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DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

PERFORMANCE EVALUATION OF FECAL SLUDGE TREATMENT PLANTS IN UGANDA

BY

KYOMUGISHA SALOME TRINAH

BSc. EHS. (MUK)

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APPROVAL

The undersigned certify that they have read and hereby recommend for acceptance by Kyambogo University, a research dissertation entitled: **Performance Evaluation of Fecal Sludge Treatment Plants in Uganda,** in fulfilment of the requirements for the award of a degree of **Master of Science in Water and Sanitation Engineering** of Kyambogo University.

Sign:…….. Date:……..

Eng. Dr Anne Nakagiri (Main Supervisor)

Sign:…….. Date: 19th September 2022……..

Dr Charles Onyutha (Co- Supervisor)

DECLARATION

I, Kyomugisha Salome Trinah, hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning, except where due acknowledgement has been made in the text and reference list.

Sign: .....

Kyomugisha Salome Trinah

Date: 30/08/2022

DEDICATION

I dedicate this work to my children, Michelle Atukunda Bwesigye, Alicia Agasha Bwesigye and Tricia Ainomugisha Bwesigye. And above all, I dedicate it to God Almighty.

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Firstly, the honour and great thanks go to the Almighty God for giving me the good health and everything else that has enabled me reach this far in life, may His holy name be glorified

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LIST OF ACRONYMS

ABRs	Anaerobic Baffled Reactors
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
COVID19	Corona Virus Disease 2019
DEFASTS	Decentralized Fecal Sludge Treatment System
DEWATS	Decentralised Water Treatment Systems
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EED	Environmental Enteric Dysfunction
FC	Fecal Coliforms
FSTP	Fecal Sludge Treatment Plant
FSTPs	Fecal Sludge Treatment Plants
MWE	Ministry of Water and Environment
NWSC	National Water and Sewerage Corporation
PGF	Planted Gravel Filters
pH	Potential of Hydrogen
PWUV	Purified Water treated by the Ultraviolet radiation
RW	Raw Water
SARS COV 2	Severe Acute Respiratory Syndrome Coronal Virus 2
SDG 3	Sustainable Development Goal 3

SDG 6	Sustainable Development Goal 6
SI	Systemic Inflammation
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UN	United Nations
UNEP	United Nations Environmental Program
UN-Habitat	United Nations Habitat
UNICEF	United Nations Children's Fund
O&M	Operation and Maintenance

OPERATIONAL DEFINITIONS

Term	Definition
Fecal Sludge Treatment Plant performance	This term was used to refer to the level at which a given FSTP removed physico-chemical and biological parameters from fecal sludge influent upon discharge. A given plant was regarded as having optimal performance if it had discharged effluent with at least 7 out of 8 physico-chemical and biological parameters compliant with the national standards.
Design related determinants of fecal sludge treatment plant performance	This term was used to refer to the characteristics of engineering and construction dynamics that were used to set up each of the plants, that had statistically significant relationships with FSTP performance.
Staff related determinants of Fecal Sludge Treatment Plant performance	This term was used to refer to the characteristics of the staff at each of the plants, that had statistically significant relationships with FSTP performance.
Systemic determinants of Fecal Sludge Treatment Plant performance	This term was used to refer to the procedural and work characteristics of the institutions that are mandated to oversee FSTP operations, which had statistically significant relationships with FSTP performance.

ABSTRACT

With the inevitably increasing urbanization of various cities, there has come an increasing amount of fecal sludge collected in all cities globally. Such an incidence has consequentially led to the increasing need to not only manage but also treat all fecal sludge following cognizance of the effects of poorly treated fecal sludge on public and environmental health. Fecal sludge treatment plants have been and still are being constructed, with engineers coming up with innovative designs for purposes of treating sludge, even in Uganda. However, whereas the plant construction process is much prioritized, there have been gaps in performance of the plants registered, globally. Those gaps are indicated by the persistence of coliforms, and solids in plant effluent, as reported in various countries. The purpose of this study was to evaluate the performance of fecal sludge treatment plants in Uganda with focus on effluent discharge, and what determines it. The assessment of plant design characteristics revealed that all of them had septage/ sludge reception points, coarse screening screens for grit and solid separation from sludge, all of which were manually raked. The majority of the plants had no sedimentation tanks. However, for those which had sedimentation tanks, they were of the settling-thickening type. The majority of the plants did not have anaerobic ponds, but for those that had anaerobic ponds, all had anaerobic baffled reactors. All plants had aerobic ponds that were all facultative. All plants had dewatering beds. All the plants had pathogen removal ponds, with the majority being constructed wetlands. Four fifths of the plants sampled did not have parts/processes for further drying/pathogen reduction. The level of performance of the fecal sludge treatment plants in Uganda is 40%. Optimal fecal sludge treatment performance was twice as likely at plants where the administrative staffs were permanent employees (aPR = 2.757 [1.515 - 6.114], p =0.028). In conclusion, Fecal Sludge Treatment Plants in the Uganda are generally designed with septage/ sludge reception points; they have coarse screening screens for grit and solid separation from sludge, all of which were manually raked. However, the majority of the plants have no sedimentation tanks, yet and neither do they have anaerobic ponds, yet they all have aerobic ponds of all which were facultative in design. All plants have pathogen removal ponds, but without processes for further drying/pathogen reduction. Fecal Sludge Treatment Plants in Uganda sub optimally perform, only 4 in 10 of them discharge effluent with more than 80% of its bio and physicoc-hemical characteristics compliant with national standards in terms of quantity. Staff characteristics are the only ones that are associated with FSTP performance.

CHAPTER ONE: INTRODUCTION

1.1 Background

Unsafe sanitation is currently associated with 800,000 deaths globally (Ritchie and Max, 2019), making it a significant public health concern of environmental health origin. It is unsurprising consequently that ensuring availability and sustainable management of water and sanitation for all was made one of the foremost international development goals to be achieved by the year 2030 (UN, 2020a; 2020b). It should however be noted that the achievement of almost all the targets of sustainable development goal 6 is significantly dependent on how well the sanitation service chain is managed, that is from the proper containment of fecal matter to its treatment for safe end use and/or disposal (World Bank, 2020). That is because fecal sludge treatment precedes exposure of the populace to fecal matter and pathogen laden water, if the process is not carried out by optimally functional Fecal Sludge Treatment Plants.

It is following the poor treatment of fecal sludge that the risk of exposure to diarrheal disease causing pathogens happen (Lauer et al., 2020), with the potential to perpetuate not only diarrheal related deaths, but also maternal and neonatal deaths, hence affecting the achievement of SDG 3 as well. The advent of COVID19 has further buttressed the need for optimal fecal sludge treatment given that fecal matter of COVID19 patients has been found to contain viable COVID19 microbes (Effenberger et al., 2020; Dhar & Mohanty, 2020) that could spread the disease if the sludge harbouring them is not treated. The fact that urban areas alone produce more than a billion tons of solid sludge per year (Orhorhoro and Oghoghorie, 2019), fecal sludge treatment remains key in for sustainable development given its links to many of the targets in the development agenda. However, for fecal sludge treatment to be effective in that respect, the fecal sludge treatment plants ought to function at peak performance at all sites they are set up.

There is unprecedented urbanisation occurring currently (Di Clemente et al., 2021; Sun et al., 2020), with more than half of the world population (4.2 billion) residing in urban settings and the number projected to be more than double by 2050 (Sun et al., 2020; UN-Habitat, 2020). More so, with increased urbanisation and overt gradually reduced prevalence of open defecation (UNICEF, 2021; Exum et al., 2020; UNICEF: WHO, 2020) have consequently resulted in increased latrine and toilet use (Caruso et al., 2019; Igaki et al., 2021; Verma et al., 2020; Ssemugabo et al., 2021). These have greatly led to an exponential rise in fecal sludge generation. In many African countries, daily per capita production of waste water ranges from 20 to 150 litres of wastewater per day and that of fecal sludge is 1 litre (UNEP, 2020). That translates into the generation of 1000m^3 of fecal sludge on a daily basis in a city occupied by about 1 million persons (UNEP, 2020). Cognizance of the increasing generation of fecal sludge has led to the embracement of the need to design and construct Fecal Sludge Treatment Plants (Edokpayi et al., 2021) not only centrally, but also in a decentralised manner (Haribal and Vaswani, 2020), particularly for small cities or municipals.

Fecal sludge treatment comprises an amalgamation of biological and physical processes designed to reduce the level of organic matter, solids, nutrients and pathogens (Jasim, 2020). In most developing countries there is limited number of centralised wastewater treatment plants and their location has often led to high emptying and transporting costs. It is for this reason that Decentralised Wastewater Treatment Systems (DEWATS) are the most commonly recommended (Vijayan et al., 2020). Such systems are often located closer to densely populated areas and usually involve treatment through the use of a settler, Anaerobic Baffled Reactors (ABRs,) Planted Gravel Filters (PGF), polishing ponds, and planted or unplanted sludge drying beds with or without ABRs (Vijayan et al., 2020; Rath et al., 2020). All the aforementioned processes are solely meant to ensure that the resultant effluent is comprised of physico-chemical and biological components that

are not in harmful quantities (Edokpayi et al., 2021; Ibrahim et al., 2020; Vijayan et al., 2020; Olabode et al., 2020). For any Fecal Sludge Treatment Plant (FSTP) to achieve the production of less harmful effluence, however, it ought to function at peak performance. It is not surprising therefore, that all fecal sludge treatment plants are designed to produce effluent that is comprised of coliforms, nutrients, organic and inorganic matter in quantities that conform to national or global regulatory standards. Such is optimal performance of any plant and the importance of achieving it per plant follows evidence that close to a quarter a billion people still rely on surface water (WHO, 2019), that is prone to pollution following discharge of effluent from treatment plants (Edokpayi et al., 2020b; Preisner et al., 2020).

Once incident, surface water pollution by effluent from Fecal Sludge Treatment Plants can increase risk of gastrointestinal infections among millions of people who use such water (Haribal and Vaswani, 2020; Deaths UNEP, 2020b). Such risks accrue from the microbiological quality of effluent (Makuwa et al., 2020), given that fecal matter contains thousands of viruses and bacteria (Sundin et al., 2020; Holcomb et al., 2020) per gram (Odih et al., 2020; Ashraf et al., 2020). If poorly treated, such microbes persist in waste water and when ingested morbidity ensues among the consumers (Castro, 2020). One of the commonest infectious diseases that results from the ingestion of poorly treated effluent is cholera, which is associated with severe sequelae including myoglobinuria, and cardiac dysrhythmia (Castro, 2020), thromboembolism, and aspiration pneumonia (Rondon, 2020; Danyalian, 2020). Besides surface water pollution, poorly treated effluent that is discharged into water bodies can cause eutrophication which has ecological and human health risks (Hwang, 2020)

Further still, exposure to fecal matter from poorly treated effluent can cause Environmental Enteric Dysfunction (EED) that is associated with Systemic Inflammation (SI), and altered intestinal

permeability (Lauer et al., 2020). That then further increases risk of chronic malnutrition (stunting), and wasting (Rahman, 2020; Chakrabarti, 2020; Budge et al., 2019). The advent of corona virus disease makes the achievement of optimal performance at fecal Sludge treatment plants even more paramount. That follows evidence that active corona virus strains are also egested along with other microbes in feces (Wölfel et al., 2020; Dhar and Mohanty et al., 2020; Zhang, 2020; Effenberger et al., 2020; Gu et al., 2020; Xu et al., 2020; Holcomba et al., 2020; Odih et al., 2020; Heller et al., 2020; Zuo et al., 2020). In essence, sub optimally performing Fecal Sludge Treatment Plants in this era of COVID19 may discharge effluent that may contain infectious SARS COV 2 pathogens, hence furthering COVID19 infections.

In order to ensure that all Fecal Sludge Treatment Plants, centralised or decentralised, perform their fecal sludge treatment functions optimally, there have been design and construction guidelines established (Tayler, 2018; Jasim, 2020; Strande, 2018). The guidelines also include those applicable to effective management systems, operator safety and good operational practice, and good quality construction (Tayler, 2018). However, whereas there is no global documentation on the level of Fecal Sludge Treatment Plant performance, there is wide ranging in-country evidence that points to sub optimal performance of FSTPs. Almost all evidence, most of which is from African settings (Edokpayi et al., 2021; Ibrahim et al., 2020; Vijayan et al., 2020; Olabode et al., 2020; Agoro et al., 2020) indicates that most Fecal Sludge Treatment Plants (FSTPs) work at less than 70% efficiency. In Uganda only 65% of the waste water treatment plants in the country discharge effluent components that are within range (Ministry of Water and Environment Water and Environment Sector Performance Report, 2018)

1.2 Statement of the problem

Whereas there have been many Fecal Sludge Treatment Plants set up within the past decade in Uganda, following the increasing urbanisation rate (World Bank, n.d), there has been one concomitant challenge at many of those plants, that has persisted since inception. At Ntugamo fecal sludge treatment for instance, all the three laboratory tests that have been annually conducted to test the quality of effluent have indicated out of range physico-chemical and biological parameters. In 2017, the quantities of coliforms identified in the effluent were more than 45 percentage points higher than the national standards (National Water and Sewerage Corporation, 2017, unpublished). That same year, COD, and BOD ranges were 23 and 14 percentage points higher than the national standards respectively (NWSC, 2017, unpublished). As of the year 2019, it was reported that COD and BOD ranges in the plant effluent were up to 6 and 3 times higher than the national standards (NWSC, 2019, unpublished).

The Iganga and Kayunga plants were not significantly different. Both plants were reported to have had effluent coliform, biochemical oxygen demand and chemical oxygen demand values that exceeded national standards by up to 12 times (in the case of BOD at Kayunga) and up to 400 times (in the case of coliforms at Kyotera plant). Considering that most of these plants discharge their final effluent into wetlands located in various lake catchments, this could account for the high levels of contaminants often recorded in the water from the lakes (Angiro et al., 2020; Dalahmeh et al., 2020). Such is both an engineering and public health concern given that the plants were designed to perform at optimal capacity yet on the contrary some of them seem to not be doing so, hence increasing the risk for outbreak of excreta related diseases. It should however be noted that the aforementioned data is only from a cross section of fecal sludge treatment plants that have been carrying out routine annual laboratory tests. The challenge could be even more wide spread

perhaps across most or all the plants. However, a representative level of performance of the FSTPs in the country is not available and is hence not known. The same applies to what determines the performance of those plants, which is also a knowledge gap that could be hampering the effectiveness of all plants that have been set up in conjunction with sanitation engineers.

1.3 Objective of the study

1.3.1 General objective

To evaluate the performance of Fecal Sludge Treatment Plants in Uganda with focus on effluent discharge and what determines it.

1.3.2 Specific objectives

1. To identify the different designs of Fecal Sludge Treatment Plants (FSTPs) being implemented in Uganda.
2. To determine the level of performance of Fecal Sludge Treatment Plants in Uganda.
3. To establish the factors influencing Fecal Sludge Treatment Plant performance in Uganda.
4. To propose measures, feedbacks and guidelines to improve Fecal Sludge Treatment Plant performance.

1.4 Research questions

1. What are the different designs of Fecal Sludge Treatment Plants (FSTPs) being implemented in Uganda?
2. What is the level of performance of Fecal Sludge Treatment Plants in Uganda?
3. What are the factors influencing Fecal Sludge Treatment Plant performance in Uganda?
4. What are the measures, feedbacks and guidelines to improve Fecal Sludge Treatment Plant performance?

1.5 Justification of the study

Excreta related illnesses are responsible for up to 115 deaths per hour (United Nations Environment Program, 2021) and continued exposure to excreta or any of its constituent infectious microbes stands to undermine the not only the achievement of sustainable development goal 6, but also goal 3. With the apparent urbanisation occurring even in Uganda (World Bank n.d; United Nations 2018) and the consequently reducing rates of open defecation, poorly treated fecal sludge remains a chief source of disease causing pathogens (UNEP, 2020a; UNEP, 2020b). That is why there have been calls to monitor and measure the performance of Fecal Sludge Treatment Plants given that they have currently become the mainstay for treating the millions of tons of fecal sludge generated in global cities (Lotfi et al., 2020). That follows evidence that it is only with routine FSTP monitoring and evaluation that their performance can be ensured. However, whereas that call has been heeded to by many countries for instance Sabbahi et al. (2018) and Ibrahim et al. (2020) in Tunisia; Edokpayi et al (2021), Agoro et al (2020), Agoro et al. (2018), Makuwa et al. (2020) and Olabode et al (2020) in South Africa, it hasn't been the case in Uganda. More countries have observed this call, Zacharia et al (2019) in Tanzania, Baharvand et al. (2019) and Ghoreishi et al. (2016) in Iran; Lotfi et al (2019), Bourouache et al (2019) in Morocco; Vijayan et al (2020) in India and Nyamukamba et al (2019) in Poland, but not in Uganda.

Despite having many studies conducted in-country to investigate fecal sludge management, namely; Schoebitz et al., 2017; Schoebitz et al., 2016; Strande et al. 2018; McConville et al., 2020; Murungi et al., 2014; Nakagiri et al., 2015; Lugali et al., 2016; Englund et al., 2020; Ssemugabo et al., 2021; Angiro et al., 2020; Lauer et al., 2020. Uganda with up to 18 and more FSTPs constructed across the country, there has only few studies conducted to evaluate the performance of FSTPs in the country (e.g. MWE, 2018, Otaka et al., 2019). Even with those few studies, none

had a national perspective, and none of them included the evaluation of both FSTP level of performance and its antecedents.

1.6 Significance of the study

Safe management of human excrete which entails proper capture, collection and transportation and treatment for safe disposal or reuse is an aspect of national and international development. It is directly related to health, education outcomes, and environmental pollution as indicated in the SDGs and Uganda's development agenda (NDP III and Uganda's Vision 2040). Following evidence of increasing fecal sludge generation and subsequent set up of more fecal sludge treatment plants, whose performance ought to be monitored and evaluated, the Ministry of Water and Environment launched staff training meant to improve the conduction of the same (monitoring and evaluation MWE, 2019). Therefore, the findings of this study may be of policy importance at the national level and perhaps globally as well. That is because the study has not only highlighted the performance of FSTPs in Uganda as part of its evaluation, but also gone ahead to identify the determinants of that performance. Such information may therefore be used by the Ministry of Water and Environment and its partners to not only get aware of which effluent components need to be regulated further, but also about which interventions they can use in order to augment plant performance.

As part of its performance assessment, the study has also revealed which of the fecal sludge treatment plants has optimal performance and which of them has sub optimal performance. Such information is expected to enable administrators/caretakers at the identified plants per category, to either uphold their current operational standards or augment them, depending on the level of performance each of them has been found to have.

The study has also identified the design related determinants of FSTP performance, and as well as the staff and systemic ones. It is expected that engineers may therefore find the study to be of significance to them as they will get to know which design characteristics are protective of optimal performance, and those that are not. The respective administrators of the plants will also find the study to be of significance to them given that staff related characteristics have also been identified, that is, both those that are protective of optimal FSTP performance and those who are not. Findings related to the systemic determinants of FSTP performance may also be of benefit to the line ministry and organisations like the National Water And Sewerage Corporation given that, they (findings) have highlighted systemic gaps that both institutions may get to close with the evidence brought forth.

Given that this study is certainly among the few that have monitored and evaluated fecal sludge treatment plant performance in Uganda, it is expected that the findings may trigger the conduction of more studies with a similar scope, by sanitation engineers and/or other scholars in general. That is in addition to the study being a significant source of in-country literature regarding what the determinants of FSTP performance are.

1.7 Scope of the study

1.7.1 Geographical

This study was conducted at fecal sludge treatment plants in Uganda, a country in East Africa neighboured to the East by Kenya, to the South by Tanzania and Rwanda, to the north by South Sudan and to the West by the Democratic Republic of Congo. The country currently has a total of 19 fecal sludge treatment plants distributed in the districts of Kiboga, Bukakata, Buwama,

Kakooge, Mityana, Kaasali, Kamuli, Pallisa, Mayuge, Iganga, Apac, Kayunga, Gulu (Pece), Kitgum 1, Kitgum 2 Micro, Yumbe, Kole, Ntungamo and Ishongororo.

Of those facilities however, 14 are functional (Table 1.1), three (03) are not yet functional, one (01) is not operational, one (01) is abandoned and four (04) are in operation with no resident caretaker. That therefore left 10 Fecal Sludge Treatment Plants to be eligible, going by their operational status with resident care takers that could be interviewed. Those plants were located in Kaasali, Pallisa, Iganga, Apac, Kayunga, Kiboga, Kitgum 2 Micro, Yumbe, Kole and Ntungamo districts.

Table 1.1: Fecal sludge treatment plants and their functional status

FST Plant	Location	Operational status	Functionality status
Kiboga FSTP	Kiboga district	In operation	Functional
Bukakata FSTP	Masaka district	In operation with no resident caretaker	Functional
Buwama FSTP	Mpigi district	In operation with no resident caretaker	Functional
Kakooge FSTP	Kakooge	Under construction	Not yet functional
Mityana FSTP	Mityana district	Abandoned	N/A
Kaasali FSTP	Rakai district	In operation	Functional
Kamuli FSTP	Kamuli district	Under construction	Not yet functional
Pallisa FSTP	Pallisa district	In operation	Functional
Mayuge FSTP	Mayuge district	In operation with no resident caretaker	Functional
Iganga FSTP	Iganga district	In operation	Functional
Apac FSTP	Apac district	In operation	Functional
Kayunga FSTP	Kayunga district	In operation	Functional
Gulu (Pece) FSTP	Gulu district	Under construction	Not yet functional
Kitgum 1 FSTP	Kitgum district	In operation with no resident caretaker	Functional
Kitgum 2 Micro FSTP	Kitgum district	In operation	Functional
Yumbe FSTP	Yumbe district	In operation	Functional
Kole FSTP	Kole district	In operation	Functional
Ntungamo FSTP	Ntungamo district	In operation	Functional
Ishongororo FSTP	Ibanda district	Construction complete not operated	N/A

Source: Ministry of Water and Environment

1.7.2 Content scope

The study was delimited to evaluating the performance of fecal sludge treatment plants in Uganda. In the assessment of FSTP performance, plant effluent was the testing medium of focus, given that it is its physico-chemical and microbial composition following passage through the treatment plant that indicates how well the treatment was executed. During assessment of effluent composition, a set of eight (08) parameters were focused on, namely; chemical oxygen demand -COD, Biochemical Oxygen Demand - BOD, Total Suspended Solids -TSS, Total Dissolved Solids - TDS, Potential of Hydrogen -PH, Nitrogen, Electrical Conductivity and E-coli. This was because; going by the propensity of their public health significance in case effluent in which they are contained is discharged whilst they are in high amounts.

One of those components that were focused on are microbial pathogens (Makuwa et al., 2020), that included E. coli (gram-negative), Enterococci (gram-positive) and total coliforms. Those microbes are indicators of fecal contamination (Carre et al., 2018; Liu et al., 2018) and are core indicators of the quality of water meant for reuse (European Union, 2016).

The second category of FSTP effluent composition that was looked out for were standard water quality parameters of physico-chemical nature, that included Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total suspended solids (TSS), Total Dissolved Solids (TDS), Potential of Hydrogen (PH), Nitrogen and Electrical Conductivity. That was because the aforementioned physic-chemical properties have a direct link with the presence or absence of fecal material in effluent (Barrios-Hernandez et al., 2020). Performance was conceptualised as a binary outcome variable, that was categorised as either optimal or sub optimal.

Optimal FSTP performance referred to the presence of at least 7 of the 8 parameters that are in the globally and/or nationally accepted ranges. Bacterial coliforms had to be in a range of 5000 CFU/100m, Biochemical Oxygen Demand had to be at 50 mg/L, Chemical Oxygen Demand had to be at 100 mg/L, Electrical conductivity had to be 1500 µs/cm, the PH had to be between 6.0-8.0, Total Suspended Solids had to be in a range of 100 mg/L, total nitrogen had to be at 10 mg/L and Total Dissolved Solids had to be at 1200 mg/L (NWSC, 2021). Fecal Sludge Treatment Plant performance was the dependent/outcome variable of the study, against which its possible determinants were analysed. The independent variables were three in number, and they included design, staff, and systemic characteristics. The choice of those three explanatory variables was informed by the systems theory and by the current Fecal Sludge Treatment Plant design guidelines in which it is mentioned that technology, process design, management systems and staff determine the efficiency of any plant (Tayler, 2018)

1.7.3 Time scope

The study was conducted over a period of 5 months (data collection) over which effluent samples were collected and tested for their physico-chemical and microbial properties, and interviews also conducted. The second time consideration that the study had was that it targeted fecal sludge treatment staff that had been attached to those respective plants for at least a year.

1.8 Theoretical framework

Fecal Sludge Treatment Plants are fully fledged systems, whose performance (in terms of efficiency of removing harmful components from effluent) depends on a number of factors within the environment that the plant is situated. Therefore, this study was informed by the systems theory in which the term 'environment' is operationalized as referring to all objects among which any change in attribute has the potential to affect the functionality of the entire system (Hall & Fagen,

1956) (Figure 1). The systems theory is interdisciplinary (Boulding, 1956; Maturana and Varela, 1975; Senge, 1990; Burns and Stalker, 1961; Lawrence and Lorsch, 1967; Aldrich, 1979) and can be applied to any system in nature, be it a sludge treatment plant, to investigate any attribute with a holistic point of view (Capra, 1997).

With a systems approach therefore, an entity is looked at as a whole and not just part of it (von Bertalanffy, 1968; Checkland, 1997; Weinberg, 2001; Jackson, 2003; Mele et al., 2010; Luhmann, 1990; Golinelli, 2009). The general stance of the theory is that the performance or behaviour of a given system cannot be satisfactorily investigated by looking at only some of its components, but rather all of them. In the current study the environment of the Fecal Sludge Treatment Plants were presumed to be composed of three main elements, that is, plant design and technology, management systems and staff as supported by (Tayler, 2018). Those three environment characteristics were adapted as plant design characteristics, plant staff characteristics, and systemic characteristics. The outcomes of the effect of those characteristics on the system (output) were adapted as the performance of the fecal sludge treatment plant.

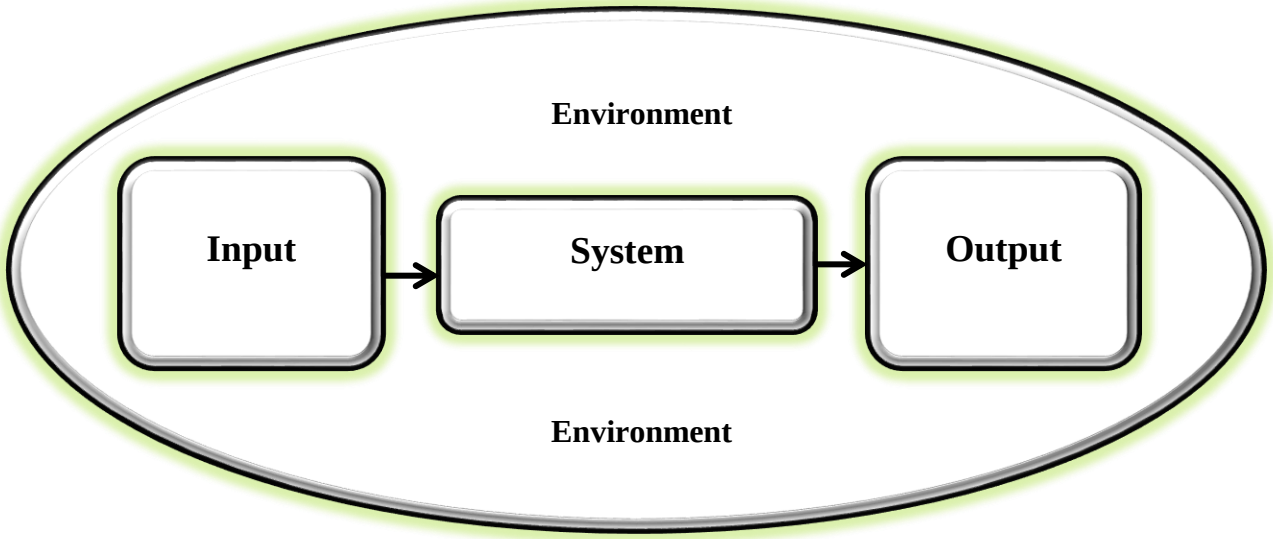

Figure 1.1: Systems theory (Battalanfy, 1968)

1.9 Conceptual framework

Figure 1.2 below shows the conceptual framework that entailed the study objectives and the relationships between them. It is shown that the study had three independent variables (design, staff, and systemic characteristics) and one dependent variable (fecal sludge treatment plant performance). Performance is indicated by Optimal (> 80% of the parameters in range) or sub optimal (< 80% of the parameters in range) performance.

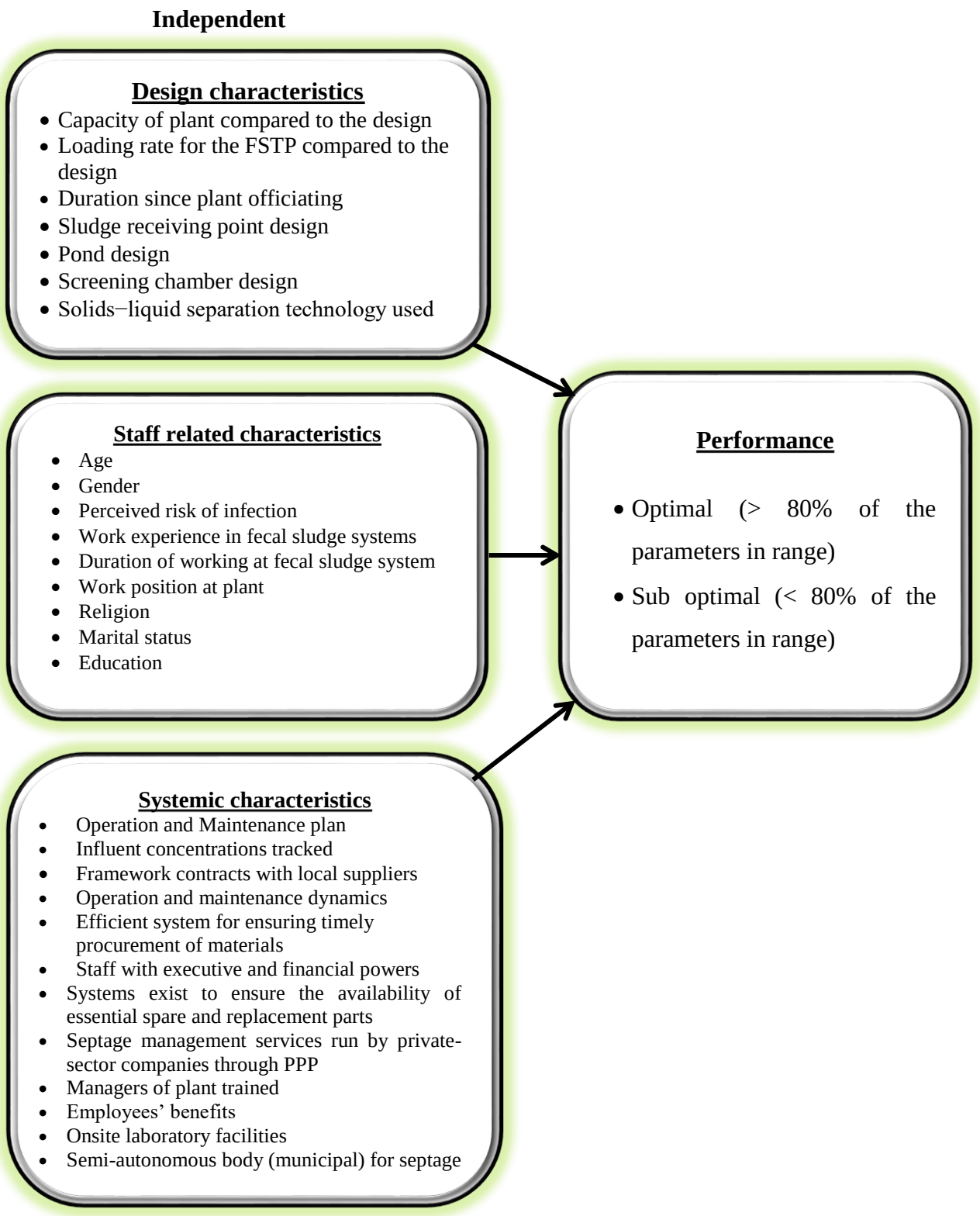

Figure 1.2: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of literature related to the study and its objectives, with the implication that the chapter is organised into 4 sections. Section 2.1 entails literature related to fecal sludge management, 2.2 design characteristics of FTSP, 2.3 which contains literature related to the performance of FSTP, and 2.4 covering literature related determinants of Fecal Sludge Treatment Plants. It should however be noted that since there have been very few studies that have assessed the determinants of Fecal Sludge Treatment Plant performance in any settings, some of the literature in sections 2.4 has been reviewed without explicit focus on Fecal Sludge Treatment Plants but also other sanitation technologies.

2.2 Fecal Sludge Management

Fecal sludge refers a mixture of waste water/fluids and solid waste including fecal matter that is collected using on-site technologies and not sewer systems (UN Environment program, 2021). That sludge could be raw, partially digested, semi-solid, slurry (Strande, 2014) and in whatever form it is always rich in disease causing pathogens, minerals and chemicals that can be harmful to the environment and human health. Therefore, fecal sludge treatment is a must in all cases following fecal sludge collection. The process of fecal sludge treatment involves five steps including "the storage, collection, transportation, treatment and safe end use or disposal of fecal" (Penn et al., 2018). Fecal sludge treatment is therefore a process that starts with storage/ containment (Tayler, 2018) using various technologies (UN Environment program, 2021). Following storage to capacity, the sludge is collected manually or with automation (Mikhael et al.,

2014) and transported to a treatment facility. At the treatment facility, treatment commences with the separation of the solid part of sludge from the liquid part using mechanical or biological means. Biologically, drying beds, stabilization ponds and wetlands are used for the process while mechanically, activated sludge, anaerobic digesters and anaerobic sludge blanket (UASB) reactors are used (UN Environment program, 2021). Both mechanical and biological treatment mechanisms of fecal sludge aim at reducing and/or maintaining certain biological and physico-chemical parameters in the sludge within acceptable limits that conform to global, regional and national limits. That is because treated fecal sludge is later on discharged into the environment and used for various purposes (Gold et al., 2016; Nikiema et al., 2014; Diener et al., 2014). It can be recycled and used in agriculture (Cofie et al., 2016; Adam-Bradford et al., 2018), in energy production (Woldetsadik et al., 2017), with the effluent discharged into water bodies.

2.3 The different designs of Fecal Sludge Treatment Plants (FSTPs)

According to the current fecal sludge and septage treatment guidelines for low and middle income countries (Tayler, 2018) all septage treatment processes are meant to achieve four objectives, one being the reduction of oxygen demand (COD and BOD), suspended solids, and nutrient concentrations within the liquid part of the effluent, in accordance with the set guidelines at a local or regional or global level. The second objective is to reduce the concentration of pathogens in effluent discharged, so as to make it safe for use. The third is to reduce sludge water content and hence make it easier to handle and transport, with the fourth being to reduce sludge pathogen numbers. However, it is argued that all the aforementioned four objectives cannot be achieved in a single process, but rather through a number of processes, with each process meant to achieve a given objective so that combined, the sludge that goes through those processes is discharged safely (Tayler, 2018).

That therefore implies that a fecal sludge treatment plant ought to be designed in a way that it is constituted with a number of parts, or in consonance with standard designs. The plants must be designed with a sludge reception point where tankers and vehicles or other carriages of sludge can empty sludge into the plant (Figure 3). That is then followed by gross solids, grit, fats, oil, and grease (FOG), and floating objects removal. The third step usually involves stabilization of the sludge to reduce odours and prepare the sludge for further treatment in other parts of the plant (Figure 1.3). After stabilization, liquids are then separated from solids, following which the liquid separated is treated, so as to reduce the microbial and organic load of the effluent. The solid part is on the other hand dewatered (Figure 1.3), with the resultant cake taken to the landfill, or used in agriculture.

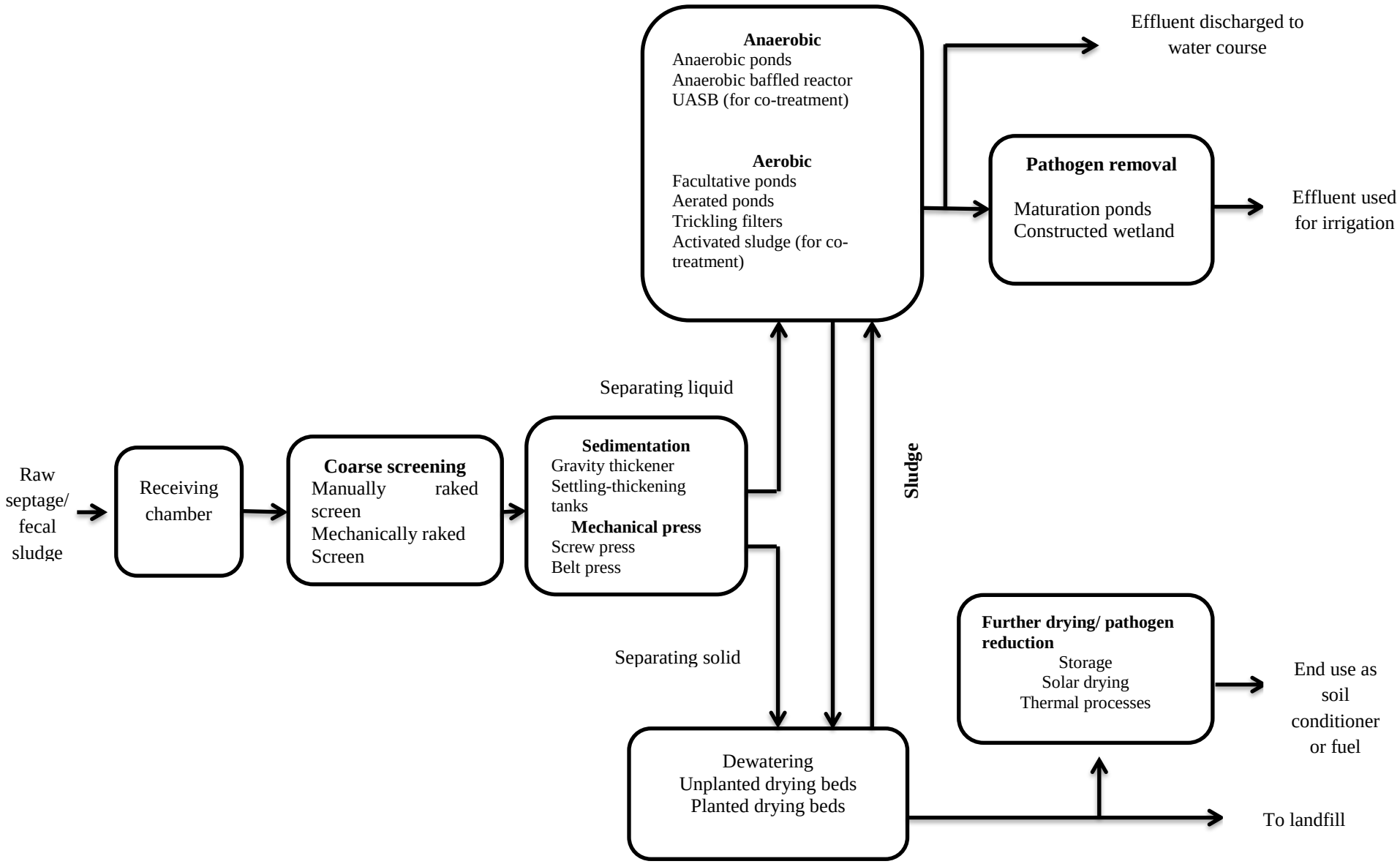

Figure 1.3: Fecal sludge and septage treatment stages and options (*source: Tayler, 2018*)

2.4 Performance of fecal sludge treatment plants

With the increasing urbanisation at global, regional and local levels, with its resultant increment in fecal sludge production, decentralised fecal sludge treatment plant set up in all cities has become the norm for all governments and their agencies. Performance of FSTP can be judged by their ability to treat fecal sludge to limits acceptable for safe disposal or reuse of the solid and liquid fractions of the waste. However, whereas that is the case, the challenge of having those plants perform at peak, as indicated by maximum removal of harmful component in fecal sludge effluent remains apparent. Enteric bacteria and coliforms of human origin have continual been identified in effluent following treatment (Osuolale and Okoh, 2017; Osuolale and Okoh, 2015; Edokpayi et al., 2015b; Naidoo and Olaniran, 2014; Ghoreishi et al., 2016; Nahavandi et al., 2015). It has been reported that optimally performing treatment plants should be in position to achieve to 6 log reductions in E.Coli, although currently, most plants only achieve between 2 – 3 log reductions (Zacharia et al., 2019; Verbyla et al., 2017). As a result, diarrheal disease outbreaks have also become quite rampant following ingestion of excreta contaminated water even in countries like South Africa where many Fecal Sludge Treatment Plants have been set up (Naidoo and Olaniran, 2014).

A very recent South African study by Edokpayi et al. (2021) reported that the microbiological parameters (Escherichia coli and enterococci) in the effluent tested were higher than those in the influent in some sampling months. The authors (Edokpayi et al., 2021) added that they noted low pathogen removal efficiency (<1 log reduction), with COD levels exceeding the limits set by the South African Department of Water Affairs and Forestry (DWAF). Still in South Africa, Olabode et al. (2020) who, however, focused on only physico-chemical properties found that of effluent

temperature (16.90–25.33 °C), Potential of Hydrogen (pH) (5.85–7.85), Electrical Conductivity (EC) (923.00–1294.17 µS/cm), Total Dissolved Solids (TDS) (590.72–828.27 mg/L), DO (1.30–5.50 mg/L), Sulphates (SO42) (3.23–163.18 mg/L), Chemical Oxygen Demand (COD) (23.70–898.58 mg/L), Biochemical Oxygen Demand (BOD) (9.17–252.44 mg/L), chloride (Cl) (48.17–378.48 mg/L) and Phosphates (PO43)− (0.10–11.32 mg/L), only pH, Temperature, and sulphates were within the recommended limits set by the country's Department of Water Affairs and Forestry. That is inconsistent with findings by an earlier study by Nyamukamba et al. (2019) who found that most of the physic-chemical properties they studied were out of range.

Nonetheless, Makuwa et al. (2020) whose study included the assessment of biological, physical and chemical measures in wastewater final effluent concluded that all the parameters tested were within recommended limits. In North Africa, studies conducted in the region have also revealed some gaps in performance of effluent treatment. In Morocco, for example Bourouache et al. (2019) tested Raw Water (RW), decanted water, purified water and Purified Water treated by the ultraviolet radiation (PWUV), following which they found that the values for COD, BOD and TSS were all in range of normalcy as per Moroccan national standards. It was electrical conductivity and Fecal Coliforms (FC) that were beyond limits. The findings by, Bourouache et al. (2019) are comparable to findings by Lotfi et al. (2019) who also reported that effluent TSS, COD and BOD had had the best performance in terms of compliance with national standards.

In Tunisia, Sabbahi et al. (2018) who tested 234 wastewater samples among which 117 were treated found that the removal efficiency of helminth eggs and protozoan cysts ranged from 50% to about 100%. Ibrahim et al. (2020) however reported removal rates ranging from 85% to 73%.

In the Middle East, some of the highest values of treatment plant performance have been reported. Baharvand et al. (2019) for instance found that the efficiency of removal Total suspended solids, Nitrates, BOD, and COD ranged from 80 to 92%

In India, on the contrary, Vijayan et al. (2020) reported a reduction of 89 to 99 per cent at one of the plants they sampled, although they reported that at some plants, removal of solids was at near zero, while for COD, it was 48 per cent, and that of BOD being 54 per cent, while that of coliform removal stood at 40%. This is due to the presence of microalgae in the polishing pond and the removal of TDS is very negligible in all the systems. Vijayan et al. (2020) added that physico-chemical properties including organic nitrogen, phosphate, and ammonia nitrogen remained below 10%.

In Tanzania, studies have reported COD values to be 52.4% in Morogoro (Zacharia et al., 2019), 63% in Mwanza (Zacharia et al., 2019), and 71.2% in Iringa (Zacharia et al., 2019), which is somewhat comparable to Akosombo - Ghana at 75% (Adu-Ofori et al., 2016). South Sudan has reported perhaps the least removal rate, at -22.8% (Manya et al., 2019). Zacharia et al. (2019), in Tanzania, however further reported that the level of parasites and FCs in the effluent exceeded global standards in South Sudan.

In Uganda, a study by Otaka et al (2019) in which effluence from a pilot Decentralized Fecal Sludge Treatment System (DEFASTS) was tested. The effluent tested had flowed through an anaerobic baffled reactor and anaerobic filter and polished by a Cyperus papyrus planted gravel filter. The authors found that the efficiency of Chemical Oxygen Demand was 95.7% that of five-day Biochemical Oxygen Demand was 96.4% that of Total Suspended Solids was 96.8%, that of pH was 78.4%, and that of coliforms was 78.4%.

The ministry of Water and Environment (MWE) (2018) also conducted a monitoring exercise of 17 municipal wastewater sites and reported that 6 of the 17 lagoons produced effluent with above limit BOD, 12 lagoons had within range TSS of 100mg/l.

2.5 Factors influencing FSTP performance

2.5.1 Design related factors of performance

As earlier mentioned (Section 1.5), there have been virtually no studies that have assessed the influence of Fecal Sludge Treatment Plant designs on their performance. However, there exist some studies and guidelines that have come up with and stipulate best practices for FSTP design, respectively. One of the design characteristics that have been mentioned as being pertinent in the operation, functionality and performance of FSTPs is the match and/or balance between the capacity and load of treatment plants. According to Tayler (2018) peak FSTP performance cannot be achieved if the treatment capacity of the plant does not match the load put into it. With higher than capacity FS loads, FSTP operators tend not to be in position to operate the plants as intended by their designers. Anaerobic ponds for instance cannot achieve full anaerobic conditions, and design velocities cannot be achieved in anaerobic baffled reactors in cases of higher than design capacity loads. That can then result into higher than designed sedimentation rates, and richer effluent.

According to fecal sludge treatment and septage guidelines by Tayler (2018), every fecal sludge treatment plant ought to be designed with a reliable electric power source given that modern plants are designed with power dependent machinery. Those include activated sludge reactors, pumps, and mechanical processes. The author suggested that all plants would perform better with three phased power supply systems, with few outages, and design voltage provision.

Another design consideration is that of safety of staff at the plant; with that consideration, it is suggested that FSTPs should be fenced or restrict unauthorised access by members of the public (Tayler, 2018). All FSTPs should be designed to restrict plant staff contact with fecal sludge and septage, given that operators who perceive any activity to be done as unpleasant seldom carry out those tasks. Such an occurrence can then affect plant treatment activities and lead to the retention of unacceptably high levels of physic-chemical and biological parameters. In addition to staff safety considerations when designing FSTP designs, pipe size deserves attention as well. Each of them should be appropriately sized and laid at points that support the transport of solids in the influent. Besides pipe size, tank size also matters in the operationability of FSTPs given that undersized tanks call for more frequent maintenance to remove of solids and sustain treatment performance while oversized ones can consume otherwise limited FSTP space (Tayler, 2018; Niwagaba et al., 2014).

The aforementioned guidelines have certainly been adopted in many FSTPs of various system designs. A systematic review by Aghalari et al. (2020) that included a review of studies in 5 Iranian environmental health journals revealed that the plants in Iran use various systems including activated sludge, stabilization ponds, wetlands, and low and medium pressure Ultra Violet (UV) systems to disinfect and remove microbial agents.

2.5.2 Staff related factors influencing FSTP performance

According to Tayler (2018), a well-designed Fecal Sludge Treatment Plant can only be fully functional and highly performing if it has staffs that are also capable of operating the plant using its designs. Therefore, the performance of a Fecal Sludge Treatment Plant in part depends on plant staff characteristics. However, just like the research gap that exists in the context of the effect of

plant design characteristics on plant performance, there are virtually no studies that have inferentially assessed the effect of plant staff characteristics on the performance of fecal sludge treatment plants that they are attached to. However, there are some studies (Hariadi and Mardiati, 2019; Kalpana and Dharmaraj, 2018; Ugwu and Ugwu, 2017) that have identified some pertinent staff characteristics that may affect employee performance and ultimately, the performance of an organisation as a whole, as per the suggestions of the systems theory. Some of the staff characteristics identified are socio demographic in nature. Studies by Hariadi and Mardiati (2019) and Kalpana and Dharmaraj (2018), found that education and age had a positive effect on employee performance. Ugwu and Ugwu (2017) also found that the age of employees explained up to 56% variations in employee performance. Banjo and Ogunkoya (2014) on the other hand found that marital status of the employees was most protective of their performance. Kalpana and Dharmaraj (2018) and Yaser (2015) on the other hand found marital status to be positively related to employee performance. Kalpana and Dharmaraj (2018) also found a relationship between gender and employee performance and although the authors did not provide the direction of the relationship, Singh and Mohan (2020) found that being female was more protective of employee performance compared to being male. However, Ugwu and Ugwu (2017) and WaelZaraket (2017) found no relationship between gender, marital status salary and employee performance. It should be noted that even in those studies that established relationships between Studies by Ugwu and Ugwu (2017) and Oyewole and Popoola (2015) identified relationships between work experience and employee performance. Ugwu and Ugwu (2017) found that work experience explained up to 56% variations in employee performance, while Oyewole and popoola (2015) found that years of working experience was protective of employee performance.

Ugwu and Ugwu (2017) also found that employee education also exhibited up to 56% variations in the overall job performance of staff, almost similar to findings by Oyewole and Popoola (2015) who found education to be important.

Job satisfaction, which is one perception and connectedness to their work (Luthans, 2016) has been found to be of significance in predicting their and organisational performance (Ratnasari et al., 2020; Martin and Gert, 2017; Raziq and Maulabakhsh, 2015). For a Fecal Sludge Treatment Plant were staffs have to endure sludge stench and at time inhygienic work environment, job satisfaction could be of importance in their performance. Dziuba et al. (2020) suggested that higher work performance can only be achieved by happy and satisfied employees. The results of this research are organizational culture has a significant effect on job satisfaction, leadership has a significant effect on job satisfaction, job satisfaction has a significant effect on employee performance.

2.5.3 Institutional factors influencing performance

Like design and individual plant staff characteristics, systemic characteristics have also not been studied as possible determinants of Fecal Sludge Treatment Plant functionality. Nonetheless, plant design and septage guidelines provide crucial systemic characteristics that ought to be observed if optimal plant performance is to be achieved. Imperative among those is the need to have consumables and spare parts available at all times at the plant of their supply assured by line organisations/ministries. Tayler (2018) asserted that good supply chains for spare parts are the life blood for the optimal operation of any process that includes fecal sludge treatment processes.

Information and information systems are also crucial components of FSTP operation, and it is the mandate of management to provide such information to all staff operating the plant. Processes like aeration treatment of sludge requires information related to the suspended solids in the reactor for

instance. Similarly, management has to provide plant staff with information related to polymer dosing rates and sludge-cake water content if the treatment process is to be successful. That is why it has been postulated that plant staff cannot operate treatment plants unless they have the knowledge and skills that are appropriate to their roles, in addition to knowledge about the treatment processes. Part of the information that should be provided to plant staff is standard operating procedures needed for staff to carry out activities correctly and always produce consistent results (Tayler, 2018).

Whereas the effect of knowledge/information provision to plant staff on plant performance has not been inferentially tested, it has been tested in other settings. In general, information provision to organisational staff depends on a number of characteristics including top management support (Shao, 2018; Brem & Wolfram, 2017; Ekrot et al., 2016), communication (Wu et al., 2017), management characteristics (Martinsuo & Hoverfält, 2018), organizational culture (Situmeang et al., 2017), and training characteristics of the organisation (Dandage et al., 2018; Ramazani & Jergeas 2015). It is those characteristics that ultimately determine whether or not an organisation will adopt knowledge management practices for staff. Staff knowledge provision has been reported to be a measure for prosperity and success in any organisation and/or intervention (Ohemeng and Kamga, 2020; Abubakar et al., 2019; Ali et al., 2019; Zaim et al., 2019; Wahda, 2017; Ha and Lo, 2018). Li et al. (2020) found that knowledge management practices had a positive and significant influence on dynamic capabilities of staff and increased organisational performance. Machado dos Santos et al. (2019) also reported that communication to staff on issues related to their work routine increased their performance and project success.

One of the ways through management can provide their staff with information and knowledge is through professional development programs, which have been found to positively influence

organisational performance. A number of studies have also found workshop professional development and its related activities to be related to improved employee performance (Khan, 2019; Abdulrazak, 2020; Maeng et al., 2020; Kapur, 2018; de Grip et al., 2019; Karim et al., 2019; Gadi and Audu, 2019; Afroz, 2018). Workshops usually take the approach of off-job training (Huang & Jao, 2016) given that they are in most cases conducted outside one's working environment. Doing so was reported by Shafini et al. (2016) to be protective of more attention on the part of the employees and possibly more impact on their performance, with the ultimate effect being augmented organisational performance. Mtulo (2014) related off-the-job training of employees to be related to fewer disruptions by external factors while Ramya (2016) linked off-the-job training to more optimized learning and a more systematic learning experience that may also have more impact. Dostie (2017) on the other hand reported that more off-job training cultivates more employee performance given its higher likeness to classroom training, and hence higher productivity. That finding agrees with findings from other studies (Afsana et al., 2016; Athar & Shah, 2015; Ugbombhe et al., 2016). The execution of all the aforementioned activities depends on organisational culture (Naqshbandi et al., 2015), which has been independently found to affect organizational performance (Kraśnicka et al., 2018; Situmeang et al., 2017). In the context of FSTP performance, organisational culture may include systemic characteristics like the provision of training to plant staff, according them close supervision, motivating them and providing them with all the equipment and resources they require to execute their tasks. Such managerial activities may positively influence plant performance, as has been confirmed in study by Taweesan et al (2017) in Thailand. Chmielewska et al. (2020) also found that supervision quality and style had the highest effect on the organizational performance, although Cera and Kusaku (2020) found no influence of such organisational culture on performance.

Tayler (2018) in his FSTP management guidelines highlighted one of the systemic issues that could influence plant performance, and that was the recruitment of employees on contracts or on a temporary basis. He mentioned that such an arrangement may be detrimental to FSTP performance since it can lead to the attrition of plant staff with experience and skills required for plant operation.

2.6 Summary of literature

Table 1 below presents a summary of some key findings from studies that have been reviewed in this study.

Table 2.1: Summary of literature reviewed

Author(s) and year	Study title	Location	Nature of facility	Main finding
Ghoreishi et al. (2016) Nahavandi et al. (2015) Zacharia et al. (2019) Adu-Ofori et al. (2016) Manya et al. (2019) Nyamukamba et al. (2019) Makuwa et al. (2020) Bourouache et al. (2019) Sabbahi et al. (2018) Ibrahim et al. (2020) Vijayan et al. (2020) Otaka et al (2019)	Studies on Evaluation of quality of effluent and bio solids from FSTP. Paraments included pathogens, parasitic particles (nematode eggs, and not protozoan (oo)cysts), organic matter Physicochemical Parameters, Heavy Metals, and Antibiotics, rotaviruses.	Iran Tanzania Ghana South Sudan South Africa Morocco Tunisia India Uganda	Conventional WWTP Waste stabilization ponds Conventional WWTP Pilot decentralized FSTP	Varying quality levels; some met discharge limits while others were above. Most of them were noted to be above discharge limits for all the types of the facilities.
Edokpayi et al. (2021)	Recent trends and national policies for water provision and wastewater treatment in South Africa.	South Africa		Low pathogen removal efficiency (<1 log reduction), with COD levels exceeding the limits set by the South African Department of Water Affairs.
Ministry of Water and Environment (MWE) (2018)	Water and Environment Sector Performance Report 2018	Uganda		It was reported that 6 of the 17 lagoons produced effluent with above limit BOD, 12 lagoons had within range TSS of 100mg/l.
Hariadi and Mardiati (2019)	The Effect Of Demography Characteristics, Remunerisation, Job Redesign On Employee Performance With Job Satisfaction As Mediation International.	Indonesia		Education and age had a positive effect on employee performance.

Table 2.1: Summary of literature reviewed				
Ugwu and Ugwu (2017)	Demographic Variables and Job Performance of Librarians in University Libraries in South East Nigeria.	Nigeria		Employee education also exhibited up to 56% variations in the overall job performance of staff
Banjo and Ogunkoya (2014)	Demographic Variables and Job Performance: Any Link? (A Case of Insurance Salesmen).	Nigeria		Marital status of the employees was most protective of their performance.
Singh and Mohan (2020)	An Analysis Of Employee's Job Satisfaction In Higher Education.	India		Being female was more protective of employee performance compared to being male.
Ratnasari et al. (2020)	The effect of job satisfaction , organization, culture, and leadership on employee performance.	Indonesia		Leadership, job satisfaction, organizational culture have an effect on employee performance
Martin and Gert (2017)	Perceptions of Organizational Commitment, Job Satisfaction, and Turnover Intensions In A Post Merger South African Tertiary Institution	South Africa		Job satisfaction significantly influences organizational performance
Raziq and Maulabakhsh (2015)	Impact of Working Environment on Job Satisfaction. Procedia Economics and Finance.	Pakistan		Businesses need to realize the importance of good working environment for maximizing the level of job satisfaction.
Ekrot et al. (2016)	Retaining and satisfying project managers–antecedents and outcomes of project managers' perceived organizational support.	German		Results stress the significance of top management involvement and the support of project management offices for project managers' perceived organizational support.
Brem and Wolfram (2017)	Organisation of new product development in Asia and Europe: results from Western multinationals R&D sites in Germany, India, and China.	Germany, India, and China		Top management support significant influences performance.

Table 2.1: Summary of literature reviewed

Wu et al. (2017)	Investigating the relationship between communication-conflict interaction and project success among construction project teams.	China		Communication willingness and formal communication were positively associated with the project success, whereas informal communication negatively affected project success.
Martinsuo & Hoverfält (2018)	Change program management: Toward a capability for managing value-oriented, integrated multi-project change in its context.			Organizational performance depends on top management orientation.
Dandage et al. (2018)	Analysis of interactions among barriers in project risk management.			Training characteristics of the organization influence performance
Ramazani & Jergeas (2015)	Project managers and the journey from good to great: the benefits of investment in project management training and education			Training characteristics of the organization influence performance
Ohemeng and Kamga (2020)	Administrative leaders as institutional entrepreneurs in developing countries: a study of the development and institutionalization of performance management in Ghana's public service	Ghana		Knowledge management practices had a positive and significant influence on dynamic capabilities of staff and increased organizational performance.
Abubakar et al. (2019)	Knowledge management, decision-making style and organizational performance.	Turkey		Decision-making style (i.e., intuitive and/or rational) will moderate the relationship between knowledge creation process and organizational performance.
Ali et al. (2019)	Key factors influencing knowledge sharing practices and its relationship with organizational performance within the oil and gas industry	Sudan		Knowledge sharing practices positively influence organizational performance
Ha and Lo (2018)	An empirical examination of knowledge management and organisational performance among Malaysian manufacturing SMEs	Malaysia		Knowledge acquisition and protection had a significant positive relationship with organisational performance,

Table 2.1: Summary of literature reviewed

Zaim et al. (2019)	Relationship between knowledge management processes and performance: critical role of knowledge utilization in organizations	Turket		Knowledge utilization mediates the relationship between rest of the knowledge management processes and organizational knowledge management performance.
Wahda (2017)	Mediating effect of knowledge management on organizational learning culture toward organization performance	Indonesia		Organizational learning culture (OLC) has the biggest effect on organizational performance.
Li et al. (2020)	Organizational factors influencing project success: an assessment in the automotive industry	Brazil		The most important predictors of organizational performance are organizational culture, change management, and top management support.
Machado dos Santos et al. (2019)	The Impact Of Staff Training And Development On Teacher's Productivity	Lebano		There exists positive and strong relations between training and development and productivity of the teachers of Kurdistan.
Abdulrazak (2020)	The effect of professional development on elementary science teachers' understanding, confidence, and classroom implementation of reform-based science instruction	U.S.A		Professional development significantly increases teacher performance.
Maeng et al. (2020)	Effects of Training on Employee Performance - A Study on Banking Sector, Tangail Bangladesh	Bangladesh		Staff training significantly influences organizational performance
Afroz (2018)	Effects Of Training Of Academic Staff On Employees' Performance In Federal Polytechnics, Nigeria	Nigeria		Staff training significantly influences organizational performance.
Karim et al., 2019;	Indicator pathogens, organic matter and LAS detergent removal from wastewater by constructed subsurface wetlands	Iran		The removal efficiency of TSS for the wetlands was 68.87%, 71.4%, 57.3%, and 66% respectively.

2.7 Summary of literature and gap

The performance of Fecal Sludge Treatment Plants has been somewhat widely studied particularly in Africa, although it is evident that most studies to that effect have been conducted in South Africa. Asia has also had FSTP performance assessments conducted, and similar to studies in Africa, their performance levels going by the biological and physicochemical quality of effluent produced has been largely sub optimal. It was also evident from literature that there have been very few studies that have quantified plant performance with consideration of multiple biological and physicochemical components in effluent. The literature gap is even more evidence when it comes to what could be the predictors of plant performance, studies in that respect is virtually inexistent, especially those with evidence that is inferentially derived.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents a description of the methods that were used to execute the study, commencing with the description and justification of the study design, the study population and eligibility criteria (inclusion and exclusion), sample size calculation and sampling procedures. The chapter also includes a description of the data collection methods, data collection tools, quality control techniques, measurement of variables, data management and analysis plan and the ethical considerations that were upheld during the conduction of the study and a dissemination plan.

3.2 Study design

This study adopted a cross sectional survey design given that one of the aims of the study was to descriptively measure the performance of fecal sludge treatment plants, and later on inferentially analyse its determinants. Such activities are ably supported by cross sectional survey designs given that they involve the collection of data from a representative sample of respondents following which the data can be numerically treated (descriptively and inferentially). In addition, with a cross sectional survey design, it was possible to target only a cross section of fecal sludge treatment plants that were apparently functional and also a cross section of staff at all the sample plants, which was of an advantage to the study since not all of them could be accessed and yet they were few in number. Thirdly, cross sectional designs incorporate the use of structured interviews as the main data collection methods, which the study could later use to collect quantifiable data for use in achieving objectives 1, 2, 3 and 4.

3.3 Study population

The study targeted FSTPs and administrattive staffs working at those plants in Uganda, given that irrespective of the design of the plant, the ultimate performance of the fecal sludge treatment plant, in part, depends on the characteristics of the staff (Tayler, 2018). Therefore, the study had to engage such staff in interviews and collect intrapersonal data from them. Secondly, it is only the staff mandated to work at the respective plants that could ably provide valid information as regards the design characteristics of the plant, and systemic characteristics as well. However, the study population was staff that were occupying administrative positions (Managers, Deputy Managers, Laboratory Technicians, Plumber, Plant Caretaker) at each of the respective fecal sludge treatment plants. That category of staff was particularly targeted because by virtue of their positions, they could provide more valid information particularly pertaining to the design characteristics, systemic ones and also human resource.

3.4 Sample size calculation

To determine the sample size of this study, two presumptions were made one being that there was no documentation of the level (prevalence) of fecal sludge performance (p) and the second being that the number of staff, who were targeted in total (N), was available. With those two assumptions therefore, it could not be possible to use formulae that require the substitution of the parameter (p) for prevalence or proportion as those would have yielded a return sample of 384 at 50% prevalence, which would have been inaccessible. That is because the population size was only 27 at all the available functional fecal sludge treatment plants. However, formulae that require the substitution of the parameter for population size (N) could be used and was the most suitable since the size was known. One such formula is a formula by Krejcie and Morgan (1970), which is given by;

$$s = \frac{X^2 N\,P\,(1 - P)}{d^2\,(N - 1) + X.P\,(1 - P)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where;

s = required sample size.

X^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.841).

N = the population size = number of administrative staff at the functional fecal sludge treatment plants in Uganda = 27

P = the population proportion (assumed to be .50 since this would provide the maximum sample size).

d = the degree of accuracy expressed as a proportion (.05).

$$s = \frac{1.96^2 \text{ x } 27 \text{ x } 0.5\,(1 - 0.5)}{0.05^2 \text{ x } (27 - 1) + 1.96^2 \text{ x } 0.5\,(1 - 0.5)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$s = \frac{3.8416 \text{ x } 27\,(0.25)}{0.0025 \text{ x } (26) + 0.9604} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$s = \frac{3.8416 \text{ x } 67.5}{0.065 + 0.9604} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$s = \frac{25.9308}{1.0254} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

s = 25 staff at the fecal sludge treatment sites

3.5 Sampling procedures

As earlier mentioned (Section 1.7.1) Uganda currently has a total of 10 functional fecal sludge treatment plants with resident care takers, located across 10 districts in all the five regions of the country. This study being cross sectional therefore, the 10 plants including Kasaali in Kyotera district, Pallisa FSTP in Pallisa district, Iganga FSTP in Iganga district, Apac FSTP in Apac district, Kayunga FSTP in Kayunga district, Kiboga FSTP in Kiboga district, Kitgum 2 Micro FSTP in Kitgum district, Yumbe FSTP in Yumbe district, Kole FSTP in Kole district and Ntungamo FSTP in Ntugamo district constituted the sampling frame at the first stage of sampling and simple random sampling was used to sample 50% of them. To carry out the simple random sampling, the names of all the 10 treatment plants were written on a sheet of paper and numbered 1 to 10. Those numbers were then each written on equal sized pieces of paper, following which the pieces of paper were folded and put in a box. The box was then ruffled and one piece of paper picked per ruffle, without replacement.

The ruffling and subsequent picking of pieces of paper was done until a total of five pieces of paper had been picked, representing 50% of the available fecal sludge treatment plants. The pieces of paper were unfolded to reveal the names inscribed on them and it is those names that then constituted the identities of the fecal sludge treatment plants that had been sampled. The fecal sludge treatment plants that were sampled at this stage were; Iganga FSTP, Kayunga FSTP, Kiboga FSTP, Kyotera FSTP and Ntungamo FSTP. At each of the plants, there was a total of 5 administrative staff occupying positions of Manager, deputy manager, plant supervisor, plant operator and sanitation marketers. Therefore, since the number of staffs who were needed for the study was 25, and yet the five sampled plants had a total of 25 as well, non-random sampling methods had to be used to sample the required staff. Purposive sampling was the sampling method

of choice since with it; it could be possible to sample each of the available staff on the premise of being an occupant of an administrative position (Managers, Deputy Managers, Laboratory Technicians, Plumber, Plant Caretaker) at their respective plants.

3.6 Data collection methods

Data that was required to achieve objective 2 and 3 was collected using structured interviews, given that to analyse the effect of a certain characteristic on FSTP performance, it had to be collected from the self-reports of each staff and later quantified. Structured interviews were the primary data collection method, given that with them, it was possible to engage the staff sampled in an interview involving more than 40 questions, within a period of 40 minutes. That was possible because structured interviews are close ended and thus relatively faster to conduct. That ensured that there was no item non-response that usually happens due to respondent fatigue and also ensured that the required number of respondents per plant could be sampled and interviewed within a short time frame (between 30 and 40 minutes). That merit is in addition to the fact that the data collected from structured interviews can be easily captured in quantifiable form, as was required to achieve the four objectives of the study.

3.7 Data collection tool

The type of questionnaire that was used was a structured questionnaire, which was found to be the most suitable type of data collection tool for this study given that the study had three study objectives, each of which required numerical data in order to be achieved. Such data could be easily captured with a structured questionnaire, whose additional merit was that it could allow for the condensation of all items in a close ended manner that could as such be posed to the respondents within a short time frame. The close ended nature of the questionnaire also made it easy for the

respondents, to comprehend the questions asked to them and respond accordingly with more accuracy. The questionnaire was designed with five sections (A, B, C, D and E) each representing one of the objectives, except section A, which was soliciting for socio demographic characteristics of the respondents (Appendix B). Section B comprised of items that were meant to capture parameters of fecal sludge treatment plant performance, Section C comprised of questions assessing plant design characteristics, section D comprised of questions that were assessing staff related characteristics, while section E comprised of questions that were assessing systemic characteristics.

3.8 Quality control techniques

3.8.1 Validity of the study tool

Validity testing of the tool was the first quality control measure that was instated, because the proceeding quality control measures (assistant training, pretesting and field editing) were reliant on the use of a pre-validated tool. In testing for validity, the content validity index was looked out for, among other types of validity, given that the principal investigator was aiming at having a tool with items that were entirely relevant in achieving all the study objectives. To carry out the content validity testing, four experts in the field of fecal sludge management, fecal sludge plant design and evaluation were identified at the Ministry of Water and Environment and furnished with the study objectives, and the questionnaire. They were then given a scale that they could use to rate each of the items in the tool. The scale was; 4 = Very relevant, 3 = for relevant, 2 = somewhat relevant, and 1 = Not relevant. Their ratings are shown in the table below;

Table 3.1: Content validity testing results

Expert number	Number of items rated 4	Number of items rated 3	Number of items rated 2	Number of items rated 1
1	44	3	3	0
2	43	3	3	0
3	44	1	5	0
4	46	2	2	0

After rating each of the items by each identified expert, the mean number of items rated 3 or 4 was computed (47 + 46 + 45 +48 / 4 = 47), and then the Content validity index calculated using the formula;

$$\text{Content Validity index} = \frac{\text{Number of items rated 3 or 4}}{\text{Total number of items}} = \frac{47}{50} = 0.940$$

The tool, having had a CVI in the range of 0.7 to 0.99, was considered to be valid and hence used during the training of the Research Assistants

3.8.2 Training of the research assistants

Given that the five plants were distributed across 5 districts in the majority of the regions of the country yet there was need to not only collect effluent samples from each of the five plants and also conduct interviews at each, there was need to have some research assistants. Their role was

to engage some of the staff in some regions and collect samples, while the principal investigator engaged staff in other regions. In some cases however, assistants and the principal investigator concurrently worked at the same plant. Four of them were recruited, of whom 3 were females and 1 was male, all university educated with prior experience in survey data collection. With that experience, the main training that was given to them was that of sample collection, although more training was provided to familiarize them with the study and its procedures. They were also taken through each of the 50 items in the questionnaire, informing them about how they were to ask the questions in order to maximize accuracy of responses from the staff. Role plays were also conducted between themselves, and they were then (after a week) invited to participate in the pretest of the study.

3.8.3 Pretesting

A pretest was also conducted along with the trained assistants, at Lubigi fecal sludge treatment plant located in targeting 4 staff (10% of the sample). Lubigi fecal sludge treatment was chosen as a pretest site because like other plants in the country, it has also had reports of physico-chemical and biological parameters being out of range, which is an indication of gaps in plant performance. The pretest was conducted in order to (1) further familiarize the assistants with the study tools and given them a feel of what the main data collection exercise would be like (2) determine the readiness of the tool for use in data collection given that any anomalies could be identified beforehand and (3) determine how long an interview would take with each respondent so that the conduction of the main study could be well organized. Following the pretest, some few rectifications were made, one of which was the adjustment of the responses in question 34, the paraphrase of question 46 and the correction of the error in questions 35 and 36.

3.9 Measurement of variables

Measurement of FSTP performance

Fecal sludge treatment plant performance was measured based on a threshold by Bloom (1967) in which a cut off of 80% is considered to be optimal. Therefore, since there was a total of 8 parameters assessed, namely; Chemical Oxygen Demand -COD, Biochemical Oxygen Demand - BOD, Total Suspended Solids -TSS, Total Dissolved Solids - TDS, Potential of Hydrogen -PH, Nitrogen, electrical conductivity and E-coli. An optimally performing Fecal Sludge Treatment Plant was that had at least 7 of the 8 parameters compliant with national standards in terms of effluent quality.

Effluent sample collection and pre-treatment

Effluent samples were taken from each of the five sampled fecal sludge treatment plants at biweekly intervals, for a month each. A litre of effluent was collected from each plant using a sterile container, following which the containers were transported on ice to the central water quality laboratory of the National Water and Sewerage Corporation (NWSC). Sample pre-treatment involved the preservation of effluent meant to be used for the testing of COD and TN, with sulphuric acid at a pH of 2 and the preservation of samples that were meant to be used for bacteriological testing with 10% formaldehyde. Biological and physicochemical laboratory analysis of the samples was conducted within 24 hours of arrival of the samples to the laboratory. The choice of the national water and sewerage corporation laboratory for effluent analysis was informed by the fact that the lab had capacity to analyse the effluent for all the parameters of interest, including BOD, COD, TN, FC, and TSS, PH, TDS and EC.

In-situ determination of effluent PH was conducted using WTW microprocessor electrodes and meters. The gravimetric method was used to determine Total Suspended Solids, while the closed reflex method was used to determine Chemical Oxygen Demand (COD). Biochemical Oxygen Demand BOD was determined using the Titrimetric method, while contamination with Fecal Coliform was determined using the membrane filtration method.

3.10 Data management and analysis

3.10.1 Data management

The analysis process started with data management; which was done both manually and digitally. Manually, all the questionnaires were mobilized and each checked for completeness and validity in filling. This was then followed by data entry, which was directly done in SPSS version 25 for windows. Each question in the questionnaire was given a name, label and appropriate values, codes, and corresponding entries done in the data screen. At completion of this process, entry sheet was manually checked first for any entry or coding errors. Three were found and corrected, and then dummy frequency distributions were also analysed for each of the entered variables to confirm the readiness of the data for analysis.

3.10.2 Data analysis

Data analysis in this study was conducted using both descriptive and inferential statistics. For the descriptive statistics, frequency distributions, crosstabs and principal component analysis were done, while for the inferential statistics, cluster, bivariate and multivariate analysis were done. Cluster analysis was done for data in objective one given the need to only measure the level of FSTP performance but also to characterise performance parameters.

Analysis of data for objective 1 and objective 2

All variables from the first objective were analysed descriptively since the aim of the objective was to assess the designs of the plants. Likewise, FSTP performance assessment in the first objective was also first analyzed descriptively, to determine the frequency and valid percentage distributions of each. It was at this point that the level of performance was computed. This was then followed by the analysis of principal components among the performance parameters that the study had. Principal Component Analysis (PCA) reduces the dimensionality of numerous variables, into fewer most correlated variables, hence increasing interpretability and concurrently minimizing information loss. It does so by creating new uncorrelated variables that successively maximize variance (Jolliffe, 2016). The Principal Component Analysis (PCA) was conducted using the Varimax Rotation Method, with the main aim of establishing what the principal components within the 8 parameters were. All variables that had Eigen values exceeding 1 were considered to be principal components. The principal components were defined as that variable that had the highest correlations with the component.

Following Principal Component Analysis, each of the definitive principal components were the ones that were considered for cluster analysis. The cluster analysis model is a multivariate technique that is used to assign each of the principal components into a cluster. Clustering was done using the K-means method, in which a distance measure was chosen, and the number of clusters was set to 2 in order to make the identification of the largest cluster easier. Each of the identified principal components was further analysed using cross tabulation distributions. The cross-tabulation distributions allowed for the establishment of the parameters that significantly defined the FSTP performance.

Analysis of data from objective 2 and 3

Cross tabulations between the independent variables (design, staff and systemic characteristics) and the quantified dependent variable (FSTP performance) were analysed during first step of bivariate analysis. Variables that were found to have no integer of zero in their cross tabulation were then considered for bivariate analysis using a statistical model. That is because cross tabulations with integers of zero in their cells cannot be used to compute ratios and hence could not generate p values. The log-binomial model was used to analyse relationships between the variables, with the choice of the model informed by the fact that it is one of the most accurate inferential statistical models (Deddens,, 2008; Wacholder, 1986; Greenland, 2004; Thompson, 1998; Nijem, 2005; Behrens, 2004). Secondly, the dependent variable of the study was binary, with its magnitude being more than 10%, at which point such a model does is most appropriate as it does not overestimate the p value (Martinez, 2017). The findings to that effect were presented in terms of Crude Prevalence Ratios (cPR) at 95% Confidence Intervals (CI), with those having any relationships with probability value (*p*-value) that was less than 5% (<0.05) being statistically significant. It is such variables that were considered for multivariate analysis, in which each of those independent variables was analyzed against the dependent variable, along with relevant confounders. The findings to that effect were presented in terms of adjusted Prevalence Ratios (aPR) at 95% confidence intervals, with those having any relationships with p values that were less than 5% (<0.05) being statistically significant.

3.11 Ethical considerations

Approval to conduct the study was obtained from the ethical review committee of the University (Appendix C) and the permission to conduct the study at those respective plants was obtained from

the Ministry of Water and Environment (Appendix C). When engaging the staff, a number of ethical considerations that ought to be observed when studied human subjects were observed in this study as well. The first was self-determination and consent with which each of the staff sampled was given a detailed introduction of the study, what the purpose of the study was, why they had been sampled, and what they were required of if they chose to be participants, and the risks and benefits of the study. After this consenting process, they were requested to show their acceptance of participation in the study, by appending a signature of thumbprint on the consent page provided to them. The ethic of protection from harm was also observed given that the data was collected during the COVID19 era in which standard operating procedures had to be observed in order to prevent transmissions and infections of staff. Social distancing of 1 meter was observed when conducting the interviews and where necessary, face masks were worn.

In order to ensure confidentiality of the study, none of the names or revealing initials of the participants were captured on the questionnaires or consent forms. In doing so, anonymity was also ensured. All questionnaires that were obtained were mobilized from the assistants and kept with the principal investigator only, without being accessed by any other persons. None of the responses provided by the staff will be shared with the MWE administration, unless with the identities of the staff are concealed. Privacy was also observed; each of the staffs who were sampled, were interviewed in a one on one basis, away from other staff.

The staffs were also assured that their participation was upon their own discretion; given the voluntary nature of the study. None of them was given any incentives, as such, and they were told that they would refuse or withdraw from the study without risking any consequences.

3.12 Dissemination plan

The principal investigator plans to provide a copy of the report to the university, a copy to each of the administrations of each of the Fecal Sludge Treatment Plants and a copy to the Ministry of Water and Environment. An article will also be prepared for publication in one of the relevant high impact journals.

CHAPTER FOUR: FINDINGS AND DISCUSSIONS

4.1 Socio demographic characteristics

Table 4.1 shows that almost a quarter of the FSTP staff sampled were males 18 (72.0%) and more than half of the sample were aged between 31 and 40 years 14 (56.0%). Nearly half of the sample were Catholic 12 (48.0%), and slightly more than half of them were married 14 (56.0%) while close to two thirds of the sampled staff were graduates 16 (64.0%). There were equal proportions of staff attached to FSTPs in Sludge treatment plant attached to Iganga 5(20%), Kayunga 5(20%), Kiboga 5(20%), Kyotera 5(20%), and Ntungamo 5(20%). There were equal proportions of FSTP staff interviewed who were Managers, Deputy Manager 5(20%), plant supervisors 5(20%), Plant Operators and Sanitation Officer 5(20%), and Marketers 5(20%) at their respective plants of station where five staff were interviewed per plant.

Table 4.1: Socio demographic characteristics of the respondents

Variable	Category	Frequency	%
Gender			
	Female	7	28.0
	Male	18	72.0
Current age (in full years)			
	20 to 30 years	3	12.0
	31 to 40 years	14	56.0
	41 to 50 years	7	28.0
	More than 50 years	1	4.0
Religious denomination			
	Catholic	12	48.0
	Anglican	8	32.0
	Muslim	1	4.0
	SDA	1	4.0
	Born again	3	12.0
Marital status			
	Married	14	56.0
	Single	4	16.0
	Cohabiting	7	28.0
Current education level			
	Certificate	5	20.0
	Diploma	4	16.0
	Graduate	16	64.0
Sludge treatment plant attached to			
	Iganga	5	20.0
	Kayunga	5	20.0
	Kiboga	5	20.0
	Kyotera	5	20.0
	Ntungamo	5	20.0
Position occupied at the plant			
	Manager	5	20.0
	Deputy manager	5	20.0
	Plant supervisor	5	20.0
	Plant operator	5	20.0
	Sanitation Marketer	5	20.0

4.2 Fecal Sludge Treatment Plant (FSTP) design characteristics

The assessment of plant design characteristics revealed that all of them 25(100.0%) had septage/ sludge reception points, coarse screening screens for grit and solid separation from sludge, all of which were manually raked . The majority of the plants had no sedimentation tanks 20(80.0%). However, for those which had sedimentation tanks, they were of the settling-thickening type. The majority of the plants did not have anaerobic ponds, but for those that had anaerobic ponds, all had anaerobic baffled reactors. All plants had aerobic ponds, that were all facultative. All plants had

dewatering beds with the majority having planted drying beds 15(60.0%). All the plants had pathogen removal ponds, with the majority having constructed wetlands 15(60.0%). Four fifths of the plants sampled did not have parts/processes for further drying/pathogen reduction. All plants used storage as the main dying process.

Table 4.2: The different designs of Fecal Sludge Treatment Plants (FSTPs) being implemented in Uganda

Variable	Category	Frequency	%
Plant has a septage/ sludge reception point	Yes	25	100.0
Plant has coarse screening screens for grit and solid separation from sludge	Yes	25	100.0
Type of screens plant uses	Manually raked screen	25	100.0
Plant has a sedimentation tank	Yes	5	20.0
	No	20	80.0
Type of sedimentation tank	Settling-thickening tanks	5	100.0
Plant has anaerobic ponds	Yes	10	40.0
	No	15	60.0
Category of anaerobic ponds plant has	Anaerobic baffled reactor	10	100.0
Plant has aerobic ponds	Yes	25	100.0
Type of aerobic ponds plant has	Facultative ponds	25	100.0
Pant has dewatering beds	Yes	25	100.0
Type of beds plant has	Unplanted drying beds	10	40.0
	Planted drying beds	15	60.0
Plant has pathogen removal ponds	Yes	25	100.0
Type of pathogen removal ponds plant has	Maturation ponds	10	40.0
	Constructed wetland	15	60.0
Plant includes a parts/processes for further drying/ pathogen reduction	Yes	5	20.0
	No	20	80.0
Type of drying processes plant uses	Storage	5	100.0

As expected, all the fecal sludge treatment plants sampled had septage/sludge reception points, in compliance with currently global guidelines (Tayler, 2018), implying that for all functional plants in the country, there are arrangements to collect all sludge at septage and prepare it for subsequent stages of treatment (screening). Given that, there were no studies that have specifically assessed the presence or absence of reception points at fecal sludge treatment plants on plant performance, comparisons could not be made with other findings. However, it was observed that at all sludge reception points, there was a high risk of spillage and hence contact between the sludge and the operators since the discharge was directly made into a tank or through pipes without a specialised coupling mechanism. At almost all the treatment plants therefore, there is not only a risk of creating and environmental nuisance but also a risk of infection of operators of transport trucks and operators at large. That alone may increase perceived risk of and susceptibility to infectious occupational diseases among plant operators. That may in turn makes them to become less engaged in FSTP operations, in fear of being infected, which may then have a negative effect on general plant performance, as has been long-established by Tayler (2018). On the whole nonetheless, at least each plant was designed with a point that prepares sludge for subsequent treatment, a stage that was found to be comprised of coarse screens for grit and solid separation from sludge. This was also a positive finding that further indicated compliance of Ugandan FSTP design characteristics with globally accepted standards. With the coarse screens in place at all the plants sampled, it is certain that all sludge receive, some of which comes from direct drop latrines, is screened free of materials like stones, bags, maize cobs, plastic bags and other solids that may devastate all subsequent fecal sludge treatment processes. Having coarse screens at all plants may have therefore buttressed fecal sludge treatment plant performance. On another positive note, all the coarse screens at the plants sampled were reportedly manually raked, which is also an

acceptable FSTP design characteristic since all the sampled plants were set up to serve populations of less than or about 400,000 persons in small to medium sized towns. Most importantly, manually raked bar screens are less labour intensive and far less costly than mechanically raked screens. That makes their operation and maintenance costs to be relatively lower, which in turn ensures that operation and maintained activities for the screens are promptly done, to the benefit of fecal sludge treatment plant performance.

Following screening, all sludge ought to be settled and stabilised, that is, its liquid part should ideally be filtered out using other technologies that include sedimentation tanks, sludge drying beds, anaerobic ponds, Imhoff tanks, settling-thickening tanks (STTs), and mechanical presses, gravity thickeners, decanting drying beds (Tayler, 2018; Bassan et al., 2014). Those liquid-solid separation technologies are meant to ensure that the effluent that results from the entire treatment process has a low solid or at least that that complies with, global, regional or local standards, and will hence have a low oxygen demand. Surprisingly, the findings of the study showed that the majority of the plants had no sedimentation tanks 20(80.0%). This finding implies that for most of the plants, there were no appropriate mechanisms explicitly designed to separate solids from the liquid part of the sludge, which possibly explains why the majority of the plants had their effluence with out-of-range values for chemical Oxygen Demand, Biochemical oxygen demand and Total dissolved solids (Table 4.3). Such an occurrence definitely affects overall plant performance, and increases risk of not only eutrophication but also discharge of infectious pathogens in the environment and water supply systems, which may then perpetuate environmental enteric dysfunction and all its sequelae. The liquid-solid separation technology that was used at all plants was the dewatering bed system 25(100.0%), the majority of which had planted drying beds. Whereas such beds can indeed carry out sludge dewatering, they associated with numerous

demerits they can only work better when they are fed with stabilised sludge. Without sedimentation tanks and/or other sedimentation technologies however, it is possible that the dewatering beds at all plants where they existed were not functioning at peak, hence also increasing risk of discharging effluent with a high solid load. That is in addition to the fact that without being fed with stabilised sludge, the beds can emit discomforting odours that could turn out to be a nuisance in the environment. The beds are extremely land intensive, can easily get clogged with sand and grit and yet they can be fully functional in the dry season. As such, dewatering beds may have high operation and maintenance costs that if not met as it sometimes is the case, may affect plant performance.

What was also equally found to be of concern was the finding that all the plants had aerobic ponds meant to carry out breakdown of organic matter, yet those ponds were not entirely preceded by anaerobic ponds, sedimentation tanks or any liquid-solid separation technologies. Therefore, for most FSTPs in the country, there are effectively pathogen removal/reduction mechanisms, but without appropriate solid removal/reduction ones. That certainly results into the discharge of effluent that has a low microbial load but with a high solid load, as was confirmed in this study as well (Table 4.3), all of which increases risk of infectious disease transmission to the public following environmental discharge of that effluent. Normally, following pathogen reduction in aerobic or facultative ponds, there should be other stages for further pathogen reduction in the form of Maturation ponds (Tayler, 2018). Such ponds were however missing at all the plants sampled, with the implication that even where pathogen reduction is done with the aforementioned facultative ponds, their reduction may not be universal (>80%), which was also found to be true in this study (Table 4.3), in the context of E.coli.

4.3 Fecal sludge treatment plant performance assessment

The assessment of fecal sludge treatment plant performance revealed that the majority of the plants had the PH of the effluent in range (6.0-8.0) 15(60.0%), had the total E. coli/coliforms in range (<=5000) 15(60.0%), and had electrical conductivity in range (<=1500) 16(64.0%). However the majority of the FSTPs 15 (60.0%) had their effluence found to have out of range chemical Oxygen demand values and as well as the biochemical oxygen demand values 15 (60.0%). The majority of the plants had effluent that had Total Suspended Solids 15(60.0%) in range, although the majority of them had Total dissolved solids in the effluent out of range 15(60.0%). Four fifths of the FSTPs had Total Nitrogen in their effluent out of range.

Table 4.3: Physico-chemical and biological quality of the FSTP effluent

Variable	Category	Frequency	%
PH-value			
	In range (6.0-8.0)	15	60.0
	Out of range	10	40.0
E. coli/coliforms			
	In range (<=5000)	15	60.0
	Out of range	10	40.0
Electrical Conductivity			
	In range (<=1500)	16	64.0
	Out of range	9	36.0
Chemical Oxygen Demand			
	In range (<=100)	10	40.0
	Out of range	15	60.0
Biochemical Oxygen Demand			
	In range (<=50)	10	40.0
	Out of range	15	60.0
Total Suspended Solids			
	In range (<=100)	15	60.0
	Out of range	10	40.0
Total Dissolved Solids			
	In range (<=1200)	10	40.0
	Out of range	15	60.0
	Total	**25**	**100.0**
Total Nitrogen			
	In range (<=10)	5	20.0
	Out of range	20	80.0
	Total	**25**	**100.0**

Going by the measurement procedure described in section 3.10, and as presented in Figure 4.1, it was found that more than a third 15(40%) of Fecal Sludge Treatment Plants sampled had at least

7 of the 8 performance parameters in range. That makes the level of performance of the Fecal Sludge Treatment Plants in Uganda to be 40%.

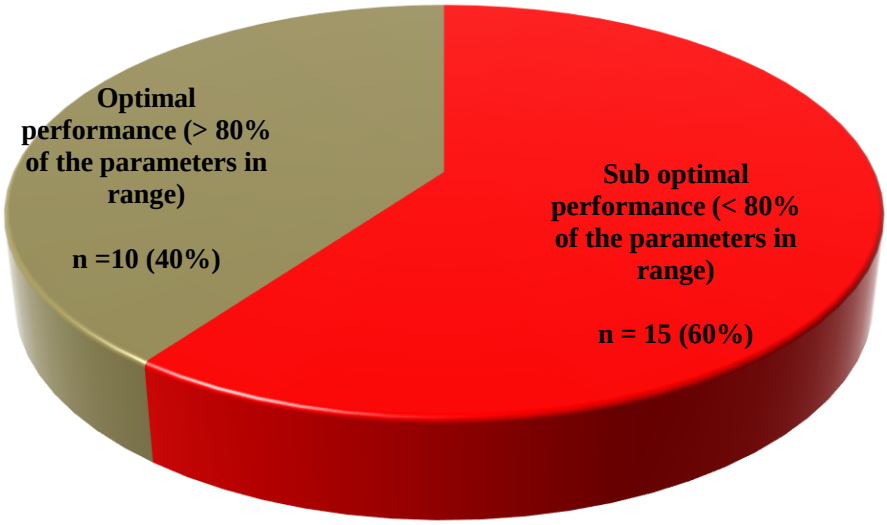

Figure 4.1: The level of performance of fecal sludge treatment plants in Uganda

Further analysis of performance involved the cross tabulation of location of FSTP by level of performance, for purposes of determining which of the plants belonged to the optimal performance group and those which belonged to the sub optimal performance group. The findings showed that only two plants featured in the optimal performance group, they are; the Kiboga FSTP 5(100.0%) and the Kyotera FSTP 5(100.0%). Three of the FSTP plants including Iganga 5(100.0%), Kayunga 5(100.0%) and Ntungamo 5(100.0%) had sub optimal performance.

Table 4.4: Cross tabulation between location of plant and FSTP performance

Location	Level of performance		Total
	Optimal [n = 10]	Sub optimal [15]	
Iganga	0(0.0%)	5(100.0%)	5(100.0%)
Kayunga	0(0.0%)	5(100.0%)	5(100.0%)
Kiboga	5(100.0%)	0(0.0%)	5(100.0%)
Kyotera	5(100.0%)	0(0.0%)	5(100.0%)
Ntungamo	0(0.0%)	5(100.0%)	5(100.0%)
Total	**10(40.0%)**	**15(60.0%)**	**25(100.0%)**

The need to have the functional Fecal Sludge Treatment Plants in Uganda function optimally cannot be overstated, given the implications of discharge of poorly treated fecal sludge effluent on public and environmental health. That need is particularly true in the context of Uganda were urbanization is steadily taking place. What is of concern however is that whereas there has been a global call to have Fecal Sludge Treatment Plants numerously set up and designed efficiently, as has been heeded by many countries including Uganda, performance gaps are persistent. That was to a large extent proven to be true in Uganda, where the current study revealed that the level of performance of the fecal sludge treatment plants was 40%. This finding implies that 4 in every 10 functional fecal sludge treatment plants in Uganda are operating at peak that is, are able to discharge effluent with about 8 in every 10 biological and physicochemical parameters in range with global and national standards. In the explicit context of the fecal sludge treatment plants that were sampled, the finding on plant performance implies that only 2 in every 5 plants discharged well treated effluent. This was statistically proven (Table 3) with the findings revealing that only the Kiboga FSTP and the Kyotera FSTP had optimal performance. That left the Iganga, Kayunga, and Ntungamo plants as having sub optimal performance.

In essence, it is the Iganga, Kayunga, and Ntungamo plants, whose proportion can be juxtaposed to be 6 in every 10 plants in the country, that discharge effluent that has 1 or more of PH, E.

coli/coliforms, Electrical Conductivity, Chemical Oxygen Demand, Biochemical Oxygen Demand, Total Suspended Solids, Total Dissolved Solids and Total Nitrogen parameters, out of range. It should be noted that the aforementioned 8 parameters are of core public and environmental health importance, and so any quantitative anomalies in each of them can have severe public health consequences, to the demerit of not only the line ministry but also the engineering community that designs fecal sludge treatment plants. The fact that it is the plants at Iganga, Kayunga, and Ntungamo districts that are sub optimally performing implies that the three plants are experiencing relatively more challenges with their current designs and components, and also liaison with plant oversight organisations.

It so happens that residents in Iganga, Kayunga, and Ntungamo district may be at risk of gastrointestinal infections that may accrue from the ingestion of contaminated water or from environmental enteropathy (Haribal and Vaswani, 2020; Deaths UNEP, 2020b; Agoro et al., 2018). Such infections significantly increase mortality risk given their severe sequelae, and when incident among pregnant women, such infections can perpetuate gestational anaemia and increase risk for obstetric complications including postpartum haemorrhage and sepsis (Ajepe et al., 2020; Ferguson and Dennis, 2019). That is in addition to the risk of transmitting Severe Acute Respiratory Syndrome Corona Virus 2 (SARS CoV 2) to the residents in those districts since COVID19 patient fecal matter harbours live pathogens (Ashraf et al., 2020; Wölfel et al., 2020; Dhar and Mohanty et al., 2020; Mesoraca et al., 2020; Zhang, 2020; Effenberger et al., 2020; Gu et al., 2020; Tian et al., 2020; Xu et al., 2020; Holcomba et al., 2020; Foladorie et al., 2020; Odih et al., 2020; Heller et al., 2020; Ashraf et al., 2020; Zuo et al., 2020). Exposure of the residence thereof results from the fact that the persistence of coliforms in large amounts in the effluent, guarantees persistence of the SARS CoV 2 viruses as well.

Of concern, the findings regarding fecal sludge treatment plant performance obtained in this study are comparable to most studies that have assessed plant performance in other settings, where sub optimal plant performance has also been reported. They include Osuolale and Okoh, (2017), Osuolale and Okoh (2015), Edokpayi et al. (2015b) in South Africa, Naidoo and Olaniran (2014) in South Africa, Ghoreishi et al. (2016), Nahavandi et al. (2015) in Iran, Zacharia et al. (2019), Verbyla et al. (2017), Edokpayi et al. (2021) in South Africa, Olabode et al. (2020) in South Africa, Nyamukamba et al. (2019) in South Africa, Sabbahi et al. (2018) in Tunisia, Vijayan et al. (2020) in India, Manya et al. (2019) and Ministry of Water and environment (MWE) (2018) in Uganda. As can be noted, most of the comparable studies are from low and middle income countries, making low fecal sludge treatment plant performance a somewhat global issue. It is not surprising therefore, that there have been rampant cases of enteric diseases reported in South Africa (WHO, 2021c), Iran (WHO, 2020c), and Tunisia (Parola et al., 2019) over the years. It is possible that like Uganda, most of the countries with FSTP performance gaps have similar design, staff and systemic challenges.

Few studies have reported higher levels of FSTP, for instance Makuwa et al. (2020) in South Africa, Ibrahim et al. (2020) (85% to 73%) in Tunisia, Otaka et al. (2019) (78 – 94%) in Uganda. There are some justifications for the difference however, the study by Sabbahi et al. (2018) focused on only helminth eggs and protozoan cysts removal, and not any other element in the biological or physicochemical spectrum. With that limited scope of assessment, the study was more likely to report a higher plant performance. The study by Otaka et al. (2019), on the other hand was conducted at a pilot decentralized Fecal Sludge Treatment System (DEFASTS), having a fully functional anaerobic baffled reactor, anaerobic filter and Cyperus papyrus planted gravel filter. That ensured that the effluent discharged had been overly thoroughly treated, unlike in the current

study were most of the fecal sludge treatment plants had been in operation for years, with rampant breakdowns over the same period.

More analysis was done in order to determine what physico-chemical and biological parameters that significantly characterized fecal sludge treatment plant performance and how they were distributed. That analysis was done using principal component and cluster analysis, and the findings to that effect are presented in table 4 and table 5.

The principal component analysis (Table 4.5) revealed that there were 2 principal components among the 8 parameters going by those two that had an Eigen value above 1 as confirmed in figure 4.2. Those parameters are the ones that have been identified in the next section.

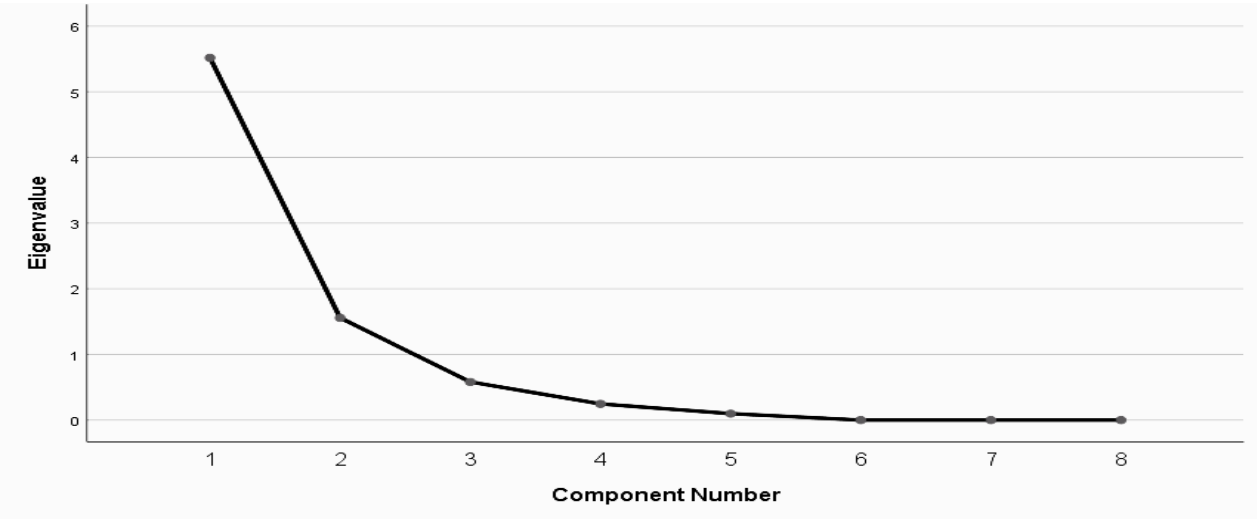

Figure 4.2: Scree plot

Table 4.5 below indicates that of the 8 physico-chemical and biological parameters that were used to assess FSTP performance, only 2 were principal components given that they are the ones that were found to have an Eigen value above 1 (Figure 4.2). Component 1 is correlated with Chemical Oxygen Demand (Coeff. = 0.855), Biyochemical oxygen demands (Coeff. = 0.855), Total

suspended solids (Coeff. = 0.898), Total dissolved solids (Coeff. = 0.855), and Total nitrogen (Coeff. = 0.648). However, the component is identified as total suspended solids given that it has the highest Coefficient (0.898). Component 2 had three parameters with similar coefficients, including PH-value (Coeff. = 0.947), E. coli/coliforms (Coeff. = 0.947), and Electrical conductivity (Coeff. = 0.947). Component 2 is therefore correlated to the three aforementioned parameters, and is identified by all the three. It thus follows that that of the 8 performance parameters, there were 4 principal components, and they include; Total suspended solids (Coeff. = 0.898), PH-value (Coeff. = 0.947), E. coli/coliforms (Coeff. = 0.947), and Electrical conductivity.

Table 4.5: Characterization of FSTP performance (PCA)

Performance parameter	Component	
	1	2
PH-value	0.265	**0.947**
E. coli/coliforms	0.265	**0.947**
Electrical conductivity	0.188	**0.947**
Chemical Oxygen Demand	0.855	0.483
Biochemical Oxygen Demands	0.855	0.483
Total Suspended Solids	**0.898**	-0.129
Total Dissolved Solids	0.855	0.483
Total Nitrogen	0.648	0.274

Those 4 components were considered for cluster analysis and the cluster analysis revealed that the FSTPs belonged to two clusters (Figure 4.3). Figure 4.3 below indicates of the two clusters, cluster 2 was the largest, representing 60% of the FSTPs and hence the majority of them. A cross tabulation was run between the principal components and cluster number in order to identify how those characteristics were distributed in the largest cluster of FSTPs (Table 5).

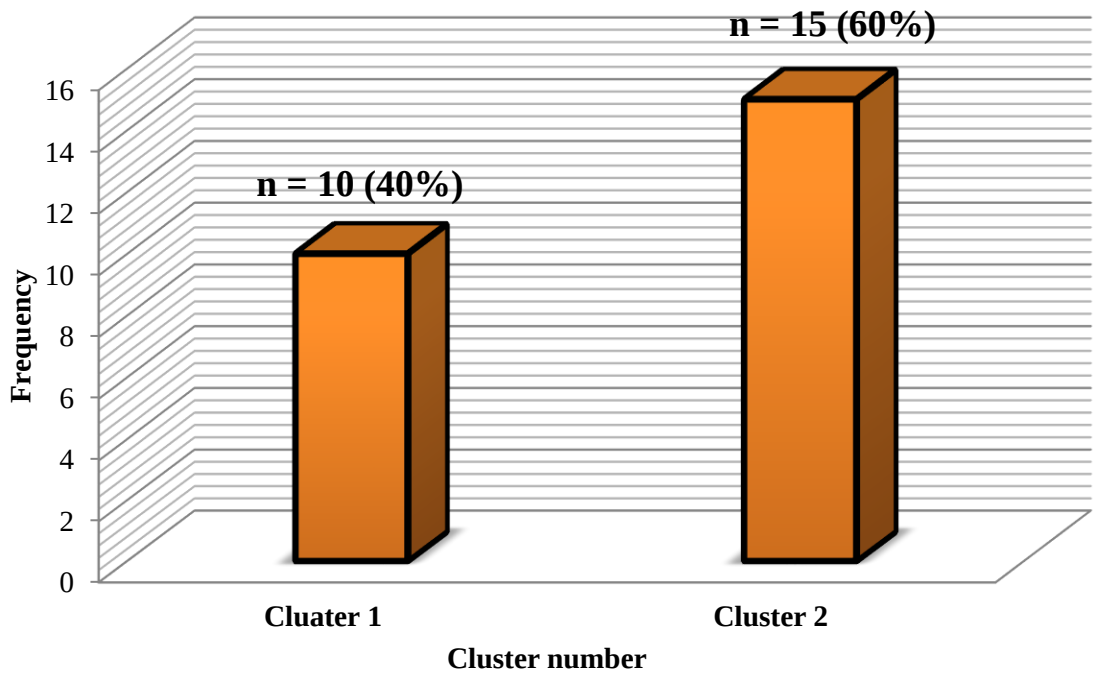

Figure 4.3: Size of clusters

Table 4.6 below shows findings obtained from the cross tabulation between the principal components and cluster numbers, with interest in cluster 2, which is the biggest cluster. It is shown that all the FSTPs in cluster 2 had the PH of their effluent in range, had, the E. coli/coliforms of the effluence in range, and had the electrical conductivity of their effluent in range. However, only two thirds of the FSTPs in that cluster had the total suspended solids in their effluent in range.

Table 4.6: Cross tabulation between performance parameter and cluster number

Parameter	Cluster number		Total
	1	2	
PH-value			
In range (6.0-8.0)	0(0.0%)	**15(100.0%)**	15(60.0%)
Out of range	10(100.0%)	**0(0.0%)**	10(40.0%)
E. coli/coliforms			
In range (<=5000)	0(0.0%)	**15(100.0%)**	15(60.0%)
Out of range	10(100.0%)	**0(0.0%)**	10(40.0%)
Electrical conductivity			
In range (<=1500)	1(10.0%)	**15(100.0%)**	16(64.0%)
Out of range	9(90.0%)	**0(0.0%)**	9(36.0%)
Total suspended solids			
In range (<=100)	5(50.0%)	**10(66.7%)**	15(60.0%)
Out of range	5(50.0%)	**5(33.3%)**	10(40.0%)

The findings from the principal component analysis indicated that of the 8 parameters that were assessed, only PH-value, E. coli/coliforms, electrical conductivity, Total suspended solids were of statistical importance. That implies that at the FSTPs in Iganga, Kayunga, Ntungamo, Kiboga, and Kyotera, there was relatively less treatment of effluent for purposes of maintaining nationally compliant levels of Chemical Oxygen Demand, Biochemical oxygen demand, Total nitrogen and Total dissolved solids. Focus at those plants was more on the other four parameters, which has its own implications, the main of which is that the effluent that particularly plants at Iganga, Ntugamo and Kayunga discharge is more likely to contain more organic and inorganic matter. That follows the fact that it may not be meeting the standards for COD and BOD, that are required to breakdown such materials. It is such effluent that can cause eutrophication and endanger aquatic food chains and ecosystems (Hwang, 2020), coupled with the contamination of freshwater sources, with ripple effects on human health.

On a positive note, three of the four parameters that defined FSTP performance at the majority of the plant were universally found to be in compliance with national standards. Those parameters

are PH, electrical conductivity, and coliforms (Table 4.6). Therefore, at 3 of the 5 FSTPs sampled, effluent discharged was less likely to promote microbial growth, less likely to have high impurity due to its normal electrical conductivity, and less likely to promulgate enteric illness when consumed along with other freshwater. However, it is only at one plant that total dissolved solids in range, which was most likely a result of the inadequate levels of oxygen for inorganic matter (COD) and organic matter (BOD) breakdown. Therefore, the findings on the level of FSTP performance general reveal that only three parameters, one biological (E.Coli) and two physico-chemical (Electrical conductivity and PH) are maintained in range across all the plants. The other five are not, which like the earlier quantified level of performance, also translates to about 38% (3/8) of the eight parameters being compliant.

4.4 Factors affecting the performance of FSTPs

This section includes findings related to the relationship between design, staff, institutional characteristics and FSTP performance. However, the findings in this section are based on unadjusted relationships and are therefore not conclusive to be deemed as factors influencing. The findings in this section serve to indicate variables that were significant so that they are considered for bivariate analysis.

4.4.1 Design characteristics and FSTP performance

The descriptive part of the findings in table 4.7 show that all 25(100.0%) the FSTPs sampled were reported to have capacities and loading rates that were comparable to their engineering design specifications. More than a third 10(40.0%) of the plants had been in operation for a period of between two and five years. Majority 15(60.0%) of the plants sampled were reported to have sludge receiving points designed to allow easy access by the emptying vehicle, and all ponds with

steps that allow for operator access. Almost two thirds 16 (64.0%) of the staff sampled reported that the plants that they were attached to did not have designs to allow for occupationally safe sample taking. All the plant staff sampled 25(100.0%) agreed that the screening chambers at their plants sloped longitudinally towards the outlet, and that the screening chambers were benched to prevent ponding in the corners of the screening chamber. Nearly two thirds of the plant staff sampled 16 (64.0%) reported that anaerobic ponds were the technologies for solids−liquid separation that the plants they were attached to used.

Bivariate statistical analysis revealed that the majority of the variables could not be analysed against FSTP performance since they had “0” integers in their cross tabulations. Therefore, it was infeasible to generate prevalence ratios and hence p values for many of those plants design characteristics. The acronym “N.A” has been used to indicate such variables. The only two which did not have integers of 0 in their cross tabulations were found to be statistically insignificant.

Table 4.7: Unadjusted relationship between fecal sludge treatment plant design characteristics and performance

Variable	n	%	FSTP performance level		cPR (CI at 95%)	P value
			Optimal [n = 10]	Sub optimal [n = 15]		
Capacity of the plant compared to the design						
In range	25	100.0	10(40.0%)	15(60.0%)	**N.A**	**N.A**
Loading rate for the FSTP compared to the design						
In range	25	100.0	10(40.0%)	15(60.0%)	**N.A**	**N.A**
Duration of plant operation						
Less than two years	5	20.0	5(100.0%)	0(0.0%)		
Two – five years	10	40.0	5(50.0%)	5(50.0%)		
Five –ten years	5	20.0	0(0.0%)	5(100.0%)	**N.A**	**N.A**
Ten – fifteen years	5	20.0	0(0.0%)	5(100.0%)		
Sludge receiving point at FSTP designed to allow easy access a vehicle						
Agree	15	60.0	10(66.7%)	5(33.3%)	N.A	**N.A**
Disagree	10	40.0	0(0.0%)	10(100.0%)		
All ponds have steps that allow for operator access						
Agree	15	60.0	5(33.3%)	10(66.7%)	1.111 (0.864 - 1.429)	0.411
Disagree	10	40.0	5(50.0%)	5(50.0%)	**Ref**	
Plant designs provides for occupationally safe access to take samples and assess processes						
Agree	9	36.0	0(0.0%)	9(100.0%)	**N.A**	**N.A**
Disagree	16	64.0	10(62.5%)	6(37.5%)		
Screening chamber at the plant slopes longitudinally towards the outlet						
Agree	25	100.0	10(40.0%)	15(60.0%)	**N.A**	**N.A**
Screening chamber is benched to prevent ponding in the corners of the screening chamber						
Agree	25	100.0	10(40.0%)	15(60.0%)	**N.A**	**N.A**
Technologies for solids−liquid separation						
Sludge drying bed	9	36.0	5(55.6%)	4(44.4%)	0.856 (0.659 - 1.112)	0.245
Anaerobic ponds	16	64.0	5(31.3%)	11(68.8%)	**Ref**	

4.4.2 Fecal sludge treatment plant staff characteristics and FSTP performance

More than two 17(68.0%) of the plant staff sampled had been working at their respective FSTP of station for less than five years, while slightly more than three quarters of them 19(76.0%) had been working in fecal sludge treatment systems for less than five years. More than half 14 (56.0%) of the plant staff had contracts, and reported that they had job security at their plants 13(52.0%). More than a third 10(40.0%) of the staff sampled had a moderate perceived risk of being infected while working at their FSTPs of station. Close to two thirds 16(64.0%) of the staff had been occupying administrative positions for less than five years. Almost half of the plant staff had received specialized training in FSTP management.

Like design characteristics, some of the plant staff characteristics happened to have integers of zero in their cross tabulations and could not therefore be analysed at bivariate analysis. Only one variable happened to have a significant relationship with fecal sludge treatment plant performance. It was the type of contract that the staff had with the employers, for which plants which had permanent staff were nearly thrice as likely to be optimally performing (cPR = 2.800 [1.097 - 7.147], p = 0.031), compared to plants whose administrative staff had contracts.

Table 4.8: Unadjusted relationship between fecal sludge treatment plant staff characteristics and the performance of fecal sludge treatment plants in Uganda

Variable	N	%	FSTP performance level		cPR (CI at 95%)	P value
			Optimal [n = 10]	Sub optimal [n = 15]		
Duration of working at FSTP						
Less than five years	17	68.0	8(47.1%)	9(52.9%)	0.802 (0.547 - 1.176)	0.258
More than five years	8	32.0	2(25.0%)	6(75.0%)	**Ref**	
Duration of working in fecal sludge treatment systems						
Less than five years	19	76.0	10(52.6%)	9(47.4%)	**N.A**	**N.A**
More than five years	6	24.0	0(0.0%)	6(100.0%)		
Kind of employment at plant						
Permanent	5	20.0	4(80.0%)	1(20.0%)	2.800 (1.097 - 7.147)	**0.031**
Temporary	6	24.0	2(33.3%)	4(66.7%)	1.167 (0.287 - 4.742)	0.829
Contract	14	56.0	4(28.6%)	10(71.4%)	**Ref**	
Feel job secure at plant						
Yes	13	52.0	3(23.1%	10(76.9%)	1.249 (0.987 - 1.581)	0.065
No	12	48.0	7(58.3%)	5(41.7%)	**Ref**	
Perceived risk of being infected while working at this plant						
High	8	32.0	3(37.5%)	5(62.5%)	1.034 (0.757 - 1.412)	0.833
Moderate	10	40.0	4(40.0%)	6(60.0%)	1.018 (0.754 - 1.375)	0.907
Low	7	28.0	3(42.9%)	4(57.1%)	**Ref**	
Duration of occupying administrative positions						
Less than five years	16	64.0	7(43.8%)	9(56.3%)	0.938 (0.736 - 1.194)	0.601
More than five years	9	36.0	3(33.3%)	6(66.7%)	**Ref**	
Specialized training in FSTP management						
Yes	12	48.0	7(58.3%)	5(41.7%)	0.801 (0.633 - 1.013)	0.065
No	13	52.0	3(23.1%)	10(76.9%)	**Ref**	
Gender						
Female	7	28.0	4(57.1%)	3(42.9%)	0.788 (0.515 - 1.207)	0.274
Male	18	72.0	6(33.3%)	12(66.7%)		
Current age (in full years)						
20 to 30 years	3	12.0	1(33.3%)	2(66.7%)		
31 to 40 years	14	56.0	7(50.0%)	7(50.0%)	**N.A**	**N.A**
41 to 50 years	7	28.0	2(28.6%)	5(71.4%)		
More than 50 years	1	4.0	0(0.0%)	1(100.0%)		
Marital status						
Married	14	56.0	6(42.9%)	8(57.1%)	1.000 (0.638 - 1.567)	1.000
Single	4	16.0	1(25.0%)	3(75.0%)	1.196 (0.682 - 2.095)	0.533
Cohabiting	7	28.0	3(42.9%)	4(57.1%)	**Ref**	
Religious denomination						
Catholic	12	48.0	5(41.7%)	7(58.3%)		
Anglican	8	32.0	3(37.5%)	5(62.5%)	**N.A**	**N.A**
Muslim	1	4.0	1(100.0%)	0(0.0%)		
SDA	1	4.0	0(0.0%)	1(100.0%)		
Born again	3	12.0	1(33.3%)	2(66.7%)		
Current education level						
Certificate	5	20.0	1(20.0%)	4(80.0%)	1.268 (0.828 - 1.943)	0.275
Diploma	4	16.0	2(50.0%)	2(50.0%)	0.939 (0.544 - 1.623)	0.823
Graduate	16	64.0	7(43.8%)	9(56.3%)	**Ref**	
Position occupied at the plant						
Manager	5	20.0	2(40.0%)	3(60.0%)	1.000 (0.545 - 1.835)	1.000
Deputy manager	5	20.0	2(40.0%)	3(60.0%)	1.000 (0.545 - 1.835)	1.000
Plant supervisor	5	20.0	2(40.0%	3(60.0%)	1.000 (0.545 - 1.835)	1.000
Plant operator	5	20.0	2(40.0%)	3(60.0%)	1.000 (0.545 - 1.835)	1.000
Sanitation Marketer	5	20.0	2(40.0%)	3(60.0%)	**Ref**	

4.4.3 Systemic characteristics and FSTP performance

Four fifths of the FSTPs were reported to have an operation and Maintenance Plan 20(80.0%), with only half of them being followed always 10(50.0%). Tracking of influent concentrations was not done at the majority of the plants 15 (60.0%). Four fifths of the staff reported the operator had not developed framework contracts with local suppliers and workshops in the area to provide items and services against a costed list covering the repair and replacement activities that might be required 20(80.0%). More than three quarters of the staff reported that there were many institutional constraints on releasing the funds required for occasional repair and maintenance tasks at the plant 20(80.0%). However, more than half of the staff reported that in the event that spare parts must be imported, the systems were effective for ordering and paying for those spare parts 15(60.0%).

More than three quarters of the plant staff reported that there existed no efficient system for ensuring timely procurement of materials, parts, and complete replacement of failed or worn-out units at their plants of attachment 20(80.0%). The same proportion reported that people with operational responsibilities at plant had no executive and financial powers required to ensure that essential procurement tasks are carried out promptly 20(80.0%). However, more than three quarters of the staff reported that there were systems in place to ensure the availability of essential spare and replacement parts 20(80.0%). The majority of the staff reported that plant managers are not often trained on issues regarding treatment processes and the logistics of ensuring safe and effective operation of the treatment processes 15(60.0%), and that they were not entitled to pension or sickness benefit rights as plant staff 20(80.0%). All the staff sampled reported that there were no plant septage management services run by private-sector companies through some form of public–private partnership arrangement 25(100.0%).

Four fifths of the plant staff sampled reported that their plants had no laboratory facilities for the measurement of chemical oxygen demand (COD), biochemical oxygen demand (BOD), or total suspended solids (TSS), and fecal coliform concentrations 20(80.0%). All staff sampled reported that their areas had no semi-autonomous body (municipal) with specific responsibility for septage management 25(100.0%). More than three quarters of the staff reported that the persons with official responsibility for operational decisions at the respective plant do not put the decisions in practice 20(80.0%). Almost two thirds of the staff reported that it is the area managers that approve expenditure on operation, maintenance, and repair 16 (64.0%)

Bivariate analysis revealed that most of the systemic characteristics had an integer of 0 in their cross tabulations, and so could not have their prevalence ratios and p values validly generated. The only systemic characteristics that had no 0 integer did not have a statistically significant relationship with the plant performance. It should be noted that these findings do not necessary imply that all systemic characteristics had no significant effect on FSTP performance, but rather that the effect of most of them on FSTP performance could not be established due to sample size limitations that resulted into cross tabulations from which prevalence or even odds ratios could not be computed.

Table 4.9: Unadjusted relationship between systemic characteristics and the performance of fecal sludge treatment plants in Uganda

Variable	n	%	FSTP performance level		cPR (CI at 95%)	P value
			Optimal [n = 10]	Sub optimal [n = 15]		
FSTP has an Operation and Maintenance Plan						
Yes	20	80.0	5(25.0%)	15(75.0%)	N.A	N.A
No	5	20.0	5(100.0%)	0(0.0%)		
Plan followed daily						
Yes	10	50.0	0(0.0%)	10(100.0%)	N.A	N.A
No	10	50.0	5(50.0%)	5(50.0%)	N.A	N.A
Track influent concentrations						
Yes	10	40.0	0(0.0%)	10(100.0%)	N.A	N.A
No	15	60.0	10(66.7%)	5(33.3%)	N.A	N.A
Operator developed framework contracts with local suppliers and workshops in this area to provide items and services against a costed list covering the repair and replacement activities that might be required						
Yes	5	20.0	5(100.0%)	0(0.0%)	N.A	N.A
No	20	80.0	5(25.0%)	15(75.0%)	N.A	N.A
Many institutional constraints on releasing the funds required for occasional repair and maintenance tasks at the plant						
Yes	20	80.0	5(25.0%)	15(75.0%)	N.A	N.A
No	5	20.0	5(100.0%)	0(0.0%)	N.A	N.A
In the event that spare parts must be imported, the systems are effective for ordering and paying for those spare parts						
Yes	15	60.0	5(33.3%)	10(66.7%)	1.111 (0.864 - 1.429)	0.411
No	10	40.0	5(50.0%)	5(50.0%)	**Ref**	
Efficient system for ensuring timely procurement of materials, parts, and complete replacement of failed or worn-out units at the plant						
Agree	5	20.0	0(0.0%)	5(100.0%)	N.A	**N.A**
Disagree	20	80.0	10(50.0%)	10(50.0%)	N.A	**N.A**
People with operational responsibilities at plant have the executive and financial powers required to ensure that essential procurement tasks are carried out promptly						
Yes	5	20.0	0(0.0%)	5(100.0%)	N.A	**N.A**
No	20	80.0	10(50.0%)	10(50.0%)	N.A	**N.A**
Plant managers often trained on issues regarding treatment processes and the logistics of ensuring safe and effective operation of the treatment processes						
Yes	10	40.0	0(0.0%)	10(100.0%)	N.A	**N.A**
No	15	60.0	10(66.7%)	5(33.3%)	N.A	**N.A**
Entitled to pension or sickness benefit rights as plant staff						
Yes	5	20.0	0(0.0%)	5(100.0%)	N.A	**N.A**
No	20	80.0	10(50.0%)	10(50.0%)	N.A	N.A

Are this plants septage management services run by private-sector companies through some form of public–private partnership arrangement						
No	25	100.0	10(40.0%)	15(60.0%)	N.A	N.A
Plant has laboratory facilities for the measurement of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and fecal coliform concentrations						
Yes	5	20.0	0(0.0%)	5(100.0%)	N.A	N.A
No	20	80.0	10(50.0%)	10(50.0%)	N.A	N.A
Area has a semi-autonomous body (municipal) with specific responsibility for septage management						
No	25	100.0	10(40.0%)	15(60.0%)	N.A	N.A
Person with official responsibility for operational decisions at this plant makes these decisions in practice						
Yes	5	20.0	0(0.0%)	5(100.0%)	N.A	N.A
No	20	80.0	10(50.0%)	10(50.0%)	N.A	N.A
Who approves expenditure on operation, maintenance, and repair						
Area Manager	16	64.0	6(37.5%)	10(62.5%)	N.A	N.A
Umbrella	3	12.0	1(33.3%)	2(66.7%)	N.A	N.A
Secretariat	4	16.0	3(75.0%)	1(25.0%)	N.A	N.A
NSWC	2	8.0	0(0.0%)	2(100.0%)	N.A	N.A

4.5 Multivariate analysis

The findings in table 4.10 below indicate that the staff characteristic that was found to be significant at bivariate analysis still remained statistically significant at multivariate analysis, and are therefore considered to be a factor influencing the fecal sludge treatment plant performance. It is shown that optimal fecal sludge treatment performance was twice as likely at plants where the administrative staffs were permanent employees (aPR = 2.757 [1.515 - 6.114], p =0.028) compared to plants where the administrative staff had contracts.

Table 4.10: Factors influencing the performance of fecal sludge treatment plants in Uganda

Variable	cPR (CI at 95%)	P value		aPR (CI at 95%)	P value
Kind of employment at plant					
Permanent	2.800 (1.097 - 7.147)	**0.031**		2.757 (1.515 - 6.114)	0.028
Temporary	1.167 (0.287 - 4.742)	0.829		1.090 (0.712 - 3.376)	0.952
Contract	**Ref**			**Ref**	

According to the systems theory, the performance of any system depends on its components, which in the context of a FSTP includes staff. This study agrees with the systems theory, having found a significant relationship between one of the staff characteristics and FSTP performance. The number of significant staff variables perhaps could have been more had the sample been larger and cross tabulations able to yield prevalence ratios. Nonetheless, the findings on the whole agrees with findings from other studies that have found staff characteristics to have significant effects on organisational performance (Mardiati, 2019; Kalpana and Dharmaraj, 2018; Ugwu and Ugwu, 2017; Banjo and Ogunkoya, 2014; Yaser, 2015; Singh and Mohan, 2020; Oyewole and Popoola, 2015; Luthans, 2016; Ratnasari et al., 2020; Martin and Gert, 2017; Raziq and Maulabakhsh, 2015; Dziuba et al., 2020; Tayler, 2018). The study revealed that that optimal fecal sludge treatment performance was twice as likely at plants where the administrative staffs were permanent employees (aPR = 2.757 [1.515 - 6.114], p =0.028) compared to plants where the administrative staff had contracts. The positive effect of this finding on FSTP performance arises from the merits that come with being a permanent employee at a given work place, especially when one is occupying an administrative position. They tend to be more engaged at work, more satisfied (Ofosuhene & Sammo, 2020; Godfrey, 2018; Kot-Radojewsk and Timenko, 2018; Keim et al., 2014) and usually more empowered to make and implement administrative decisions which in an

FSTP context may include designing, and enforcing operation and maintenance plans at the plant in their jurisdiction. That alone can be protective of FSTP performance since following the fact that in engineering, even the simplest technology will breakdown or cease to function if basic maintenance and operation tasks it requires are not carried out routinely (Tayler et al., 2018). That is particularly true in the context of fecal sludge treatment plants, which are designed with multiple equipment and moving parts that function mechanically, with some requiring polymer pre-treatment to function. Fecal sludge at times contains materials that can clog screens and damage other moving parts, which may hence require part replacement or the replacement of an entire unit if severely damaged, short of which the whole plant can become dysfunctional. Such short notice repair and/or maintenance can only be executed if a given plant has an operation and maintenance plan that had a forecast for O&M labour costs, replacement part costs, and other maintenance costs. With those in place, sustained peak performance of each component of the plant becomes certain, hence leading to effective and more efficient sludge treatment. With the empowerment and job satisfaction that comes with being a permanent employee also come the ability to evade certain bureaucratic processes that may get incident when it comes to the procurement of the parts and materials required in plant maintenance and repair. Part of that bureaucracy arises from having to wait for authorisation from a third of fourth party in order to effect procurement and payment of parts, even when there are administrators at a given plant. That was found to be true in the current study where some respondents, all of whom were occupying administrative positions at their respective plants of attachment, reported that they had not executive powers to carry out crucial procurement plants. In such cases, any emergency breakdown of a given plant part can take days, weeks or even months to repair or replace, at the expense of having out of range parameters

in the effluent. On the other hand, with staff having executive powers to execute procurement activities at any time, emergency O&M can be carried out.

Further still, permanent employees tend to be more likely to be recipients of continuous professional development (CPD) (Lyons, 2020). In the context of FSTPs, the CPD would rotate around issues regarding treatment processes and the logistics of ensuring safe and effective operation of the treatment processes. Whereas plant managers themselves usually do not have to get practically involved in plant O&M, their being trained enables them make timely decisions and delegation of duty to other staff that execute that practically execute O&M. It is with the training that apt O&M can be executed, and hence optimum fecal sludge performance achieved. The importance of training of staff in achieving organisational performance has also been found to be true in many management studies (Dandage et al., 2018; Ramazani & Jergeas 2015; Khan, 2019; Abdulrazak, 2020; Maeng et al., 2020; Kapur, 2018; de Grip et al., 2019; Karim et al., 2019; Gadi and Audu, 2019; Afroz, 2018; Huang & Jao, 2016; Mtulo, 2014; Ramya, 2016; Dostie, 2017; Afsana et al., 2016; Athar & Shah, 2015; Ugbombhe et al., 2016; Taweesan et al., 2017; Chmielewska et al., 2020).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusion, and recommendations of the study, based on the key findings that were obtained by the study. The chapter also includes assertions on the recommendations of further study, and the study strengths and limitations.

5.2 Conclusion

Objective 1

Fecal sludge treatment plants in the country are generally designed with septage/ sludge reception points; they have coarse screening screens for grit and solid separation from sludge, all of which were manually raked. However, the majority of the plants have no sedimentation tanks, yet and neither do they have anaerobic ponds, yet they all have aerobic ponds of all which were facultative in design. All plants have pathogen removal ponds, but without processes for further drying/pathogen reduction.

Objective 2

Fecal sludge treatment plants in Uganda sub optimally perform. The level of performance of the fecal sludge treatment plants in Uganda is 40%; only 4 in 10 of them discharge effluent with more than 80% of its bio and physicochemical characteristics compliant with national standards in terms of quantity.

Objective 3

Whereas it is possible that design, staff and institutional characteristic could be associated with FSTP, only staff characteristics happened to be important. It is the kind of employment terms of the staff at the plant that is associated with FSTP performance.

5.3 Recommendations

5.3.1 Recommendations for policy

The importance of having a well-designed fecal sludge treatment plant for purposes of achieving high performance cannot be overstated. Whereas the plants in Uganda are generally well designed in accordance with global standards, there are some designs features that will need to be augmented in order to augment plant performance. One of those will be to set up appropriate solid-liquid separation technologies at each of the plants, options of which may include sedimentation tanks, anaerobic ponds, sludge drying beds or Imhof tanks. Having any of those technologies set up will service to increase the efficiency of aerobic ponds that are available at all plants, in pathogen reduction. The NWSC could also considering modifying the designs of the small and medium sized FSPTs to include maturation ponds, as a way of furthering drying/pathogen reduction, so as to ensure low microbial loads in the resultant effluent. In cases where the plants have little land mass to set up maturation ponds, then alternatives that do not require much land could be considered. They include; chlorination, ultraviolet radiation, and ozone treatment.

The augmentation of fecal sludge treatment plant performance in Uganda will have to focus on the improvement of sludge treatment processes at Ntugamo, Iganga and Kayunga treatment plants, with much focus on reducing COD, BOD, nitrogen and total suspended solids content. Coagulation and flocculation processes at all plants, and at the aforementioned three in particular could be strengthened further by introducing and/or augmenting the use of chemicals like ferric chloride, aluminium, ferrous sulphate, and lime and polyaluminium chloride.

The ministry of water and environment should consider making it a policy for all contracted engineers to mandatorily ensure that all FSTP designs are made in much more cognizance and

appreciation of the need for staff safety. That should be to the extent that plant parts like anaerobic reactors, tanks, ponds, filters, beds should be designed in a way that they allow for occupationally safe sample taking. All parts should be able to prevent even the slightest contact between a sample taker and fecal matter, while concurrently preventing falls and any other occupational injuries.

It should be made a policy that each fecal sludge treatment plant whether functional currently or will be made functional in future, must have a comprehensive operational and maintenance plan. Ministerial policies could be devised to ensure that those plans are universally adhered to by all plant administrators/managers, so as to achieve a level of consistent use. It is with an O&M plan that efficient systems for ensuring timely procurement of materials for repair and complete replacement will be developed. Whereas having O&M plans will be to the advantage of plant performance, their effectiveness will only be realised when plant managers are accorded all necessary autonomy to make financial decisions without having to go through bureaucratic processes that included waiting upon third parties to authorise procurement processes. It is only with the removal of bureaucratic process that timely repairs and maintenance will be made.

The ministry of water and environment should consider providing routine professional development and/or training aligned towards FSTP management to all functional plant managers in the country. Private firms could even be contracted for that purpose, at least biannually to as to ensure that managers carry out their oversight, supervisory and managerial roles more effectively.

Whereas it is laudable that the country has a central laboratory for testing effluent samples, run by the national water and sewerage concentration, there is great need to have laboratories or laboratory facilities set up at each functional treatment plant. That will allow for timely tracking of influent concentrations in real-time, and subsequent informed decision making as informed by

the lab results. At the very least, portable filed laboratory facilities could be procured and deployed at each plant for that purpose.

To make operator developed framework contracts with local suppliers and workshops effective, a more stringent bidding process should be made, in which capacity to provide all items, supplies, and parts required may be assessed before awarding contracts.

5.3.2 Recommendations for further studies

This study targeted 5 fecal sludge treatment plants, out of the 18 that the country has. Although the 5 represented half of the currently functional ones, other studies could be conducted to assess the performance of a larger number of plants, since most of the currently non-functional ones will be repaired and operationalized soon. The conduction of a study covering more fecal sludge treatment plants will allow for a larger sample size to be targeted and hence a higher chance of obtaining inferential findings.

Secondly the study was justifiably biased on the assessment of performance based on biological and physicochemical parameters that are of relatively more significant public health performance. Other studies could be conducted to assess fecal sludge treatment plant performance, with the inclusion of other mainly physicochemical parameters.

5.4 Strengths and limitations

This study had a number of strengths, one of which was that it included half of the currently functional fecal sludge treatment plants in the country, with the implication that the findings obtained are highly externally valid and reliable. Fecal sludge treatment plant performance was assessed following globally and nationally recognised laboratory procedures, along with

compliance to sample collection and pre-treatment guidelines and as well as a globally recognised threshold as a cut-off for plant performance. When it came to the assessment of design, staff, and systemic characteristics, the study relied on responses from plant staff that had been occupied in administrative positions at each plant, for at least a year. That certainly increased the reliability and validity of the findings.

The main limitation that this study had was the inevitably small sample size of staff at the plants, which could not allow for the full conduction of relationship analysis in order to reveal all factors that influence FSTP performance. The second limitation was the reliance on only self-reports, when collecting data for the exposure variables of the study. Therefore, there may have been some exaggeration by some staff especially in the context of design and systemic characteristic assessment, since no physical verifications were made. However, any such cases of exaggeration may have certainly been very minimal since a lot of probing was done, in addition to assuring the staff of confidentiality and anonymity.

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APPENDIX A: CONSENT FORM

Title: Performance evaluation of fecal sludge treatment plants in Uganda

Purpose of the study: The purpose of this study is to assess the performance of fecal sludge treatment plants in Uganda

Why you have been sampled: You have been selected as one of the potential participants in this study because you happen to be a staff at one of the sample fecal sludge treatment plants in Uganda, occupying an administrative position

What the study will involve: When you choose to be one of the participants in this study, you will only be required to participate in interview that will be structured in nature and hence not likely to fatigue you. In this interview, you will be asked a question and given corresponding response options from which you will be required to choose what your response will be. The interview is expected to last not more than 40 minutes.

Risks and benefits of your participation: There are virtually no risks associated with your participation in this study, given that you will only participate in an interview, without any other practical invasive procedures. There are more benefits than risks following your participation.

the findings of this study may be of policy importance at the national level and perhaps globally as well. That is because the study has not only highlighted the performance of FSTPs in Uganda as part of its evaluation, but also gone ahead to identify the determinants of that performance. Such information may therefore be used by the ministry of water and environment and its partners to not only get aware of which effluent components need to be regulated further, but also about which interventions they can use in order to augment plant performance.

As part of its performance assessment, the study has also revealed which of the fecal sludge treatment plants has optimal performance and which of them has sub optimal performance. Such information is expected to enable administrators/caretakers at the identified plants per category, to either uphold their current operational standards or augment them, depending on the level of performance each of them has been found to have.

The study has also identified the design related determinants of FSTP performance, and as well as the staff and systemic ones. It is expected that engineers may therefore find the study to be of significance to them as they will get to know which design characteristics are protective of optimal performance, and those that are not. The respective administrators of the plants will also find the study to be of significance to them given that staff related characteristics have also been identified, that is, both those that are protective of optimal FSTP performance and those who are not. Findings related to the systemic determinants of FSTP performance may also be of benefit to the line ministry and organisations like the national water and Sewerage Corporation given that, they (findings) have highlighted systemic gaps that both institutions may get to close with the evidence brought forth.

Confidentiality, privacy, anonymity: You can be certain that all the information you will provide during the interview will not be shared with anyone else, not even your immediate supervisors, or local leaders in this area. However, when the findings are being disseminated, the responses you will provide will not have visible links to your identity; it will be concealed. Your names will not be capture on neither the consent form nor the questionnaire you will respond to, and all the interviews will be conducted in privacy.

Voluntary participation: Please know that participation in this study is totally voluntary, you will not be forced to be a participant and neither will be given any incentives for your participation if

you choose to participate. You are free to decide not to participate, which choice will have no repercussions whatsoever.

Contacts: In case of any queries or inquiries, please do not hesitate to contact the principal investigator on Tel: 0782 853 020

CONSENT FORM

Name of Researcher: Kyomugisha Trinah Salome

Please initial all boxes

1. I confirm that I have read and understand the information sheet dated …… for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that relevant sections of my medical notes and data collected during the study, may be looked at by the interviewers, and some other person, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records, although anonymously ☐

4. I agree to take part in the above study. ☐

_____ _____ _____

Name of Participant Date Signature

APPENDIX B: QUESTIONNAIRE

Section A: Socio demographic characteristics

Question number	Question	Response options	Choice of code made
1	Gender	1. Female 2. Male	
2	What is your current age (in full years)	……. …….	
3	What is your current marital status	1. Married 2. Single 3. Cohabiting 4. Other…….	
4	To what religious denomination do you subscribe?	1. Catholic 2. Anglican 3. Muslim 4. SDA 5. Born again 6. Others……	
5	What is your current education level?	1. Certificate 2. Diploma 3. Graduate 4. Other……	
6	Fecal sludge treatment plant attached to?	1. Iganga 2. Kayunga 3. Kyotera 4. Kiboga 5. Ntungamo	
7	What position do you occupy at the plant?	……. …….	

Section B: Plant designs

Question number	Question	Response options	Choice of code made
8	Does the plant have a septage/ sludge reception point?	1. Yes 2. No	
9	Does the plant have coarse screening screens for grit and solid separation from sludge?	1. Yes 2. No	
10	If yes, what type of screens does the plant use?	1. Manually raked screen 2. Mechanically raked 3. Both manual and mechanically raked screens	
11	Does the plant have a sedimentation tank?	1. Yes 2. No	
12	If yes, what type of sedimentation tank does the plant have?	1. Gravity thickener 2. Settling-thickening tanks 3. Both gravity and settling thickening tanks	
15	Does the plant have anaerobic ponds?	1. Yes 2. No	
16	If yes, what category of anaerobic ponds does the plant have	1. Anaerobic ponds 2. Anaerobic baffled reactor 3. UASB (for co-treatment) 4. Other……	
17	Does the plant have aerobic ponds?	1. Yes	

		2. No	
18	If yes, what type of aerobic ponds does the plant have	1. Facultative ponds 2. Aerated ponds 3. Trickling filters 4. Activated sludge (for co-treatment) 5. Other……..	
19	Does the plant have dewatering beds?	1. Yes 2. No	
20	If yes, what type of beds does the plant have	1. Unplanted drying beds 2. Planted drying beds	
21	Does the plant have pathogen removal ponds?	1. Yes 2. No	
22	If yes, what type of pathogen removal ponds does the plant have?	1. Maturation ponds 2. Constructed wetland 3. Other	
23	Does the plant include a parts/processes for further drying/ pathogen reduction	1. Yes 2. No	
24	If yes, what type of drying processes does the plant use	1. Storage 2. Solar drying 3. Thermal processes 4. Proprietary processes	

Section C: FSTP performance assessment

Indicator	Effluent test value	National discharge standard	Test result
PH-value		6.0-8.0	1. In range 2. Out of range
E. coli/coliforms		5000	1. In range 2. Out of range
Electrical conductivity		1500	1. In range 2. Out of range
Chemical Oxygen Demand		100	1. In range 2. Out of range
Biochemical oxygen demands		50	1. In range 2. Out of range
Total suspended solids		100	1. In range 2. Out of range
Total dissolved solids		1200	1. In range 2. Out of range
Total nitrogen		10	1. In range 2. Out of range

Category of FSTP

Optimal performance (> 80% of the parameters in range) ☐

Sub optimal performance (< 80% of the parameters in range) ☐

PART C: FSTP Design characteristics

Question number	Question	Response options	Choice of code made
25	What is the Capacity of the plant compared to the design?	1. In range 2. Out of range	
26	What is the loading rate for the FSTP compared to the design	3. In range 4. Out of range	
27	How long has the plant been in operation?	1. Less than two years 2. two – five years 3. five –ten years 4. ten – fifteen years 5. over fifteen years	
28	The sludge receiving point at this FSTP was designed to allow easy access by the vehicle	6. Agree 7. Disagree	
29	All the ponds have steps that allow for operator access	1. Agree 2. Disagree	
30	The plant designs provides for occupationally safe access to take samples and assess processes	1. Agree 2. Disagree	

31	The screening chamber at the plant slopes longitudinally towards the outlet	1. Agree 2. Disagree	
32	The screening chamber is benched to prevent ponding in the corners of the screening chamber	1. Agree 2. Disagree	
33	Which of the following technologies for solids−liquid separation does the plant have?	1. Sludge drying beds 2. Anaerobic ponds 3. Imhoff tanks 4. Settling-thickening tanks (STTs) 5. Mechanical processes,	

Section D: Individual characteristics

Question number	**Question**	**Response options**	**Choice of code made**
34	For how long have you worked at this fecal sludge treatment plant?	1. Less than five years 2. More than five years	

35	For how long have you worked in fecal sludge treatment systems?	1. Less than five years 2. More than five years	
36	What kind of employment are you under, at this plant?	1. Permanent 2. Temporary 3. Contract	
37	Do you feel that your job at this plant is secure?	1. Yes **2.** No	
38	How do you perceive your risk of being infected while working at this plant?	1. High 2. Moderate 3. Low	
39	For how long have you occupied administrative positions as an employee?	1. Less than five years 2. More than five years	
40	Do you have any specialized training in fecal sludge treatment plant management?	1. Yes 2. No	

Section E: Systemic characteristics

Question number	Question	Response options	Choice of code made
41	Does the FSTP have an Operation and Maintenance Plan?	1. Yes 2. No	
42	If yes, Is it followed daily?	1. Agree 2. Disagree	
43	Do you track Influent concentrations	1. Agree 2. Disagree	
44	Has the Operator developed framework contracts with local suppliers and workshops in this area to provide items and services against a costed list covering the repair and replacement activities that might be required	1. Agree 2. Disagree	
45	There are many institutional constraints on releasing the funds required for occasional repair and maintenance tasks at the plant?	1. Agree 2. Disagree	
46	In the event that spare parts must be imported, the systems are effective for ordering and paying for those spare parts	1. Yes 2. No	

47	There is an efficient system for ensuring timely procurement of materials, parts, and complete replacement of failed or worn-out units at the plant	1. Yes 2. No	
48	Do the people with operational responsibilities at this plant have the executive and financial powers required to ensure that essential procurement tasks are carried out promptly?	1. Yes 2. No	
49	Do systems exist to ensure the availability of essential spare and replacement parts?	1. Yes 2. No	
50	Are this plants septage management services run by private-sector companies through some form of public–private partnership arrangement?	1. Yes 2. No	
51	Are the managers of this plant often trained on issues regarding treatment processes and the logistics of ensuring safe and effective operation of the treatment processes	1. Yes 2. No	
52	As an employee at this plant, are you entitled to pension or sickness benefit rights?	1. Yes 2. No	
53	Does the plant have laboratory facilities for the measurement of chemical oxygen demand (COD),	1. Yes 2. No	

	biochemical oxygen demand (BOD), total suspended solids (TSS), and fecal coliform concentrations		
54	If not, are the plant managers aware of external resources that are available to them and have clear procedures for laboratory obtaining services from external organizations?	…….. …….. ……..	
55	Does this area have a semi-autonomous body (municipal) with specific responsibility for septage management?		
56	Is the person who has official responsibility for operational decisions at this plant the one that makes these decisions in practice?	1. Yes 2. No	
57	Who has the power to approve expenditure on operation, maintenance, and repair?	…… ……	

END

APPENDIX C: LETTERS

KYAMBOGO UNIVERSITY

Department of Civil and Building Engineering

P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA
Website: www.kyu.ac.ug, Email: civil@kyu.ac.ug
TEL: +256-41-4287340, FAX: +256-41-4289056/4222643

March 10, 2020

Manager,
International Resource Center,
National Water & Sewerage Cooperation – Bugolobi,
Kampala, Uganda.

Dear Eng./Dr./Sir/Madam,

RE: INTRODUCTION LETTER FOR KYOMUGISHA SALOME TRINAH AND REQUEST FOR PERMISSION TO CONDUCT RESEARCH ON SELECTED FEACAL SLUDGE TREATMENT PLANTS

Ms. Kyomugisha Salome Trinah is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. She is conducting a research study on "Performance Evaluation of Faecal Sludge Treatment Plants in Uganda". The researcher is being supervised and co-supervised by Eng. Dr. Anne Nakagiri and Dr. Charles Onyutha, respectively.

In her research, Kyomugisha Salome Trinah will conduct research on selected Faecal Sludge Treatment Plants in Uganda. She will require support on a number of occasions for the various specific objectives of her study (see next page). Both primary and secondary data are required. Importantly, the student will need support regarding experimental sites and setup, laboratory testing of samples, etc. This letter is therefore to introduce the researcher and seek your support where necessary. The necessary support rendered to ensure timely completion of this research, will be duly acknowledged in the dissemination of the results.

I shall be grateful for any assistance rendered to Ms. Kyomugisha Salome Trinah to allow her conduct her research study timely.

Yours Sincerely,

THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY

Dr. Lawrence Muhwezi
Head of Department of Civil and Building Engineering

Cc. Dean, School of Graduate Studies, Kyambogo University
Dr. Charles Onyutha - Department of Civil and Building Engineering, Kyambogo University
Eng. Dr. Anne Nakagiri - Department of Civil and Building Engineering, Kyambogo University

APPENDIX D: LABORATORY TEST FINDINGS

Parameters	Units	Kiboga Effluent (20/11/2020)	Kayunga Effluent (21/11/2020)	Kyotera Effluent (22/11/2020)	Ntungamo	Iganga	National Standards for Effluents Discharge
Bact: Fecal Coliforms	CFU/100mL	0	10	1303	111	626000	1500
BOD	mg/L	15.44	2.42	5.42	320.1	182	50
COD	mg/L	26	1179	33	487	295	100
Electrical Conductivity (EC)	µs/cm	204	1446	315	10100	1639	1500
PH (Physical-Chemical)	……	7.34	7.59	6.52	8.7	7.94	6.0-8.0
Total Dissolved Solids (TDS)	mg/L	130.56	925.44	201.6		1821	1200
Total Suspended Solids (TSS)	mg/L	47	79	96	300	332	100
Total Nitrogen (TN)	mg/L	0	340	4	246.7	238	10

APPENDIX E: LABORATORY CERFICATES

NATIONAL WATER & SEWERAGE CORPORATION

CENTRAL LABORATORY- Plot M11, Old Portbell Rd, Bugolobi

P.O BOX 7053 KAMPALA, Email: external.services@nwsc.co.ug

CERTIFICATE OF ANALYSIS

Client: Trinah Kyomugisha
Address: Luzira
Date Sample Received: 09/12/2020
Sample Description: Kayunga sewage Plant, Raw Sewage 21/11/2020
Sampled By: Client's Staff
Sample Number : 50/4356/2020/C/B

Document No: NWSC/WQ/QF/21.2A
Invoice No:131/INV/2020/976_QUO

Parameters	Units	Test Results	National Standards for Waste Water	Test Method
Alkalinity: Total	mg/L	1000	800	APHA - 2320B
Ammonia-N	mg/L	19.07	10	Hach 8038
B.O.D	mg/L	605.72	50	APHA-5210-B
Bact: Faecal coliforms	CFU/100mL	100	5000	Colilert – 18
Chloride	mg/L	200	500	Hach 8206
COD	mg/L	41900	100	APHA - 5220-2
Electrical Conductivity (EC)	uS/cm	1480	1500	APHA-2510
Ortho-Phosphate: Reactive	mg/L	70.45	5	APHA-4500-P- E
pH (Physical-Chemical)	--	6.95	6.0-8.0	APHA- 4500-H+ B
Sulphate	mg/L	184.92	500	Hach 8051
Total Dissolved Solids (TDS)	mg/L	947.2	1200	APHA-2540C
Total Nitrogen (TN)	mg/L	560	10	Hach 10071
Total Phosphorous (TP)	mg/L	85.602	10	APHA-4500-P- E
Total Suspended Solids (TSS)	mg/L	388	100	APHA-2540D
Turbidity	NTU	214	300	HACH 8195

Remarks:

Biology :The bacteriological characteristics of the sample tested complied with the National Standards for Effluent Discharge.

Chemistry :The waste water sample tested showed uncomplying physiochemical characteristics with exception of Chloride, EC, pH, Sulphate, TDS and Turbidity as compared to the National Standards for Effluents Discharge.

AUTHORISED BY: Manager Central Labaratory Services.....
APPROVED BY: Senior Manager - Water Quality Management Department .....

NATIONAL WATER & SEWERAGE CORPORATION
ES
P.o. Box 7053 Kampala, Uganda
Tel:+256633231511/715
Email:external.services@nwsc.co.ug
REF. NO.: 2020/976
SIGN:.....
DATE: 15/12/2020
EXTERNAL SERVICE

**** The NWSC certificate of analysis by no means continues to permit to any person or company undertaking to conduct [illegible] that reflects results of the sample as received at the labaratory premises.*

NATIONAL WATER & SEWERAGE CORPORATION

CENTRAL LABORATORY- Plot M11, Old Portbell Rd, Bugolobi

P.O BOX 7053 KAMPALA, Email: external.services@nwsc.co.ug

CERTIFICATE OF ANALYSIS

Client: Trinah Kyomugisha
Address: Luzira
Date Sample Received: 09/12/2020
Sample Description: Kiboga Plant Raw sewage, 26/11/2020
Sampled By: Client's Staff
Sample Number : 50/4354/2020/C/B

Document No: NWSC/WQ/QF/21.2A
Invoice No:131/INV/2020/976_QUO

Parameters	Units	Test Results	National Standards for Waste Water	Test Method
Alkalinity: Total	mg/l	2800	800	APHA - 2320B
Ammonia-N	mg/L	768.28	10	Hach 8038
B.O.D	mg/L	583.94	50	APHA-5210-B
Bact: Faecal coliforms	CFU/100mL	14000000	5000	Colilert – 18
Chloride	mg/L	200	500	Hach 8206
COD	mg/L	37100	100	APHA - 5220-2
Electrical Conductivity (EC)	uS/cm	5260	1500	APHA-2510
Ortho-Phosphate: Reactive	mg/L	268.93	5	APHA-4500-P- E
pH (Physical-Chemical)	–	7.80	6.0-8.0	APHA- 4500-H+ B
Sulphate	mg/L	1129.2	500	Hach 8051
Total Dissolved Solids (TDS)	mg/L	3366.4	1200	APHA-2540C
Total Nitrogen (TN)	mg/l	4320	10	Hach 10071
Total Phosphorous (TP)	mg/L	807.502	10	APHA-4500-P- E
Total Suspended Solids (TSS)	mg/L	4865	100	APHA-2540D
Turbidity	NTU	2650	300	HACH 8195

Remarks:

Biology :The bacteriological characteristics of the sample tested did not comply with the National Standards for Effluent Discharge.

Chemistry :The waste water sample tested showed uncomplying physiochemical characteristics with exception of Chloride, EC and pH as compared to the National Standards for Effluents Discharge.

AUTHORISED BY: Manager Central Laboratory Services .....

APPROVED BY: Senior Manager - Water Quality Management Department .....

**** The NWSC certificate of analysis by no means continues to permit to any person or company undertaking ... the sample as received at the laboratory premises.*

NATIONAL WATER & SEWERAGE CORPORATION
P.O. Box 7053 Kampala (Uganda)
Tel: +256 (0)312/312 111/115
Email: external.services@nwsc.co.ug
REF. NO. .....
SIGN: .....
DATE: .....
EXTERNAL SERVICES

NATIONAL WATER & SEWERAGE CORPORATION

CENTRAL LABORATORY- Plot M11, Old Portbell Rd, Bugolobi

P.O BOX 7053 KAMPALA, Email: external.services@nwsc.co.ug

CERTIFICATE OF ANALYSIS

Client: Trinah Kyomugisha
Address: Luzira
Date Sample Received: 09/12/2020
Sample Description: Kayunga Sewage Plant Effluent, 21/11/2020
Sampled By: Client's Staff
Sample Number : 50/4357/2020/C/B

Document No: NWSC/WQ/QF/21.2A
Invoice No:131/INV/2020/976_QUO

Parameters	Units	Test Results	National Standards for Waste Water	Test Method
Alkalinity: Total	mg/L	504	800	APHA - 2320B
Ammonia-N	mg/L	122.61	10	Hach 8038
B.O.D	mg/L	2.42	50	APHA-5210-B
Bact: Faecal coliforms	CFU/100mL	10	5000	Colilert – 18
Chloride	mg/L	3	500	Hach 8206
COD	mg/L	1179	100	APHA - 5220-2
Electrical Conductivity (EC)	uS/cm	1446	1500	APHA-2510
Ortho-Phosphate: Reactive	mg/L	3.12	5	APHA-4500-P- E
pH (Physical-Chemical)	--	7.59	6.0-8.0	APHA- 4500-H+ B
Sulphate	mg/L	21.31	500	Hach 8051
Total Dissolved Solids (TDS)	mg/L	925.44	1200	APHA-2540C
Total Nitrogen (TN)	mg/L	340	10	Hach 10071
Total Phosphorous (TP)	mg/L	7.502	10	APHA-4500-P- E
Total Suspended Solids (TSS)	mg/L	79	100	APHA-2540D
Turbidity	NTU	33.4	300	HACH 8195

Remarks:

Biology :The bacteriological characteristics of the sample tested complied with the National Standards for Effluent Discharge.

Chemistry :The waste water sample tested showed complying physicochemical characteristics with exception of Ammonia-N, COD and TN as compared to the National Standards for Effluents Discharge.

AUTHORISED BY: Manager Central Labaratory Services.....
APPROVED BY: Senior Manager - Water Quality Management Department .....

NATIONAL WATER & SEWERAGE CORPORATION
ES
P.O. Box 7053 Kampala, Uganda
Tel:+256(0)3126111/7715
Email:external.services@nwsc.co.ug
REF. NO.: 2020/976
SIGN:.....
DATE: 16/12/2020
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CENTRAL LABORATORY- Plot M11, Old Portbell Rd, Bugolobi

P.O BOX 7053 KAMPALA, Email: external.services@nwsc.co.ug

CERTIFICATE OF ANALYSIS

Client: Trinah Kyomugisha
Address: Luzira
Date Sample Received: 09/12/2020
Sample Description: Kyotera Plant Effluent, 22/11/2020
Sampled By: Client's Staff
Sample Number : 50/4359/2020/C/B

Document No: NWSC/WQ/QF/21.2A
Invoice No:131/INV/2020/976_QUO

Parameters	Units	Test Results	National Standards for Waste Water	Test Method
Alkalinity: Total	mg/L	58	800	APHA - 2320B
Ammonia-N	mg/L	52.58	10	Hach 8038
B.O.D	mg/L	5.42	50	APHA-5210-B
Bact: Fecal coliforms	CFU/100mL	300	5000	Colilert – 18
Chloride	mg/L	5	500	Hach 8206
COD	mg/L	33	100	APHA - 5220-2
Electrical Conductivity (EC)	uS/cm	315	1500	APHA-2510
Ortho-Phosphate: Reactive	mg/L	2.55	5	APHA-4500-P- E
pH (Physical-Chemical)	–	6.52	6.0-8.0	APHA- 4500-H+ B
Sulphate	mg/L	776.09	500	Hach 8051
Total Dissolved Solids (TDS)	mg/L	201.6	1200	APHA-2540C
Total Nitrogen (TN)	mg/L	4	10	Hach 10071
Total Phosphorous (TP)	mg/L	4.752	10	APHA-4500-P- E
Total Suspended Solids (TSS)	mg/L	96	100	APHA-2540D
Turbidity	NTU	268	300	HACH 8195

Remarks:

Biology: The bacteriological characteristics of the sample tested complied with the National Standards for Effluent Discharge.

Chemistry: The waste water sample tested showed complying physiochemical characteristics with exception of Ammonia-N and Sulphate as compared to the National Standards for Effluents Discharge.

AUTHORISED BY: Manager Central Labaratory Services .....

APPROVED BY: Senior Manager - Water Quality Management Department .....

NATIONAL WATER & SEWERAGE CORPORATION
ES
P.O. Box 7053 Kampala, Uganda
Tel: +256(0)3015111/715
Email: external.services@nwsc.co.ug
REF.NO: 2020/931
SIGN: .....
DATE: .....
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CENTRAL LABORATORY- Plot M11, Old Portbell Rd, Bugolobi

P.O BOX 7053 KAMPALA, Email: external.services@nwsc.co.ug

CERTIFICATE OF ANALYSIS

Client: Trinah Kyomugisha
Address: Luzira
Date Sample Received: 09/12/2020
Sample Description: Kiboga Plant Effluent, 21/11/2020
Sampled By: Client's Staff
Sample Number : 50/4355/2020/C/B

Document No: NWSC/WQ/QF/21.2A
Invoice No:131/INV/2020/976_QUO

Parameters	Units	Test Results	National Standards for Waste Water	Test Method
Alkalinity: Total	mg/L	72	800	APHA - 2320B
Ammonia-N	mg/l	1.97	10	Hach 8038
B.O.D	mg/L	15.44	50	APHA-5210-B
Bact: Faecal coliforms	CFU/100mL	0	5000	Colilert – 18
Chloride	mg/L	3	500	Hach 8206
COD	mg/l	26	100	APHA - 5220-2
Electrical Conductivity (EC)	uS/cm	204	1500	APHA-2510
Ortho-Phosphate: Reactive	mg/L	0.615	5	APHA-4500-P- E
pH (Physical-Chemical)	–	7.34	6.0-8.0	APHA- 4500-H+ B
Sulphate	mg/L	92.778	500	Hach 8051
Total Dissolved Solids (TDS)	mg/L	130.56	1200	APHA-2540C
Total Nitrogen (TN)	mg/L	5	10	Hach 10071
Total Phosphorous (TP)	mg/l	2.177	10	APHA-4500-P- E
Total Suspended Solids (TSS)	mg/L	47	100	APHA-2540D
Turbidity	NTU	113	300	HACH 8195

Remarks:

Biology :The bacteriological characteristics of the sample tested complied with the National Standards for Effluent Discharge.

Chemistry :The waste water sample tested showed complying physiochemical characteristics compared to the National Standards for Effluents Discharge.

AUTHORISED BY: Manager Central Laboratory Services.....

APPROVED BY: Senior Manager - Water Quality Management Department .....

NATIONAL WATER & SEWERAGE CORPORATION
P.O. Box 7053 Kampala, Uganda
Tel:+256(31)3315100-1/0414-315100
Email: external.services@nwsc.co.ug
REF. NO.: 2020/116
SIGN:
DATE: 16-12-2020
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APPENDIX F: INTRODUCTORY LETTER FROM MWE

TEL. GENERAL: +256 41 4505942
TELEPHONE: +256 41 4505945
+256 41 4505950
+256 41 4220203
+256 41 4321316
+256 41 4221198
FAX: +256 414505941
Email: mwe@mwe.go.ug
ps@mwe.go.ug
website: www.mwe.go.ug

THE REPUBLIC OF UGANDA

Ministry of WATER AND Environment

P. O. Box 20026

In any correspondence on this subject please quote Ref. No **MWE/03/2020**

16th March 2020

The Manager

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RE: INTRODUCTION OF KYOMUGISHA SALOME TRINAH TO CONDUCT RESEARCH ON SELECTED FEACAL SLUDGE TREATMENT PLANTS

Ms. Kyomugisha Salome Trinah is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. She is conducting a research study on "Performance Evaluation of Faecal Sludge Treatment Plants in Uganda". The researcher is being supervised and co-supervised by Eng. Dr. Anne Nakagiri and Dr. Charles Onyutha respectively.

Ms. Kyomugisha Salome Trinah will conduct research on selected Faecal Sludge Treatment Plants in Uganda. She will require support on a number of occasions to achieve the specific objectives of her study. Both primary and secondary data are required. Importantly, the student will need support regarding experimental sites and setup, laboratory testing of samples, etc. Ministry of Water and Environment finds her research relevant to the sanitation sub-sector, this letter is therefore to introduce the researcher and seek your support where necessary. The necessary support rendered to ensure timely completion of this research, will be duly acknowledged in the dissemination of the results.

Any assistance rendered to Ms. Kyomugisha Salome Trinah to allow her conduct her research study timely shall be highly appreciated.

Eng. Felix Twinomucunguzi
For: PERMANENT SECRETARY