources that were used include online journals, books, field visits, laboratory experiments and result analysis.

3.3.1 Research design

This research was done following a systematic procedure informed from literature reviews and previous studies.



3.4 MATERIAL AND METHODS

3.4.1 Determining the physical chemical parameters of fecal sludge.

The physical chemical parameters of interest were pH, electrical conductivity, moisture content and total solids. Characterisation was done using standard laboratory procedures.

3.4.1.1 Sample collection and preservation

Representative fecal sludge samples were collected from 10 cesspool emptier trucks. The collection bucket was cleaned with soap and water and dried so as to collect uncontaminated samples. The samples were then collected and emptied into a larger bucket of 10 litres so as to make a composite sample. The samples were then homogeneously stirred using a wooden stick and then poured in 6 clean bottles with each of capacity 1.5 litres. the samples were then analysed immediately for parameters of pH, electrical conductivity, moisture content and total solids.

Figure 7 Preparation of fecal sludge samples for laboratory analysis

3.4.1.2 Sample analysis

The samples were analysed from the waste water quality laboratory at Lubigi fecal sludge and wastewater treatment plant. For pH and electrical conductivity, the glass beakers to be used were cleaned using distilled water and dried. The samples were shaken thoroughly well and the 30 ml of fecal sludge poured into the beakers. A calibrated hatch sension+ MM374 GLP laboratory Multi-meter was used to measure pH and electrical conductivity. The electrode stands of the equipment were rinsed with distilled water and then immersed into the sludge samples. Each time before a new sample was tested, the electrode stands were cleaned using distilled water.

Figure 8 Determination of pH and electrical conductivity

Moisture content and total solids were determined using gravimetric method where by a known volume of sample is evaporated to a constant weight. 9 aluminium crucibles were cleaned and oven dried at 105^{0}C for 1 hour. The mass of dry aluminium crucibles was measured using a PDW 753e precision balance. Homogenised raw fecal sludge samples were then placed in the crucibles and weighed to obtain mas of wet sample,

M_1. The samples were then oven dried for 24 hours at 105^{0}C. The samples were then cooled in a desiccator so as to keep away moisture. At room temperature, the crucibles were removed and weighed again to obtain the mass of dry sample. Moisture content was then calculated as shown below.

$$\text{Total solids} = \frac{W_{c+s} - W_c}{W_s} \text{ x } 100$$

$$\text{Moisture content} = \frac{W_s - W_{c+s} - W_c}{W_s}$$

3.4.2 Characterisation of water treatment sludge

3.4.2.1 Sample collection and preservation

Dried water treatment sludge was collected from Katosi Drinking Water Treatment plant. The sludge was wrapped into aluminium papers for preservation and to keep away external contaminants like moisture content and dust. The samples were then carried to the laboratory for analysis. The laboratory used was the Geochemistry **Laboratory of College of Natural Sciences of Makerere University.**

3.4.2.2 Sample analysis

The moisture content of the water treatment sludge was determined. The aluminium crucibles (3) were cleaned with distilled water and then oven dried for 30 minutes at 105^{0}C. The crucibles were weighed using an FX – 300i reloading precision balance and the respective weights recorded. Part of the sludge was weighed and placed in an oven set at 105^{0}C for 24 hours. The samples were then cooled, weiged again and moisture content calculated.

Then, 8g of dry water treatment sludge was mixed homogeneously with 2g of ceridust cellulose using a mortar. The cellulose was used as binder so as to hold the sludge together when making a pellet. The mixture was then placed in collapsible aluminium cups and moulded into a pellet using a bench top press TP 20E set at 200KN. The pellet was then analysed using a Rayonsx PAN analytical Epsilon1 X-Ray spectrometer to determine the chemical composition of the water treatment sludge.

3.4.2.3 Preparation of water treatment sludge granules

100g of starch, an organic binder was added to 400g of water treatment sludge and mixed with 220ml of distilled water. the mixture was kneaded in a basin until a uniform paste was made. The paste was then cast in a moulding tray and then air dried for 12 hours. The granules were then removed and oven fried for 24 hours at a temperature of $120^{0}C$. This was done so as to improve on their water resistance through thermal modification (Lui Zhang, 2019).

3.4.2.4 Preparation of Poly aluminium chloride

80g of water treatment sludge was placed in a glass beaker and 270ml of 1M hydrochloric acid was added to the sludge and then stired for 20 minutes so as to dissolve the aluminium ions present in the sludge (Wang et al., 2020). 550ml of distilled water waere then added to the mixture and stirred for 5 minutes to dissolve the aluminium chloride (Lui et aj., 2019). The mixture was then filtered and 1M sodium hydroxide added to synthesise a poly aluminium chloride solution. The solution obtained was pale yellow with a pH of 3.74 which is in the range of 3.5-5.5 for poly aluminium chloride (Lui et al., 2013; Yan et al., 2016).

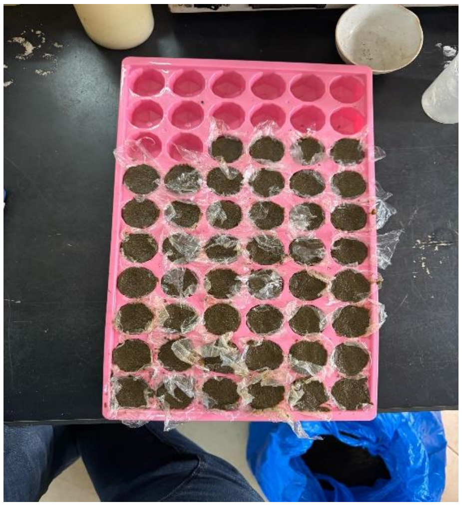


Figure 9 granulation of water treatment sludge (left) Figure 10 Synthesis of poly aluminium chloride (right)

3.5 Determination of dosage of water treatment sludge granules required

A small scale field unit of $1m^3$ at Lubigi fecal sludge and waste water treatment plant was used. The unit has four dosing components 1,2,3,4 which were dosed with 0,3,6,9 water treatment sludge granules respectively. 20l of fecal sludge from the sedimentation tank was added to each of the compartments. The initial parameter of moisture content and total solids were determined.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter contains results obtained from the different tests carried out on the fecal sludge samples collected from Lubigi wastewater and fecal sludge treatment plant and the water treatment sludge samples obtained from Katosi Drinking Water Treatment Plant intended to answer the research questions of the study and ultimately achieving the main aim of the study.

4.2 Fecal sludge analysis

The composite mixture of the fecal sludge samples was tested to obtain the base line data of the raw fecal sludge parameters.

Table 2: Averaged sample results of fecal sludge characterisation

PARAMETER	REPLICATE 1	REPLICATE 2	REPLICATE 3	AVERAGE
pH	7.50	7.51	7.52	7.51
Electrical conductivity (μS/cm)	9090	9320	7980	8796
Moisture content (%)	74.1	70.9	72.8	72.6
Total solids (%)	25.9	29.1	27.2	27.4

pH refers to the measurement of hydrogen ions activity present in solution (Alar, 2019), whereby a very low pH limits the aggregation of particles due to presence of less than optimum ions to support agglomeration (Xuan Lui et al., 2012). A high pH causes the aggregated particles to re-disperse because of the direct correlation that exists between the size of the particles and the pH which later leads to disintegration (Xuan Lui et al., 2012). The pH test on the fecal sludge samples gave a neutral pH with an average value of 7.5. This offers am optimum environment to support the addition of a chemical conditioner.

Moisture content influences the mechanical properties of fecal sludge and this affects its handling and final disposal process (Van Haandel and lettinga, 1994). An average moisture content of 72.6% was obtained and this falls within the range of < 75% of moisture content which indicates that the sludge is solid sludge and therefore a chemical conditioner would enhance the dewatering efficiency of sludge (Strande).

Total solids concentration comes from a variety of organic and inorganic matter comprised of floating, settleable matter, colloidal material and matter in solution (Niwagaba, 2014). The average value of total solids obtained was 27.4% and this value falls within range of 15-40% which suggests that the sludge is solid sludge (Strande).

4.3 Water treatment sludge

Following the understanding of the sludge parameters that influence the rate of dewatering, there is need to comprehend the chemical characteristics of a conditioner, that is water treatment sludge granules coated with poly aluminium chloride. The poly aluminium chloride was synthesed from water treatment sludge based on the 38.8% composition of aluminium oxide.

Table 3: Chemical composition of water treatment sludge

CHEMICAL COMPOSITION	COMPOSITION (%)
Al_2O_3	38.8
SiO_2	10.3
MnO_2	0.4
Fe_2O_3	10.5
Moisture content	19.4

With reference to the results in the above table, about 60% of the water treatment sludge is composed of oxides and 19.4% moisture content.

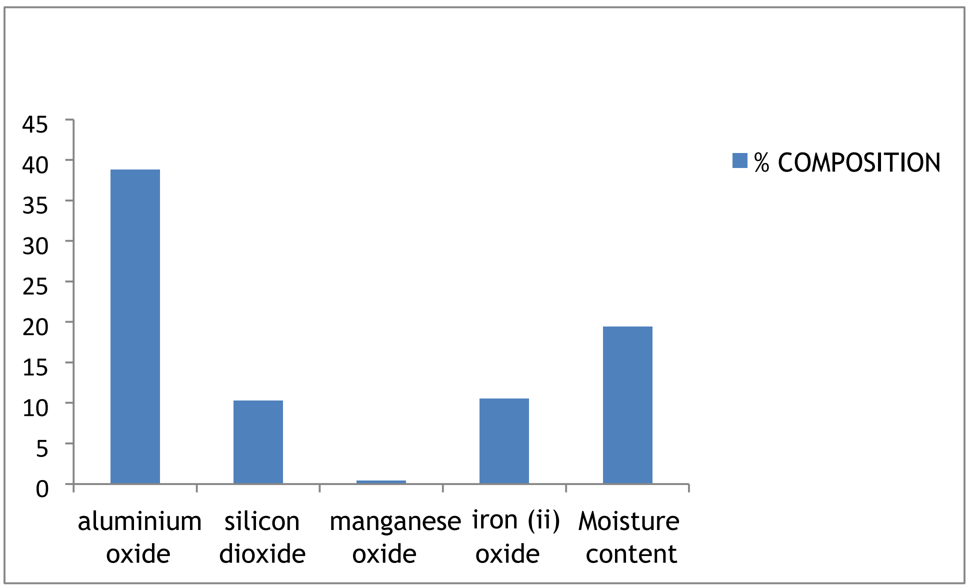


Figure 11 Percentage composition of water treatment sludge

The presence of Al_2O_3, SiO_2, MnO_2 and Fe_2O_3 indicate that the water treatment sludge itself can be used as a chemical conditioner for dewatering fecal sludge since the cations of these compounds are coagulants. The presence of Al_2O_3 as the dominant component illustrates the water treatment sludge can effectively be used in the preparation of poly aluminium chloride.

4.4 Effect of water treatment sludge granules coated with Poly aluminium chloride

Fecal sludge was dosed with 0 g/l, 2g/l, 4g/l and 6g/l of water treatment sludge granules coated with poly aluminium chloride and the change in parameters of moisture content and total solids was monitored after an interval of 7 days for 28 days.

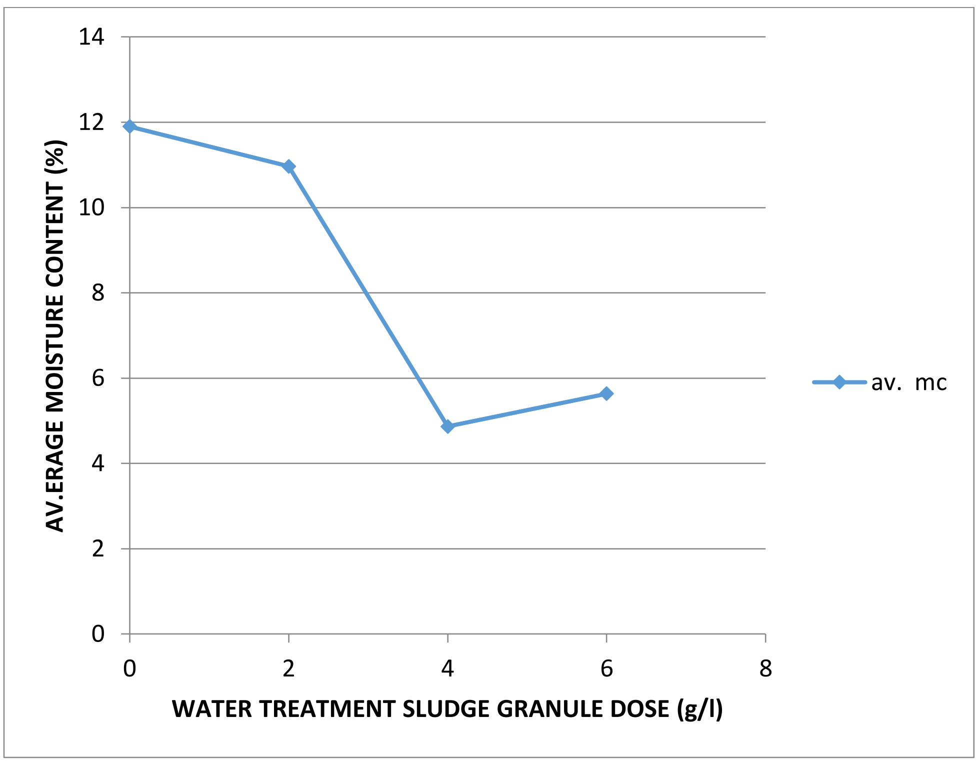


Figure 12 Relationship of moisture content and granule dosage

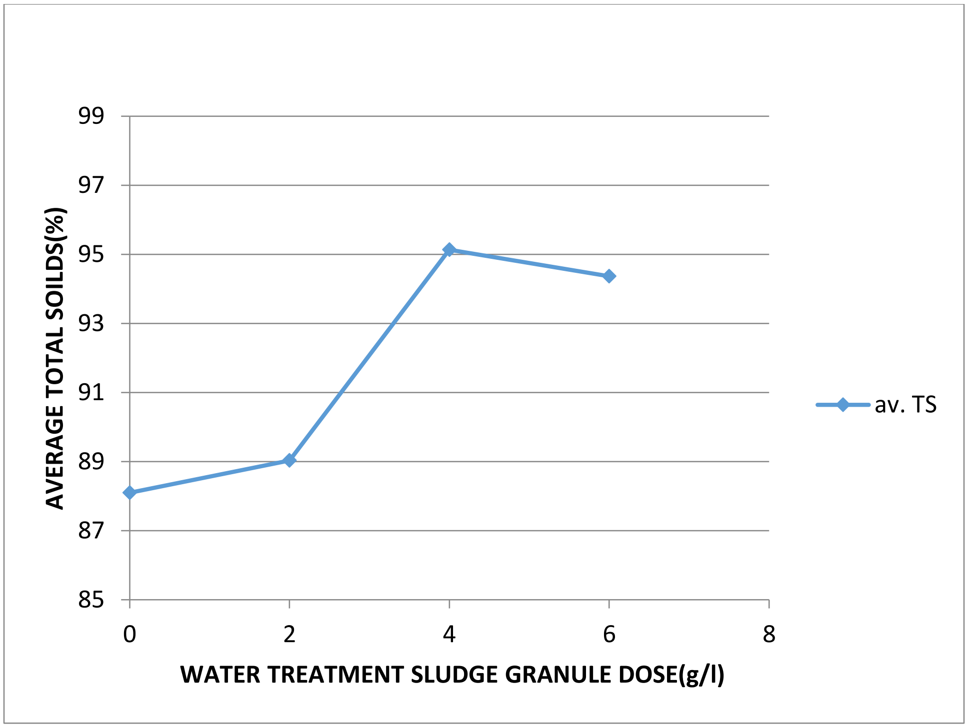


Figure 13 Relationship of total solids concentration with granule dosage

4.4.1 Moisture content

From the graphs, it was observed that 4g/l dosage of the water treatment sludge granules achieved the least moisture content of 25.3% compared to the other doses 0,2,4 and 6 g/l that yielded 36.1%, 34% and 29.3% moisture content observed after 28 days.

The moisture content of the fecal sludge reduced rapidly for the first 14 days and then gradually for the latter 14 days. The dose of 4g/l had a faster dewatering which was obtained as 25.3% and thus this was taken as the optimum dose for fecal sludge dewatering.

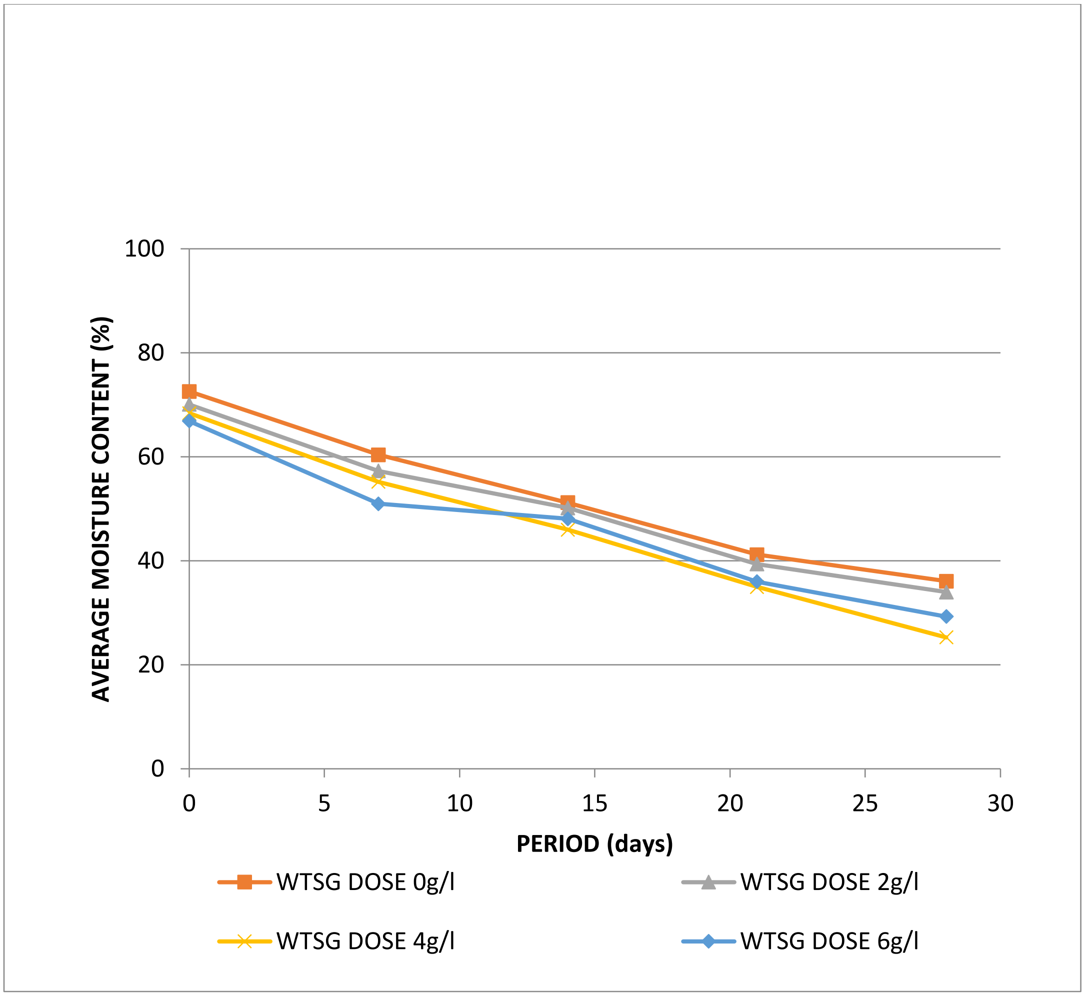


Figure 14 Variation of moisture content with time

4.4.2 Total solids

Similarly, the water treatment granule dose of 4g/l achieved the highest concentration of total solids of 74.7% compared to the other dosages of 0g/l, 2g/l and 6g/l that gave a total solids concentration of 63.9%, 66.1% and 70.7% respectively after 28 days of drying.

The concentration of total solids in fecal sludge depends on the moisture content. Moisture content reduces as the quantity of total solids increases.

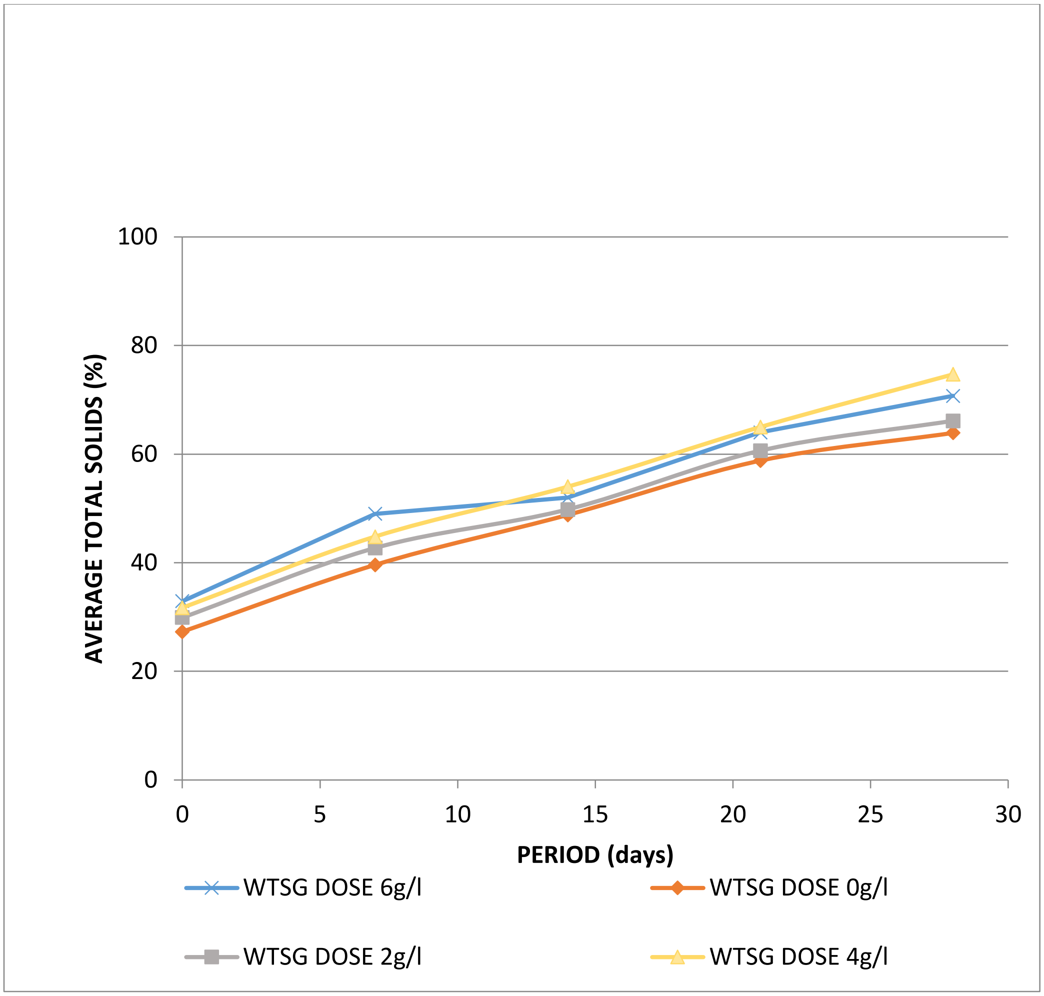


Figure 15 Variation of total solids with time

4.4.3 Dosage in wet conditions

During the wet season, the moisture content within the fecal sludge in the sludge drying beds increases considerably due to rainfall infiltration (Kaza, 2017). This affects the dosage of water treatment sludge granules (Murray et al., 2018).

From the obtained results for the dry season, the poly aluminium chloride coated water treatment sludge granules achieved a dewatering efficiency of 25.3% for the dose of 4g/l. Using the obtained dose and the moderate increase in the doses used can be used to obtain the required dose required for dewatering of fecal sludge during the wet season (Tchobanoglous et al., 2014).

$$\text{Increase in dosage} = \text{percentage reduction in moisture content x optimum dosage}$$

$$= 0.253 \text{ x } 4 = 1.012$$

$$\text{optimum dose in wet season} = \text{dosage in dry season x increase in dosage}$$

$$= \frac{4\text{g}}{\text{l}} \text{ x } 1.5$$

= 6g/l

Maximum dosage for wet season:

$$= \text{dry season dosage x increment in dosage}$$

$$= \frac{4\text{g}}{\text{l}} \text{ x } 2 = \frac{8\text{g}}{\text{l}}$$

Therefore the dosage of 6g/l – 8g/l will be added to the sludge drying beds in the wet season to achieve the dewatering of fecal sludge.

4.5 DESIGN

The sludge drying beds were designed in accordance with the United States Environmental Protection Agency which gives the basic components and their operations.

4.5.1 Fecal sludge generated

Fecal sludge is collected from pit latrines and septic tanks from around Kampala by Cesspool emptier tanks and transported to Lubigi waste water and fecal sludge treatment plant where it treated before disposal. The plant has a capacity of 400m^3 /day.

Monthly capacity = 400 x 28 = 11200 m^3/day

Table 4: Design Calculations

CALCULATIONS	SOURCE	APPROVAL
Sludge produced monthly Fecal sludge per day = volume of fecal sludge per day x 28 days $\text{sludge per day} = \frac{15}{100} \text{ x } 400 = 60\text{m}^3/\text{day}$ $\text{sludge produced per month} = 60 \text{ x } 28$ $= 1680\text{m}^3/\text{month}$	Tillley et al., 2014 Compendium of sanitation systems and technologies	
Flow rate (Q) For the small scale unit; $$Q = \frac{V}{T}$$ Where, T = time V = volume of fecal sludge loaded T = time in days	Tilley et al., 2014	

CALCULATIONS	SOURCE	APPROVAL
$$Q = \frac{0.020}{28} = 0.0007\text{m}^3$$ **Flow rate in the existing drying beds** $$\text{flow rate before dosing, } Q_i = \frac{105\text{m}^3}{28 \text{ days}}$$ $$= \frac{3.75\text{m}^3}{\text{day}}$$ With addition of the water treatment sludge granules coated with poly aluminium chloride; Volume Reduction Factor (VRF) $$= \frac{\text{initial total solids content}}{\text{final total solids content}}$$ But; Initial total solids content = 31.7% Final total solids content = 74.7% $$\text{VRF} = \frac{0.317}{0.747} = 0.424$$ The new flow rate after dosing is; $$\text{new flow rate after dosing, } Q_f = Q_i \text{ x } \frac{1}{\text{VRF}}$$ $$= 3.75 \text{ x } \frac{1}{0.424} = 8.84 \frac{\text{m}^3}{\text{day}}$$ $Q_f > Q_i$		

CALCULATIONS	SOURCE	APPROVAL
Suitability of the existing bed with increase in flow rate A = l x w Drying bed area = 30m x 7m = <u>210</u> m^2 $$\text{loading rate} = \frac{\text{sludge volume}}{\text{drying bed area}}$$ $$= \frac{105}{210} = \frac{0.5\text{m}}{\text{day}}$$ $$\text{required surface area} = \frac{\text{new flow rate}}{\text{loading rate}}$$ $$= \frac{8.84\text{m}^3/\text{day}}{0.5\text{m}/\text{day}}$$ $$= 17.68\ \text{m}^3$$ **Suitability of the existing drain pipe diameter** Existing pipe diameter = 300mm Current flow rate = 3.75m^3/ day New flow rate = 8.84 m^3/day Obtaining a new pipe diameter for the new flow rate From the manning's equation, $$Q = \frac{1}{n} \text{ x } AR^{\frac{2}{3}}S^{\frac{1}{2}}$$		

CALCULATIONS	SOURCE	APPROVAL
R = hydraulic radius n = manning's coefficient, 0.013 S = slope of the pipe, 0.02 for sewer pipes $R = \frac{A}{P} = \pi\frac{d^2}{4} \div \pi d = \frac{d}{4}$ $Q = \frac{0.099}{n} \text{ x } \pi d^{\frac{8}{3}} S^{\frac{1}{2}}$ Q = 8.84m^3/day = 1.023 x 10^{-4} m^3/s $d = \left(\frac{1.023 \text{ x } 10^{-4} / 0.02 \text{ x } 0.013}{0.099\pi \text{ x } 0.02^{0.5}}\right)^{\frac{1}{2.67}}$ $d = 0.302\text{m}$ $d = 302\text{mm} \approx 350\text{mm}$	Manning's equation	

The final design considering the design calculations in table influenced the design below.

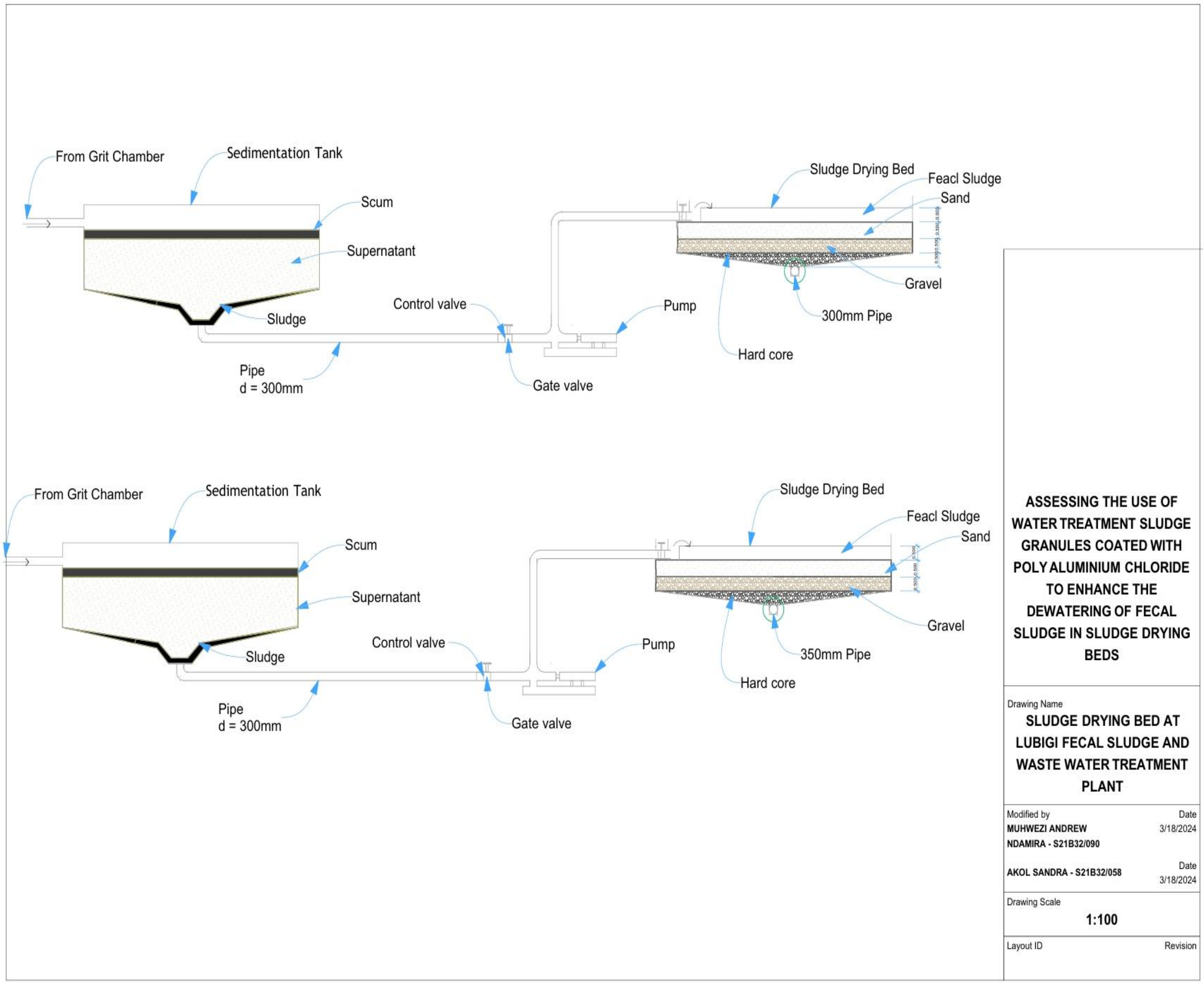


Figure 16 Design layout

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research focused on assessing the use of water treatment sludge granules coated with poly aluminium chloride to improve on the dewatering of fecal sludge at Lubigi Fecal sludge and waste water treatment plant. The raw fecal sludge was tested for parameters that influence the addition of a conditioner.

The chemical composition of water treatment sludge was also determined with aluminium oxide as the dominant compound with 38.8% composition. This percentage was sufficient enough for the production of poly aluminium chloride solution from water treatment sludge. The solution obtained was of pH 3.48 and had a yellowish colour. The water treatment sludge was also used to form granules each of weight 10g and these granules dipped in a solution of poly aluminium chloride to improve the polymeric structure and adsorption potential of the granules to be used for dewatering fecal sludge. A small scale field unit with 4 dosing compartments was then used to determine rate of dewatering of the coated granules after 28 days with the dosage of 4g/l yielding the lowest moisture content of 25.3% and maximum total solids concentration of 74.7%.

5.2 Recommendations

From this research study, the addition of water treatment sludge granules coated with poly aluminium chloride had a comparative effect on the dewatering performance in the sludge drying bed and the quality of manure.

However further studies should be conducted to determine the impact of the water treatment sludge granules coated with Poly aluminium chloride on the volatile solids and the pathogenic organisms in the fecal sludge and how fast pathogens in the fecal sludge can be reduced before use for agriculture.

The management of Lubigi fecal sludge and waste water treatment plant should adjust the size of the drainage pipes in the sludge drying beds from 300mm to 350mm so as to handle the increased flow rate due to addition of the material.

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Zewde, A.A., Li, Z. and Xiaoqin, Z. (2021) ‘Improved and promising fecal sludge sanitizing methods: treatment of fecal sludge using resource recovery technologies’, Journal of Water, Sanitation and Hygiene for Development, 11(3), pp. 335–349.

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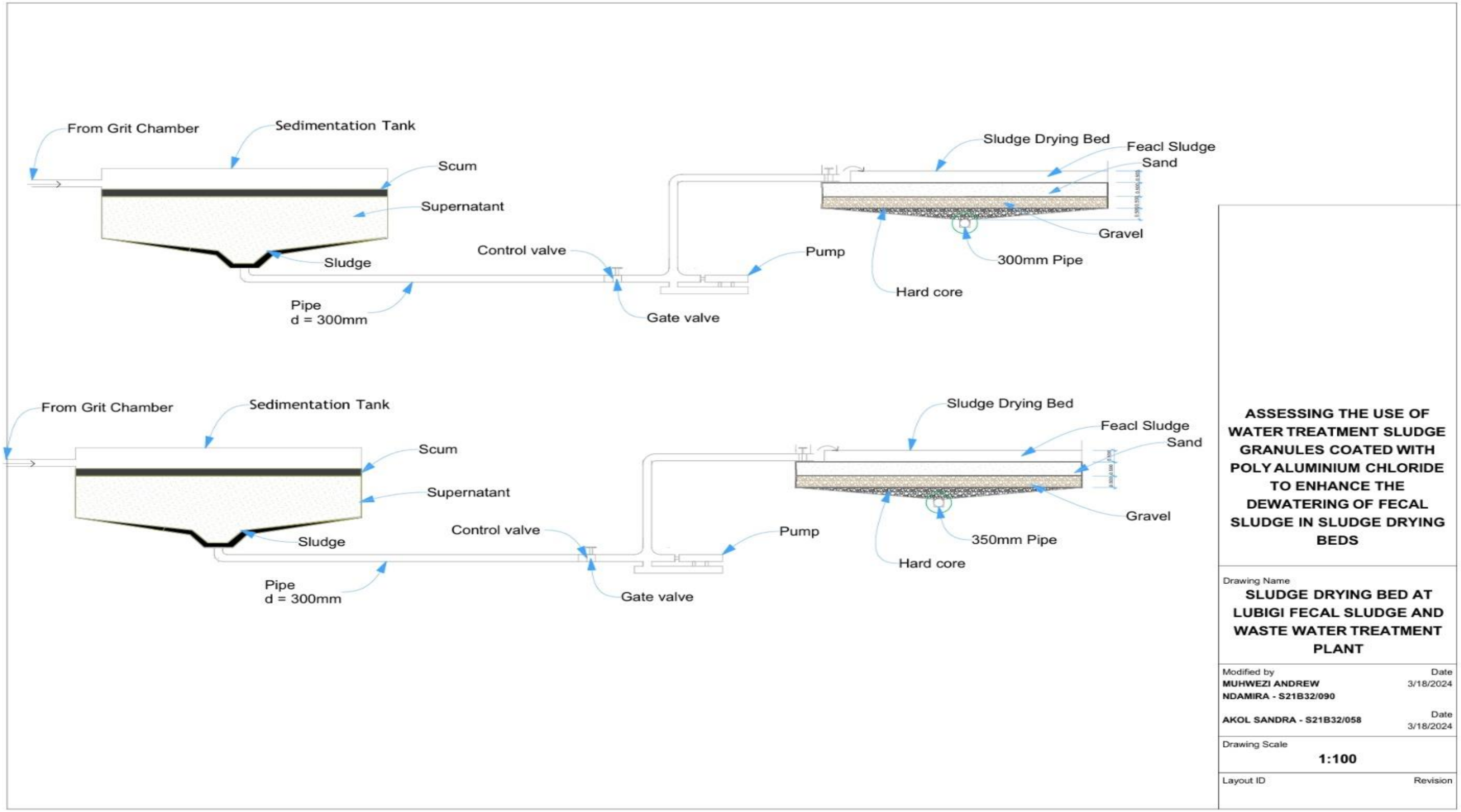
APPENDICES

Appendix 1: Drawing



Appendix 2: Results of Fecal sludge characterisation for sample 1

NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI
P.O BOX 7053 KAMPALA Email: waterquality@nwsc.co.ug

Student: ANDREW Muhwezi Ndamira (S21B32/090) &
SANDRA Akol (S21B32/058)
Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 19/12/2024
Date of Report: 20.12.2024

Wastewater Quality assessment lab results

PARAMETERS	Replicate 1	Replicate 2	Replicate 3	AVERAGE
pH	7.49	7.49	7.52	7.50
Electrical conductivity (µS/cm)	9090	9090	9090	9090
Moisture content (%)	74.1	74.1	74.1	74.1
Total solids (%)	25.9	25.9	25.9	25.9

Remarks: The results for the water samples tested were as above.
Analysed by: Sandra Akol &
Andrew Muhwezi Ndamira
Supervised by: Irene Adong (QCO Lubigi)
Report prepared by: Bayo Robert (QCO Chem/ES Central Lab)

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Appendix 3 Results of fecal sludge characterisation for sample 2

NATIONAL WATER AND SEWERAGE CORPORATION
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Student: ANDREW Muhwezi Ndamira (S21B32/090) &
SANDRA Akol (S21B32/058)
Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 19/12/2024
Date of Report: 20.12.2024

Wastewater Quality assessment lab results

PARAMETERS	Replicate 1	Replicate 2	Replicate 3	AVERAGE
pH	7.51	7.51	7.51	7.51
Electrical conductivity (µS/cm)	9320	9319	9321	9320
Moisture content (%)	70.9	70.9	70.9	70.9
Total solids (%)	29.1	29.1	29.1	29.1

Remarks: The results for the water samples tested were as above.
Analysed by: Sandra Akol &
Andrew Muhwezi Ndamira
Supervised by: Irene Adong (QCO Lubigi)
Report prepared by: Bayo Robert (QCO Chem/ES Central Lab)

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Appendix 4: Results for fecal sludge characterisation for sample 3

NATIONAL WATER AND SEWERAGE CORPORATION
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Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 19/12/2024
Date of Report: 20.12.2024

Wastewater Quality assessment lab results

PARAMETERS	Replicate 1	Replicate 2	Replicate 3	AVERAGE
pH	7.52	7.52	7.52	7.52
Electrical conductivity (μS/cm)	7980	7.7980	7980	7980
Moisture content (%)	72.8	72.8	72.8	72.8
Total solids (%)	27.2	27.2	27.2	27.2

Remarks: The results for the water samples tested were as above.
Analysed by: Sandra Akol &
Andrew Muhwezi Ndamira
Supervised by: Irene Adong (QCO Lubigi)
Report prepared by: Bayo Robert (QCO Chem/ES Central Lab)

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Appendix 5: Initial results of raw fecal sludge after dosing

NATIONAL WATER AND SEWERAGE CORPORATION
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Student: ANDREW Muhwezi Ndamira (S21B32/090) &
SANDRA Akol (S21B32/058)
Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 03/02/2025
Date of Report: 06.03.2025

Sample : 3rd /02/2025						
PARAMETER / SAMPLE DOSE (g/L)	Moisture Content (%)			Total Solids (%)		
0	72.7	73.4	71.9	27.3	26.6	28.1
2	70.2	70.5	69.6	29.8	29.5	30.4
4	68.5	68	68.4	31.5	32	31.6
6	66.9	67.5	66.9	33.1	32.5	33.1

Remarks: The results for the water samples tested were as above.

Analyzed by: Sandra Akol &

Andrew Muhwezi Ndamira

Supervised by: Irene Adong (QCO Lubigi)

Report Prepared by: Bayo Robert (QCO Chem/ES Central Lab)

Signature : ....

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Appendix 6: Results of water treatment sludge composition

MAKERERE UNIVERSITY

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WE BUILD FOR THE FUTURE

College of Natural Sciences
School of Physical Sciences
DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

Wednesday, 05 February 2025

Muhwezi A. and Akol S.

UCU Student

Dear Sir/ Madam

RE: <u>ANALYSIS OF A SLUDGE SAMPLE</u>

The Department received one sample in the laboratory to be analysed for Al_2O_3, SiO_2 and other chemical components. During analysis the sample was dried, ground to fine powder, from which a pressed powder pellet was prepared and scanned using an XRF spectrometer (Epsilon 1) for Al_2O_3, SiO_2, MnO_2 and Fe_2O_3, determination. Moisture content was determined gravimetrically. The results below expressed in weight percentages (wt %) were obtained.

Sample No	Al_2O_3 (%)	SiO_2 (%)	MnO_2 (%)	Fe_2O_3 (%)	Moisture content (%)
Sludge sample	38.8	10.3	0.4	10.5	19.4
Detection Limit	1.0	1.0	1.0	1.0	0.1

Analyst:......M. Kasaka..............

KASAKA MOSES

Geochemistry Laboratory

Appendix 7: Results before dosing

NATIONAL WATER AND SEWERAGE CORPORATION
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Student: ANDREW Muhwezi Ndamira (S21B32/090) &
SANDRA Akol (S21B32/058)
Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 10/02/2025
Date of Report: 06.03.2025

Sample : 10th /02/2025						
PARAMETER / SAMPLE DOSE (g/L)	**Moisture Content (%)**			**Total Solids (%)**		
0	58.9	60.9	61.3	41.1	39.1	38.7
2	57.7	57	57.2	42.3	43	42.8
4	55.6	55.2	54.9	44.4	44.8	45.1
6	50.9	50.3	51.8	49.1	49.7	48.2

Remarks: The results for the water samples tested were as above.

Analyzed by: Sandra Akol &

Andrew Muhwezi Ndamira

Supervised by: Irene Adong (QCO Lubigi)

Report Prepared by: Bayo Robert (QCO Chem/ES Central Lab)

Signature : ....

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06 MAR 2025
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Appendix 8: Results after first week of dosing

NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI
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Student: ANDREW Muhwezi Ndamira (S21B32/090) &
SANDRA Akol (S21B32/058)
Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 17/02/2025
Date of Report: 06.03.2025

Sample : 17th /02/ 2025						
PARAMETER / SAMPLE DOSE(g/L)	**Moisture Content (%)**			**Total Solids (%)**		
0	50.5	51.2	51.9	49.5	48.8	48.1
2	50.2	49.9	50.6	49.8	50.1	49.4
4	46.5	46.8	44.8	53.5	53.2	55.2
6	47.4	48.1	48.7	52.6	51.9	51.3

Remarks: The results for the water samples tested were as above.

Analyzed by: Sandra Akol &

Andrew Muhwezi Ndamira

Supervised by: Irene Adong (QCO Lubigi)

Report Prepared by: Bayo Robert (QCO Chem/ES Central Lab)

Signature : ....

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WATER QUALITY MANAGEMENT DEPT.
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Appendix 9: Results after second week of dosing

NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI
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Student: ANDREW Muhwezi Ndamira (S21B32/090) &
SANDRA Akol (S21B32/058)
Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 24/02/2025
Date of Report: 06.03.2025

Sample : 24th /02/2025						
PARAMETER / SAMPLE DOSE(g/L)	**Moisture Content (%)**			**Total Solids (%)**		
0	41	41.4	41.1	59	58.6	58.9
2	39.9	38.5	39.9	60.1	61.5	60.1
4	35.4	35.7	33.8	64.6	64.3	66.2
6	36.9	34.9	36.3	63.1	65.1	63.7

Remarks: The results for the water samples tested were as above.
Analyzed by: Sandra Akol &
Andrew Muhwezi Ndamira
Supervised by: Irene Adong (QCO Lubigi)
Report Prepared by: Bayo Robert (QCO Chem/ES Central Lab)

Signature : ....

NATIONAL WATER AND SEWERAGE CORPORATION
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WATER QUALITY MANAGEMENT DEPT.
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Appendix 10: Results after third week of dozing

NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI
P.O BOX 7053 KAMPALA   Email: water.quality@nwsc.co.ug

Student: ANDREW Muhwezi Ndamira (S21B32/090) &
SANDRA Akol (S21B32/058)
Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 24/02/2025
Date of Report: 06.03.2025

Sample : 24th /02/2025						
PARAMETER	**Moisture Content (%)**			**Total Solids (%)**		
SAMPLE DOSE(g/L)						
0	41	41.4	41.1	59	58.6	58.9
2	39.9	38.5	39.9	60.1	61.5	60.1
4	35.4	35.7	33.8	64.6	64.3	66.2
6	36.9	34.9	36.3	63.1	65.1	63.7

Remarks: The results for the water samples tested were as above.

Analyzed by: Sandra Akol &
Andrew Muhwezi Ndamira
Supervised by: Irene Adong (QCO Lubigi)
Report Prepared by: Bayo Robert (QCO Chem/ES Central Lab)

NATIONAL WATER AND SEWERAGE CORPORATION
0 6 MAR 2025
WATER QUALITY MANAGEMENT DEPT.
THE CENTRAL LABORATORY

Signature : ....

Appendix 11: Results after fourth week of dosing

NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI
P.O BOX 7053 KAMPALA Email: waterquality@nwsc.co.ug

Student: ANDREW Muhwezi Ndamira (S21B32/090) &
SANDRA Akol (S21B32/058)
Address: Uganda Christian University
Mukono (Uganda)
Date Sample Tested: 03/03/2025
Date of Report: 06.03.2025

Sample : 3rd /03/2025						
PARAMETER / SAMPLE DOSE (g/L)	**Moisture Content (%)**			**Total Solids (%)**		
0	36.5	35.7	36.2	63.5	64.3	63.8
2	33.5	34.4	33.9	66.5	65.6	66.1
4	25.6	24.9	25 3	74.4	75.1	74.7
6	29.3	29.5	29	70.7	70.5	71

Remarks: The results for the water samples tested were as above.

Analyzed by: Sandra Akol &

Andrew Muhwezi Ndamira

Supervised by: Irene Adong (QCO Lubigi)

Report Prepared by: Bayo Robert (QCO Chem/ES Central Lab)

Signature : ……………………………………

NATIONAL WATER AND SEWERAGE CORPORATION
06 MAR 2025
WATER QUALITY MANAGEMENT DEPT.
THE CENTRAL LABORATORY