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Sustainability assessment of existing septic systems in residential buildings: a case study of Mwanza city, Tanzania

Salvatory, Siliacus

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**SUSTAINABILITY ASSESSMENT OF EXISTING SEPTIC SYSTEMS IN
RESIDENTIAL BUILDINGS: A CASE STUDY OF MWANZA CITY,
TANZANIA**

Siliacus Salvatory

**A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of
Master's in Hydrology and Water Resource Engineering of the Nelson Mandela African
Institution of Science and Technology**

Arusha, Tanzania

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ABSTRACT

Septic system (SS) is the oldest anaerobic wastewater treatment system still widely employed today in suburban and urban areas. The sustainability of SS in developing countries, including Tanzania, is restricted by several constraints (e.g., poor installation and hydraulic overloading (technical issues), poor resource recovery practices (economic issue), maintenance and awareness (social issues), etc.). Efforts have been done to improve SSs' sustainability, but the improvement is hindered by a lack of information on how to guarantee SSs sustainability mainly, at the household level. Therefore, this study was aimed to assess the SSs' sustainability in residential buildings in Mwanza city, Tanzania emphasizing economic, environmental, technical, and social aspects. The sustainability assessment (SA) was accomplished by study area and sustainability indicators (SIs) selection methods, diverse data collection methods, and the Fuzzy-based Indices Approach (FIA) (data analysis method). The results from SA show that 18 out of 50 indicators were selected as appropriate indicators for SA of 200 households having SSs in the Nyegezi area. Also, the entire systems in the city had an index of 0.42 and fall in a danger state. It was concluded that the SIs assessed were relevant to the studied system. They demonstrate the importance of matching any set of indicators to the characteristics of the specific sanitation system being examined. Indeed, corrective measures must be suggested for immediate livelihood improvement and sustainability considerations. The study provided a tool and framework for assessing the sustainability of SSs in Tanzania using a set of most 18 relevant SIs.

Keywords: Septic system; Sustainability indicators; Sustainability index; Fuzzy-based indices approach.

DECLARATION

I, Siliacus Salvatory, do hereby declare to the Senate of The Nelson Mandela African Institutions of Science and Technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

Siliacus Salvatory

Name and Signature of Candidate

Date

The above declaration is confirmed by:

Prof. Revocatus L. Machunda

Name and Signature of Supervisor 1

Date

Dr. Tulinave B. Mwamila



Name and Signature of Supervisor 2

Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Senate of the Nelson Mandela African Institution of Science and Technology the dissertation entitled: “*Sustainability Assessment of Septic Systems in Residential Buildings, in Mwanza City, Tanzania*”, in Partial Fulfilment of the Requirements for the Degree of Master’s in Hydrology and Water Resource Engineering of the Nelson Mandela African Institution of Science and Technology.

Prof. Revocatus L. Machunda

Name and Signature of Supervisor 1

Date

Dr. Tulinave B. Mwamila



Name and Signature of Supervisor 2

Date

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DEDICATION

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LIST OF ABBREVIATIONS AND SYMBOLS

APHA	America Public Health Association
ATU	Aerobic Treatment Unit
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CW	Constructed Wetland
FC	Faecal Coliform
FIA	Fuzzy-based Indices Approach
GSI	General Sustainability Index
LVWB	Lake Victoria Water Basin
MWAUWASA	Mwanza Urban Water Supply and Sanitation Authority
MWZQL	Mwanza Water Quality Laboratory
NM-AIST	The Nelson Mandela African Institution of Science and Technology
NPS	Non-Point Source
O & M	Operation and Maintenance
OSDS	Onsite Sewage Disposal System
OSS	Onsite Sanitation System
OWT	Onsite Wastewater Treatment
PE	Person Equivalent
SA	Sustainability Assessment
SD	Sustainable Development
SI	Sustainability Indicator
SS	Septic System
ST	Septic Tank
STE	Septic Tank Effluent
TC	Total Coliform
TN	Total Nitrate
TP	Total Phosphorus
TSS	Total Suspended Solid
URT	United Republic of Tanzania
US	United States
USEPA	United State Environmental Protection Agency
WHO	World Health Organization

WIS	Wastewater Infiltration System
WSAS	Wastewater Soil Absorption System
WWTP	Wastewater Treatment Plant

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Globally, over 70 diverse onsite sanitation systems (OSSs) may be available and suitable for certain site conditions (Ho, 2005). In African countries such as Tanzania, over 60% coverage of sanitation is OSS (Banerjee & Morella, 2011; Nansubuga *et al.*, 2016). The main OSSs are septic tanks (STs) or septic systems (SSs), pit latrines, and ventilated improved pit (VIP) latrines (Nakagiri *et al.*, 2015). These latrines and seepage pits are not viable alternatives with increasing population density and the resultant groundwater pollution except the SSs. The SSs refers to a small self-sufficient, below-ground OSS used to collect, store, and treat domestic wastewater at or near the source of generation in areas not connected to sewers (Adegoke & Stenstrom, 2019). The SSs include two distinct system designs: The STs and soakaway systems. The STs have the following innovative and cheapest option in the sanitation ranking, have been considered the most common in urban and peri-urban areas without sewers and new housing structures (Kihila & Balengayabo, 2020; United Republic of Tanzania [URT]., 2020). Soak away systems are suitable for removing fine residue as well as related contaminants. In general, SSs are easy to design and formal ones that require no chemical or energy inputs, commonly low-cost installation and maintenance, etc. Then, SSs are still the appropriate choice of OSSs, specifically for individual residential buildings, in developing or developed countries (Kazora & Mourad, 2018; Schaidler *et al.*, 2017).

The OSSs in Tanzania need specific sustainability indicator (SIs) to monitor their performance or sustainability. However, in earlier research, several sets of SIs for wastewater treatment system assessments have been suggested (Balkema *et al.*, 2002; Bracken *et al.*, 2005; Capodaglio *et al.*, 2017; Cossio *et al.*, 2020; Muga & Mihelcic, 2008; Murray *et al.*, 2009; Palme *et al.*, 2005). The SIs derived from the intensive literature review help to identify the problems and become the reference in assessing the sustainability of sanitation conditions in the city. By these references, it is expected that the decision-makers can make the decision based on a comprehensive perspective, not a fragmented view of sustainability. Also, these studies have attempted to define sustainability from various dimensions, scopes, contexts, or broad ranges. A sustainable sanitation system means the system that protects and promotes human health, protects the environment from degradation or depletion of the resource base, is technically and institutionally appropriate, economically viable and socially acceptable (Flores, 2011; Katukiza *et al.*, 2010; Kvarnström *et al.*, 2004). Such the

sustainable sanitation characteristics contained within the above meaning lead to the sustainability dimensions (i.e., social, technical, environmental, and economic sustainability).

The evaluation of sustainability of existing OSSs which are underperforming or having several restrictions in many countries is vital in achieving the 6th Sustainable Development Goal by 2030 and The City of Future Concept (Capodaglio *et al.*, 2017; De-Feo & Ferrara, 2017). Numerous sustainability assessment (SA) issues or challenges connected to wastewater issues have been identified in these literature reviews (Kazora & Mourad, 2018; Vidal *et al.*, 2019). Firstly, no set of indicators is available which are applicable or appropriate to all cases. From numerous studies, indicators' sets are very contextual and only usefully for a particular study (Murray *et al.*, 2009). Secondly, the researchers are not aware of the local context importance when evaluating the sustainability of a particular wastewater answer in their understanding of the sustainability of a certain kind of system. (Hoffmann *et al.*, 2000). Thirdly, currently, the sustainability of OSSs in developing countries, such as Tanzania, remains restricted. Such restrictions are technical (wrongly dimensioned, poor installation, lack of maintenance, hydraulic overloading), environmental (water resource pollution or failure to come across the standard disposal demands), social (diseases to humans due to improper hygiene practices), economic (cost of construction and operation, non-recovery or reuse of end products) restrictions (Capodaglio *et al.*, 2017; De-Feo & Ferrara, 2017). Hence, this study aimed at evaluating the sustainability of existing SS with a Fuzzy-based Index Approach (FIA) in the residential buildings of Mwanza city, Tanzania, using sustainability indicators (SIs), indicating environmental, economic, social, and technical dimensions. It helps in identifying limitations and opportunities for future SS improvement. This study came in the nick of time considering the popularity of SS in Tanzania's residents, public and private institutions and backing up on the limited-service offered by the conventional centralized wastewater system.

1.2 Statement of the Problem

In Mwanza city, Tanzania about, 95% coverage of sanitation is OSSs with SSs being the furthestmost common, among others (VIP latrines, traditional pit latrines (TPL), etc.) in residential buildings. But SSs are mostly related to the various issues, classified into environmental, economic, social, and technical (operating difficulties) that render their sustainability. The maximum efforts have been made in various studies in other countries to improve the sustainability of OSS but still: (a) No clear answers on what situations the SSs promote sustainability dimensions? Where to start making improvements? How to prioritize activities during the decision-making process? and (b) No comprehensive analysis on how the OSS would relate and

the effects of such relations with the added situation (e.g., the OSS's economic, environment, social and functional issues). Consequently, the need to assess the sustainability of SS using four sustainability dimensions to support the decision making process is of vital importance.

1.3 Rationale of the Study

In Tanzania, few publications exist on sanitation systems SA using indicators (Seleman, 2012). However, most studies did not discuss the existing or commonly used OSSs sustainability in urban (STs/SSs, pit latrines, VIP for flush toilets, etc.). In addition, currently, the literature shows that Tanzania does not have a suitable tool to evaluate the sustainability of OSSs at the household level. Thus, comprehensive SA of SS in Mwanza city using SIs was done by identifying the suitable SIs, developing and applying FIA, and identifying the corrective measures. The SA of SS at household level using chosen indicators could enable the policymakers, users, and other stakeholders in the sanitation value chain to monitor their interventions towards sustainability.

1.4 Research Objectives

1.4.1 General Objective

This study general objective was to assess sustainability potential of existing residential septic systems (SSs) in Mwanza City, Tanzania, during their operational phase.

1.4.2 Specific Objectives

- (i) To identify the most appropriate sustainability indicators under the social, environmental, technical, and economic dimensions (SIs) for assessing the sustainability of existing septic systems (SSs) in the study area.
- (ii) To assess the sustainability of the existing SSs using the fuzzy-based index approach (FIA).
- (iii) To recommend actions and measures to improve the SIs in the city and other similar urban and suburban towns in Tanzania.

1.5 Research Questions

- (i) What are the most appropriate sustainability indicators categorized in social, environmental, technical, and economic dimensions for the SSs SA?
- (ii) How to obtain the sustainability index using the FIA of the existing SSs in the selected study area?

- (iii) What measures are to be undertaken concerning SS condition in the selected study area?

1.6 Significance of the Study

Improving the sustainability of Tanzania's sanitation system needs a good understanding of its sustainability status. This study has contributed to the present understanding of SA methods, the development and application of the '*conceptual framework*' and the '*FIA*' for assessing sustainability potential of SS. It was based on economic, social, environmental, and technical sustainability in residential buildings (at household level). Nonetheless, some critical problems are not fully covered, so more exploration may be needed to improve and endorse the FIA:

(i) Regarding Aggregating the Total Score of the System

Depending on the conceptual framework, there are four (4) levels with three aggregation steps and either 2 or 3 variables of the indicators only. However, these are straightforwardly identified with a compromise between level of detail and ease of the method used. Therefore, it might be essential to "explore the effect of the number of aggregation stages and variables on the final results".

(ii) Regarding FIA's Applicability for other Case Study

No numerous SA or decision supporting methods are accessible in developing countries to deal with particular sanitation issues and the issues encountered by decision-makers. The key obstacle to the decision process is the absence of software, data, and references. It is thus crucial to establish an approach that may be practical in the above conditions and is still appropriate and precise to enhance the decision-making process. Then, FIA has been based on experiential indications acquired after a sustainability-potential assessment of SS in the residential buildings in Mwanza city, Tanzania. The general process of the FIA is legitimately transferrable, demonstrating a wide relevance of the methodology. Developments in "data collection" must improve the index's quality as well as precision. In the case of other case studies and OSS, site evaluation and constant checking would further improve index accuracy. Even if FIA is prepared using methodical broad view; it has never been verified for its further application or other case studies. To utilize the approach in different OSSs and domains or other case studies in developing countries may develop a method and approach applicability. It will discover appropriate destinations for more economical OSSs and correctly deal with parameters/indicators/variables that were not addressed at a household level as greenhouse gases (GHG) emission quantity and loading of wastewater to water bodies from septic tanks.

Also the study is expected to be beneficial in the following ways:

- (i) Help policymakers in urban areas to target merely SIs/dimensions, which fail to achieve a sustainable outlook using the sustainability indices.
- (ii) Help the SSs design, location, and management improvement in the field of study and other major Tanzanian cities.
- (iii) Open up fertile areas for research in the fuzzy-based indices concept, develop a base of facts, and support the SS in the urban development of developing countries for the management of wastewater.

1.7 Delineation of the Study

The present study aimed at evaluating the sustainability of existing septic system with a Fuzzy-based Index Approach (FIA) in the residential buildings of Mwanza city, Tanzania, using sustainability indicators (SIs), indicating environmental, economic, social, and technical dimensions. It helps in identifying limitations and opportunities for future SS improvement. This study came in the nick of time considering the popularity of SS in Tanzania's residents, public and private institutions and backing up on the limited-service offered by the conventional centralized wastewater system.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sustainability and Sustainability Assessment Concepts

2.1.1 Sustainability Definitions

Every sustainability issue began from a clear understanding of an operative description of the sustainability concept (Waas *et al.*, 2014). Sustainability and sustainable development (SD) concepts are implemented in an exchangeable manner though their definition is under debate among individuals (Seghezzi, 2009). Indeed, the widely accepted meaning of the term sustainability as defined by the World Commission on Environment and Development (1987) is development that meets current demands without jeopardizing future generations' ability to satisfy their own needs. Many people have challenged this concept for its ambiguity and subjectivity. For example, defining the term "need" is problematic because what some people consider "needs" may be supposed as something else, such as "desires" by others (Waas *et al.*, 2014). Because of this ambiguity, what one person considers sustainable may be reflected marginally or non-sustainable by another. Meanwhile, Seghezzi (2009) points out other flaws in the World Commission on Environment and Development's definition of sustainability, such as being primarily anthropocentric, exaggerating the role of the economy, and ignoring space, time, and human factors. Sustainability in this study is defined as the desired state where human requirements are met without natural resource depression. If possible, it has to be accomplished at a global level, but in practice, this high level is difficult to supervise. The SD is the process towards sustainability and needs to be addressed at lower levels: Individual, company, national or regional. The term sustainable has its roots in the Latin word *subtenir* means to hold up or support from below. Then, according to Malisie (2008), a sustainable system is defined as a system that does not threaten the natural resources and has the lowest cost concerning the physical, socio-cultural and economic environments. A challenge here is to decide at what level a system is sustainable. Although it is not necessary to define the level reasonably emphasize sustainable or unsustainable patterns (Waas *et al.*, 2014).

2.1.2 Sustainability Dimensions

Sustainability is characterized by dimensions that are termed as aspects, criteria, domains, or pillars. According to Molinos-Senante *et al.* (2014) the significant sustainability dimension to characterize sustainability are economy, society and environment recognized as the triple bottom

line. However, Cossio *et al.* (2020) proposed that the good governance or institutional, health and technical dimensions to be brought within the “framework for Sustainability Assessment of Wastewater Treatment Systems (SAWTS) that is viewed as a universal framework. Also, an alternative sustainability triangle formed by Place, Permanence and Persons (the new three Ps) was proposed to understand the sustainability concept (Iribarnegaray *et al.*, 2012; Seghezzi, 2009). Meanwhile, “sustainability is a multi-dimensional concept” whereby economic, technical, social and environmental dimensions should be measured as well as combined (Mara *et al.*, 2007). As a result, an inclusive SA technique is needed for evaluating sustainability concerning multi-dimensional sustainability standpoints.

(i) Social Dimension

The social dimension refers to people's social, cultural and spiritual requirements, which must equally be met while maintaining the stability of human relationships and institutions. Concerning the system's activities and organizational connections with the community, this dimension is based on human relations and the necessity to interact and organize their society. The population's knowledge, behavior, health and combined Social Dimension (SD) management are all societal issues of SD. If a system's presence adds to society's welfare and the impacted populace has some influence above its activities, it may work in a socially sustainable manner. Amenities and events which, are not equitably administered will not be sustainable due to a lack of support from the community. Potential consequences must also be clear as well as connected to stakeholders. Decisions should be prepared by the involvement of the public and taken seriously.

(ii) Environmental Dimension

The environmental dimension talks about the environment's ability to support human ways of existence that are preliminary based on ethical principles. It assesses the system's performance and environmental impacts in terms of compliance with legislation and requirements for treated wastewater, intermittent overflow discharges, and disposal of hazardous and non-hazardous solid wastes to the environment. The natural environment's sustainability must be preserved to promote SD or sustainability through providing resources and absorbing emissions. As a result, environmental resources must be protected and used efficiently.

(iii) Economic Dimension

Economic sustainability is a critical component of long-term growth or SD. It enables long-term reforms as well as economic development with minimal environmental effects. In other words,

increased eco-efficiency is required to decouple economic growth and environmental effect. Economic policy and market mechanisms should be used to help achieve long-term development or SD. In terms of the value of tools like legislation and public awareness, the economy is a highly powerful weapon for long-term development or SD. It offers enough motivations for adopting SD decisions. Economic sustainability emphasizes that all expenses associated with any action should be measured when making financial and business decisions. Such comprises long-term environmental and social costs, in particular. The economic dimension is critical to classify or assess the project's long-term economic drivers.

(iv) Technical Dimension

This technical dimension offers tools for comparing the technical elements of several systems and a decision-making tool for determining which system can give the best long-term service for the public while being straightforward to implement with little complexity and technical challenges. The use of low-cost systems that are acceptable to local financial and geographical conditions and within the technical capacity of the benefiting community is related to sustainable system selection. The essential system must be easily accessible, and there should be documented examples of the suitable application of the system for identical treatment goals with similar regional and environmental characteristics. It should be able to comply with all applicable legislation and treatment standards. Systems may fail to prevent to technical issues for instance, mechanical failures; nevertheless, these incidents must be avoided as much as possible, and the systems must be able to recover without undue expense or effort.

2.1.3 Sustainability Assessment

The measurement and assessment concepts operate together within sustainability concept nevertheless separately means an unlike procedure. Measurement procedure, variables related to SD or sustainability are recognized and data are collected and investigated with precisely suitable methods. Assessment procedure here the performance is compared against a standard for a criterion (or for several criteria). The assessments are applied activities within estimation and conclusion creating with anticipated chipping in of interested party. It should include characteristics like all-inclusive, harmonious, habit-forming, usefulness, hassle-free, promising and humane. Moreover, it should be expressive to the entire group of people who participated (Poveda & Lipsett, 2011). According to Vidal *et al.* (2019), sustainability is a highly complex measure in the domain, especially in sanitation systems. Then, to understand the situation and direct measures for its development, sustainability must be assessed based on sustainability

dimensions (Capodaglio *et al.*, 2017; Palme *et al.*, 2005). Decision-makers and other stakeholders will use sustainability assessment (SA) to determine what steps they should and should not take to enhance sustainability (Devuyst *et al.*, 2001).

(i) Sustainability Assessment Definition

The Sustainability Assessment (SA) is a pretty novel field and is an initial development step, whereby the first exercise has been changed to match the novel conditions and settings (Alan *et al.*, 2012). There are several SA patterns and descriptions. For example, SA is any process that directs decision-making towards sustainability. The SAs depending on Poveda and Lipsett (2011), are practical undertakings in evaluation and decision making with planned stakeholder involvement. While according to Waas *et al.* (2014), based on three challenges facing the decision-making process within SD perspective defined SA as follows: Any process that purposes to:

- Contribute to a better understanding of the meaning of sustainability and its contextual interpretation (interpretation challenge).
- Integrate sustainability issues into decision-making by identifying and assessing (past and/or future) sustainability impacts (information-structuring challenge).
- Promote the growth of sustainability objectives (influence challenge).

(ii) Sustainability Assessment Method

Based on the different SA purposes, numerous methodological features should be well-thought-out. For example, all SA ought to: (a) be directed by describing the SD principles; (b) be done for supporting the decision-making; (c) be centered on a theoretical outline as well as its SIs; (d) be made communicative effectively (perfect semantic, reasonable and unbiased, picturing tools and graphs, cause proper information availability); (e) be modified as well as combined in recognized setting; (f) adopt an iterative assessment process; (g) improve and keep up suitable capacity; and (h) raise nonstop learning as well as development (Waas *et al.*, 2014).

The SA by SIs is recommended in many studies as the sustainability idea's operating means. Previous research in assessing the sustainability of sanitation systems followed diverse approaches (based on single indicators versus multidisciplinary indicators) (Diaz-Elsayed *et al.*, 2017; Molinos-Senante *et al.*, 2014). However, according to Ness *et al.* (2007), several approaches, frameworks, and tools have been established over the years to assess sustainable practices. They are categorized into three (3) different categories, as presented in Table 1.

Table 1: Sustainability assessment categories

Categories	Description	Examples of SA methods
Indicator based	Use indicators to describe a specific aspect of a system or sustainability dimension. These indicators are either integrated into an index or used separately.	Environmental Performance Index, SEAMLESS-IF, Principal Component Analysis (PCA), Analytical Hierarchical Principle (AHP).
Product-related	Frequently applied in industry for the production and/or consumption of goods and services assessment.	Fuzzy logic approach Life cycle Assessment, Life cycle Costing, Product Energy Analysis
Integrated	Commonly used in project/system or policy decision-making actions. They look at the understanding of a system as a whole through alternative scenarios and conceptual modelling. They combine a variety of methodologies and tools.	Multi-Criteria Analysis, Vulnerability Analysis, Risk Analysis, Cost-Benefit Analysis, System Analysis

At present, the number of methods used within SA is a discussion and alteration topic because it is taken as a reasonably new field or subject. Also, existing methods for SA have the following shortcomings: Defining the weights and ranking due to inborn preferences; handling comprehensiveness, uncertainty and fuzziness; and representation of results (Lozano-Oyola *et al.*, 2012). According to Ness *et al.* (2007), the methodology selection to be applied in SA mostly depends on the scope of the assessment itself. The proposed study aims at supporting policymakers so, the assessment ease and simplicity are the principal conditions for the selection of the SA method. In this study, the indicator-based category will be used depending on the objective to be achieved by integrating the indicators into an index using the FIA (Section 2.1.6).

2.1.4 Sustainability Indicators

The appropriate sustainability indicators (SIs) that cover sustainability dimensions are important and strong instruments for any sustainability and SA decision-making (Dahl, 2012; Pintér *et al.*, 2012; Waas *et al.*, 2014). Indicators are key tools aimed at making the sustainability idea assessable by measuring tendencies within the public. Also, to attempt the main statement that are we moving towards sustainability or not? In other words, the indicators are intended for answering the query: How might I know objectively, whether things are getting better or getting worse? An essential notion in support of the SIs usage is simplicity and importance.

(i) Sustainability indicator Definition

Every day in a lifetime, endlessly the indicators were applied to know, translate and improve the globe, frequently devoid of truly understanding them (e.g., levels, traffic signals) as well as acting

on them (Bell & Morse, 2013). For that reason, we are all likely to immediately know what an indicator is. More clarification is obtained from a theoretical perspective because meanings and terms differ a lot, for example, a variable, a parameter, a measure, a value, a meter, measurements, a measuring device, an index, something, a piece of data, representation, a proxy that is often puzzling (Bell & Morse, 2013; Moldan & Dahl, 2007).

According to Waas *et al.* (2014), an indicator may be well-defined from two points of view. The current agreement describes an indicator from a system point of view as an operational representation of the attribute (quality, characteristics, property, aspects, etc.) of a system (Bell & Morse, 2013; Gallopin, 1997). A system means an interconnected collection of elements that are organized coherently in a way which accomplishes something (Meadows, 2008). It may approximately be all things still requires three features: interconnectivity; components; and aim/intention (Meadows, 2008). From a technical point of view, an indicator is a variable or an aggregation of some variables associated with a reference value which gives meaning to the values taken by the variables (Bell & Morse, 2012; Pintér *et al.*, 2012; Singh *et al.*, 2009). For example, an objective, a target, a norm, a standard or a benchmark may be taken as a reference value (Gallopin, 1997). The existence or non-existence of a reference value separates an indicator from a variable. A reference value requirement and the discrepancy between a variable and an indicator are the subjects of confusion often. Due to all facts in general, according to Waas *et al.* (2014), an indicator is the operational representation of an attribute (quality, characteristic, or property) of a given system, by a quantitative or qualitative variable (for example, numbers, graphics, colors, symbols, or function of variables) including its value, related to a reference value.

(ii) Sustainability indicators Development and Selection Methods

The SI development methodologies have been highly informed within several fields (e.g., financial development, community change, life, quality climate, natural resources, safe societies and sustainability (Hezri & Dovers, 2006). In general, it is possible to distinguish two comprehensive methods aimed at SI development: Top-down/expert-driven approaches are considered to be quantitative indicators established by specialists having defined methods and bottom-up/stakeholder-driven approaches are taken to be qualitative indicators established by the locally interested party and without evidently defined methods (Bell & Morse, 2013; Reed *et al.*, 2006). Naturally, every approach ought to have its advantages and disadvantages. The method integration is probable and highly commended in many studies (Dahl, 2012; Gallopin, 1997; Hak *et al.*, 2012; Milicevic, 2008).

One of the most important stages of SA is the collection of a set of specific indicators. During the selection of the appropriate indicators, several approaches were used. Several types of research utilize participatory method, as well as hierarchical methods to pick appropriate measures/indicators (Cossio *et al.*, 2020). Many studies, for example, suggested defining SIs by multiple stages in their selection/collection process: Reviewing several kinds of literature, enlisting an initial set of relevant SIs, then expert results assessment. Stakeholders can also define metrics/indicators by filling out questionnaires (e.g., Delphi technique). Alternatively, Cossio *et al.* (2020) proposed present indicators adjustment concerning local setting measured.

Selected indicators must be having some fulfillment of several criteria. From various studies key various quality criteria of SI or selection criteria were identified in the following classification: Robustness, democratic, longevity and relevance in more detail (Waas *et al.*, 2014). These criteria confirm if selected indicators may be suitable and relevant regarding the decision makers' info about a particular system and fulfillments of other SI purposes intended. Such is because there are no universal indicators set that are relevant in all circumstances.

(iii) Sustainability indicators Interpretation and Presentation

Several variables/indicators/dimensions were joined to a single value known as an index to simplify the information. Many indicators categorized together represent huge issues/themes or dimensions. Indicators may be problematic in interpretation if they are shown independently. Hence, the best extreme demonstration of SI is detected by forming a single value, measurable sustainability index, or the quest for the unicorn. It is significant in decision-making and competitive perspective as it makes simpler, difficult into a single value which willingly permits judgment (Bell & Morse, 2012). Babicky (2013) revealed the need for indices, but simultaneously debates to put on several viewpoints on parameters selection and weighting while thinking on the procedures to advance their value.

The aggregation level of the first choice differs depending on the persons' group. For example, the policy-makers or community, property owners (householders), and scientists are further mattered to the uppermost, moderate, and lowermost aggregation level respectively. The relationships among data, indicators and indices are represented in the information pyramid or iceberg (Fig. 1) (Waas *et al.*, 2014).

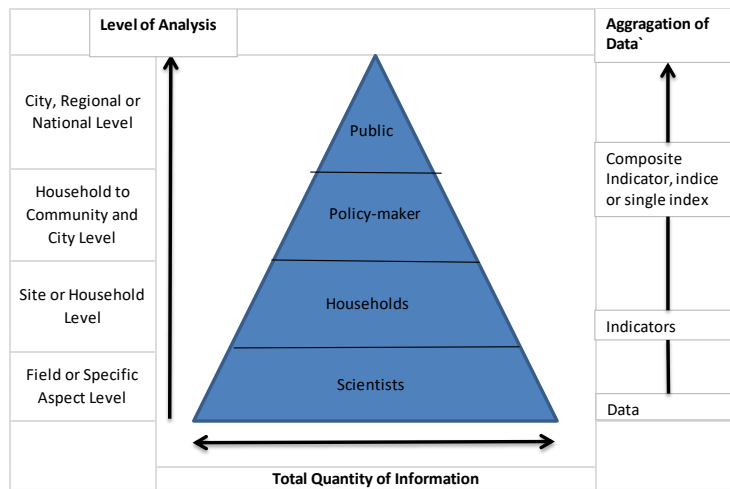


Figure 1: Interactions among information, stakeholders as well as analysis level (Iribarnegaray *et al.*, 2012)

Sustainability indicators and indices can be in detail presented within diverse diagrams comprising radar, spider, or amoeba diagram. The diagram allows end-users or stakeholders to see an indicator's weaknesses and strengths wherever an interference is required (Iribarnegaray *et al.*, 2012).

2.2 Assessment of Sustainability of Septic System in Mwanza City, Tanzania

2.2.1 Features, Designing and Operating of Septic Systems

Septic system (SS) refers to a small self-sufficient, below-ground OSS used to collect, store, or treat domestic wastewater (individual homes) at or near the generation source, in areas not connected to sewers (Adegoke & Stenstrom, 2019). Sometimes, in various studies, the SSs are termed as onsite sewage disposal systems (OSDS), onsite wastewater treatment systems (OWTS) or wastewater infiltration systems (WIS) (Swann, 2008). Also, SS is termed as a wastewater soil absorption system (WSAS) (Siegrist *et al.*, 2000), which can often be quite confusing. The SSs were classified into three key groups: Conventional, alternative, and innovative (Siegrist *et al.*, 2000); or traditional, contemporary and emerging (Swann, 2008). In developing countries, the conventional SS is widely used as efforts to enhance the ST are more cost-effective and need amplified operating input (Oladoja, 2017). Such enhanced types have a tendency to distance themselves from a low-cost, relative maintenance-free element concept.

The SS is the oldest anaerobic treatment system still in use worldwide (UNWWAP, 2017). In the context of Tanzania, about 90% of the entire inhabitants are served by OSSs (i.e., pit latrines, ST, and soak-away) (Brandes, 2015). Some 60-70% of the inhabitants in urban areas primarily depend on septic tank-soak away and pit latrines sanitation systems. In major cities, sewer coverage is

below 15% for instance Arusha, Dar es Salaam and Mwanza except for Moshi with coverage of 40%. However, according to URT (2020) the flush toilet-ST- soak away pit combination (septic system) is the most common type of OSS in suburban and urban zones in developing countries such as Tanzania. The SS includes over 80% of the sanitation system in the field of study (Mwanza City). Such is specifically in new housing structures. The SSs are easy to plot and the traditional/conventional ones that do not need any chemical or energy input, then installing and maintaining them are at a low cost. The SS is usually used in the middle and high-income urban settings of developing countries for single homes or homes clusters. The entire SS may be operated alone or with lift pump incorporation when topographical concerns are needed. The SSs can offer limited ages of harmless, efficient, and economical provision once suitably constructed and sustained. Also, SS functions considerably when the soil is soaked and not vulnerable to fluke or water blockages, and if sludge is rid of at sufficient intervals to prevent the filling of large space in the septic tank. In general, SSs offers good sustainable natural resource use and adequate ecological or wellbeing protection, if it properly is situated and obeys earlier design manual recommendations (Capps *et al.*, 2020).

A typical onsite SS consists of two fundamental units: ST and a subsurface soil absorption system (Vidal *et al.*, 2019). Other parts are the distribution system and user interface (a home's indoor plumbing) (Fig. 2). The study is restricted toward these three parts at the household level. It will not comprise a secondary system out of SS (latest referred to) prepared from the business persons or institutes (e.g., emptying truck, central sludge treatment plant).

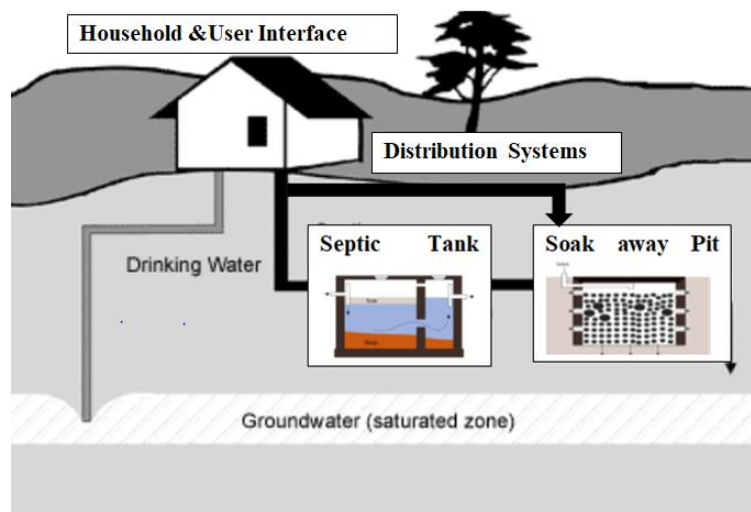


Figure 2: Typical septic system

(i) User Interface

User interfaces comprise toilets that discharge black water and kitchen sinks and bathrooms that discharge greywater. These toilets can be a cistern or conventional flush-a toilet that has high water consumption differs from a squatting toilet that is both set up as an isolated unit. Water is related to hygiene in several cultures then these toilets are undoubtedly hygienic and comfy toilets for the user. But it has a problem like pathogens dilution and disperses widely to the environment if not properly treated and become a danger to drinking water supplies. In addition, valued constituents, like nutrients, in excreta are likewise diluted and likely gone for recycling. The pour-flush squatting toilet is used and accepted in Mwanza town, so it is used for analysis. It collects black water (i.e., excreta, urine, water and toilet paper for anal cleansing, water for flushing toilet, and chemicals (cleaning detergents, pharmaceuticals)) from the toilet. It is a steady toilet where water is spilled once used by the user (Fig. 3). Under a pedestal or pot, a U-bend (siphon) serves as a water screen to inhibit insects and odors from the toilet. It is particularly appropriate where water is used for anal purification, and continuous water supply is obtainable. It needs a smaller amount of water equated to a cistern flush toilet. The 2-3 liters is usually adequate. Otherwise, greywater could be used to flush once freshwater is not obtainable. Clogging may happen when the amount of water used for flushing is not sufficient. Then, it must be considered within the repairs process.

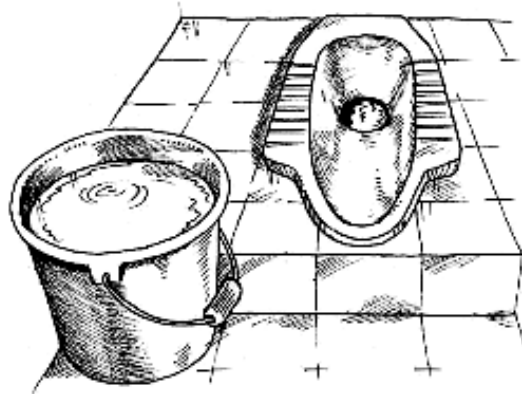


Figure 3: Pour flush toilette

(ii) Septic Tank

It is a buried, watertight small rectangular or circular chamber designed either anaerobic or aerobic and built to collect wastewater from a building. The calm environment inside the septic tank enables solids to be separated from liquids, allows partial ingestion of organic substances and storage of solids (Oladoja, 2017). According to Schaidler *et al.* (2017) the septic tank aims to offer a setting to initial processing of OSSs by supporting physical deposition, floatation and anaerobic ingestion of sewerage.

They kept homes wastewater for 1 to 3 days before discharge, usually has two or three chambers (Adegoke & Stenstrom, 2019). Sludge accumulation is usually quicker in a septic tank than solid degradation and then it must be removed after some years. For example, each after 2-3 years it must be drained (URT, 2009). Then, they must be constructed at a reachable location for emptying trucks if not; they must be emptied by hand.

The design of septic tanks depends largely on the: (a) Number of users, (b) Per capita wastewater production, average yearly temperature as well as the frequency of wastewater consumption. Usually, 48 hours of hydraulic retention time is used for moderate treatment. As it is built underground, the pathogens are not contacted by users while elimination efficiency is lesser. In the prevention of soil water pollution, ST waterproof is too significant. Bounds (1997) identified some aspects affecting the purpose of septic tanks: Inlet concentration; pH; addition of severe chemicals, drainage purifiers, paints or other unsuitable matters that can influence pH and biological activity into the water stream; addition of fats, oil, and grease (FOG); highly varying fluency patterns that disturb septic tanks (flow patterns); failure to maintain the build-up of solids, reduction of efficient volume and time in detention etc.

Conventional septic tank effluent (STE) will add to the drain field/soak-away pit the nutrients, and microorganisms whereby part will ultimately reach the soil or near water resources (directly or by storm water runoff or groundwater discharge) (Schaidler *et al.*, 2017). Indeed, SSs contribute to non-point source (NPS) pollution (Capps *et al.*, 2020). Table 2 offers typical concentrations of total nitrogen (TN), total phosphorus (TP), total coliform (TC), total suspended solids (TSS) and biological oxygen demand (BOD) found in STE and untreated residential wastewater (URW) (Tchobanoglous & Burton, 1991).

Table 2: Quality of the septic tank effluent and the untreated residential wastewater

Parameters	Units	Quality of STE		Quality of URW	
		Range	Range	Typical	
TSS	mg/L	50-90	240-600	436	
BOD	mg/L	140-200	216-540	392	
TN	mg/L	25-60	31-80	57	
TP	mg/L	10-30	10-27	19	
TC	#/100 mL	10 ³ -10 ⁶	10 ⁷ -10 ¹⁰	10 ⁸	

Note that it is not simple to estimate the exact quantity of nutrient contents that at last arrives at ground/surface water. The final deliverance of pollutants to ground/surface water is decided by site situations or kind of system failure that it may be facing (Swann, 2008).

(iii) **Distribution System**

It is a process whereby waste is transferred from the user interface to ST then into the soak way pit (Fig. 2). It can comprise of a lifting or dosing pump tank or draw-off chamber, a gravity supply line. There may be no distinct distribution system in the case of a cesspool system.

(iv) **Soak-away System**

It is a deep, narrow, rock-occupied pit with a pervious bottom for effluent treatment and disposal (unusable) (Fig. 2). Onsite disposal is allowed if wastewater is processed to infiltrate, recycle or discharge. The effluent is kept in the stones' space and penetrates through the bottom into the earth layer. It is suitable for removing fine residue and related contaminants. In principle, before treatment (using a ST) is essential for the coarse sediments reduction in the pit which, could block and make it useless (Schaidler *et al.*, 2017).

2.2.2 Sustainability issues in Septic Systems in Tanzania

In a study executed in the United Kingdom (Bounds, 1997; Butler & Payne, 1995) found that septic tank problems are prevalent in many countries. The most common failure features are the drainage system that can be clogged or insufficient, and the sludge-filled septic tank, which may cause the drainage field to be blocked. They concluded by stating that several problems defined may be due to the inappropriate site or maintenance deficiency. The SS failure has traditionally been destined as a soil ability to take in STE has been surpassed. The STE travels above lateral lines to the soil surface. The consequence of soil clogging and loss of infiltrative capability, this form of failure might be due to collective chemical, physical and biological issues. Failing systems can be viewed as SSs that discharge pollutant amounts of effluent that affect downstream water quality (Swann, 2008). The SSs failure may usually be divided into hydraulic failures, subsurface failures, and treatment failures (Schaidler *et al.*, 2017). In general, weak setting up, hydraulic overfilling, and insufficiency repairs can be attributed to the major causes of these SS failures (Swann, 2008).

Experts assume septic tank density is one valuable measure of SSs (i.e., septic tanks per square mile) which, can impact the water systems. Nitrogen and other toxins are associated with the loading of groundwater, lakes, rivers and other bodies of water (Gold *et al.*, 1990).

Age can play a role in the failure (hydraulic system failure) rate of septic tanks. For example, the risk factors are increased by 5 for 10-29 years and by 12 for 30 and above years of SSs. A mixture of SS coverage, failures, and age variables pose very severe environmental and human health

problems. Therefore, it is important to determine the level of sustainability and formulate respective policy and advice in order to improve the sustainability of SS in Tanzania and to maintain their existence.

2.2.3 Tools for Assessing Sustainability at household in Tanzania

A large number of integrated sustainability assessment tools involving sanitation systems exist in developed countries and less so in developing countries. These tools could be used in other areas including Tanzanian sanitation systems. However, the tools may manifest some incompatibilities as the systems and interests by the stakeholders are not the same. This could be explained by many factors like the indicators not being adapted to the context, scoring and aggregation method, time requirement and data input (Molinos-Senante *et al.*, 2014). Cossio *et al.* (2020) suggested adapting the tool to the context being studied by excluding / modifying the indicators which are not compatible with the context. Therefore, the developers of the sustainability assessment tools should pay attention on all stages since they are the ones make value judgements and assumptions about the working definition of sustainability, sustainability level to be considered, the indicators to be selected, how the indicators are measured and aggregated (Ness *et al.*, 2007; Plakas *et al.*, 2016). For this reason, developing an accurate sustainability assessment tool requires specific weight and reference values adapted to Tanzania's context using experts and stakeholders' involvement, instead of using the existing tools with predetermined indicators and weights.

Numerous index makers have recently begun to apply fuzzy indices that have been established from the fuzzy logic method. The fuzzy logic method is a major method for ambiguous, unclear, or inaccurate information/data and knowledge (Zadeh, 1965). It is about using fuzzy values which capture the words' significance, people's rationale and decision-making. As a way of coding and applying human knowledge in a way that precisely redirects an expert's understanding of complex and difficult problems. Then, it is a means to overcome traditional expert systems' computational bottleneck. The language variable idea is at the heart of fuzzy logic where their values are words, not a numeral. It also offers a syntax and semantics language that translates qualitative information/data into numerical thinking. Data on the different danger items possibilities are just vague in many engineering issues. Zadeh introduces the term word computing to clarify a reasoning concept linguistically and not numerically. In several issuing systems linked to science and engineering, this reasoning is important. Such method has been verified to be too valuable for: Medical diagnosis (Di Lascio *et al.*, 2002), information technology, water quality, and many other industrial applications (Abdelgawad & Fayek, 2010; Sadiq *et al.*, 2004; Yan & Vairavamoorthy, 2003). Also, wherever described information is qualitative or decision-making is done based on

professional views. Due to these facts, this study proposed the SA method called the Fuzzy-based Index Approach (FIA).

The FIA has been established based on experiential indications compiled from several literature reviews. It is aimed at assisting end-users, sanitation planners, policymakers, implementers, or decision-makers to understand the SS situation in a particular setting. It incorporates a sustainability idea in the decision-making process. It is simple and clear in its stages, does not need much data or an advanced computational software package. Moreover, it is an appropriate and efficient method to reduce the shortcomings of other SA methods mostly used and deal with unclear circumstances wherever old calculation is inefficient (Karimi *et al.*, 2011). For instance, many approaches used like Life Cycle Assessment (LCA) or Multi-Criteria-Decision-Analysis (MDA) have several limitations, not limited to: (a) use of the system user perception, (b) inborn first choice while assigning the weights and ranks, (c) completeness, (d) uncertainty, (e) fuzziness handling and (d) findings representation. According to Sadiq *et al.* (2004), in a fuzzy-based index, there are two (2) key steps (parameters selection/identification and their weighing) similar to the conventional indices. Additionally, further steps comprising interpretation approaches are achieved by rules (specialist's decision) as well as sets of language calculations. Therefore, in this dissertation FIA modified and simplified further into six generic steps regarding the objectives of the study from various steps in literature Nardo *et al.* (2005) as listed: (a) Selection of parameters (S step); (b) Measurement of the indicators' condition of SS in the City (M step); (c) Normalization of the SIs (N step); (d) Weighting of the SIs (W step); (e) Aggregation of the indicators (A step) and (f) Interpretation of the indicators (I step).

(i) Selection of Parameters

Fuzzy-based indices utilize an open system means, any parameter (i.e., dimension, theme, indicator, or variable) that can be selected based on decentralized wastewater treatment systems problems/context or a fixed set of parameters from existing literature yet, developing the hierarchical framework involving key parameters should be the first step. Sustainability dimensions are a group of dimensions that enable systems SA (Lundin *et al.*, 1999). Sustainability themes are key issues to be discussed to bring the sustainable system.

(ii) Normalization (Generation of Sub-indices)

Normalization is the process of assigning ranges from 0 to 1 for each SI (Balkema *et al.*, 2002). It follows the selection of the variables, whereupon they are transformed into unit less values. In SI-based assessment, the variables/indicators/dimensions values are recognized as sub-index values

while general value is termed as index value. This is an important step as the variables are stated in diverse units and not comparable. Therefore, they cannot be aggregated. There are several normalization methods for obtaining sub-index as well as each is appropriate for different cases (Gaidajis & Angelakoglou, 2016; Nardo *et al.*, 2008; Pollesch & Dale, 2016). These methods are ranking method (based on the relative importance); continuous re-scaling method; percentage of annual differences over two conservative years; categorical scaling method; and distance to a reference for more clarities (Juwana *et al.*, 2012). The selection of a suitable method depends on the data properties and the index development purpose (Nardo *et al.*, 2005). Exceptional consideration or investigation is need because diverse methods can lead to diverse results (Ebert & Welsch, 2004). In this dissertation, as SIs have different dimensions with diverse measurement units, then normalization method follows the below steps:

Assignment of Variables under Fuzzy Set Theory

Fuzzy assessment procedure at the initial step, the language variables of input/data or reference value required per indicator need to be defined with rating scales, 1-3. Each variable must be described to indicate the maximum and minimum value of input variable which normally, utilized three degrees (low, medium and high). Likewise, the linguistic variables of output must be described which normally utilized five degrees (low; low to medium; medium; medium to high; and high).

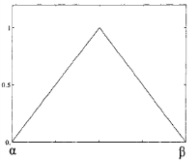
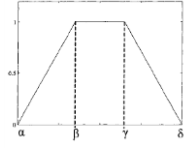
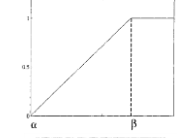
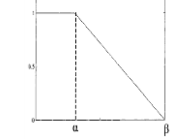
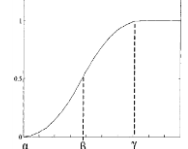
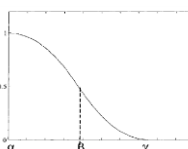
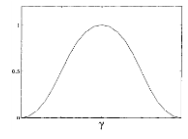
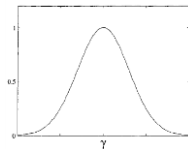
Fuzzy Membership Function

The fundamental fuzzy notion state that statements are not just true or false but also fractional fit into a set, named a fuzzy set. These sets are regarded as “membership functions which describe the SIs’ level contributed to SD. Then the main fuzzy set concept means that SI (parameter/element) ensures membership degree within a fuzzy set. A fuzzy set is well-defined using a membership function that maps elements/SIs to degrees of membership within a certain interval i.e. [0, 1]. Whereby, 0 to 1 in fuzzy logic and 0 or 1 in classical logic were used. Fuzzy sets are sets introduced to define the objects’ classes without exact definitions but rather can be characterized by a range of grades of membership (Zadeh, 1965). Degrees/grades of membership represent the belongingness level of a variable value to the linguistic scales which are more understandable by human intelligence. For example, one cannot be sure how much value of tire pressure is high and low (which is linguistic representation), however, one can say with a certain degree of confidence how much value of tire pressure is high or low. The degree of confidence shows the degree of membership. Essentially, the fuzzy set concept identifies the partial truth

concept and assigns a degree of truth values between 0 and 1 to the linguistic scales. Therefore, this approach allows the modeling of imprecise information with different linguistic scales of performance (Yager, 1977).

Also, membership function (MF) is the function which assigns a number in $[0, 1]$ to individual SI or element of the world of a fuzzy set sermon. However, a reference value that is 0 (lower sustainability) to 1 (higher sustainability) must be arranged for output membership function formation. Then, the fuzzy membership function is a fuzzy concept's essence. The toughest fuzzy membership function describes a soft verge that permits the input variable smooth assessment just before sustainability index. Even though, the function's weakest is that its formation is too personal (Rajaram & Das, 2010). The best normally utilized membership functions are shown in Table 3 (Dubois & Prade, 1980). The best and most used membership functions were linear, triangular, and trapezoidal functions in most of the studies because they are easy to comprehend and calculate. Linear or triangular MF too may be prepared with least data or well-matched with the best normal phenomena (Pedrycz, 1994). Then this research opts for linear membership function.

Table 3: Type of membership functions

Type of MF	Formula	Graph
Triangular MF	$\text{Tri}(x; \alpha, \beta, \gamma) = \begin{cases} 0 & x < \alpha \\ \frac{x - \alpha}{\beta - \alpha} & \alpha \leq x \leq \beta \\ \frac{\gamma - x}{\gamma - \beta} & \beta \leq x < \gamma \\ 0 & x \geq \gamma \end{cases}$	
Trapezoid MF	$\text{Tra}(x; \alpha, \beta, \gamma, \delta) = \begin{cases} 0 & x < \alpha \\ \frac{x - \alpha}{\beta - \alpha} & \alpha \leq x < \beta \\ 1 & \beta \leq x < \gamma \\ \frac{\gamma - x}{\delta - \gamma} & \gamma \leq x < \delta \\ 0 & x \geq \delta \end{cases}$	
The monotonically increasing linear MF	$L(x; \alpha, \beta) = \begin{cases} 0 & x < \alpha \\ \frac{x - \alpha}{\beta - \alpha} & \alpha \leq x \leq \beta \\ 1 & x > \beta \end{cases}$	
The monotonically decreasing linear MF	$L(x; \alpha, \beta) = \begin{cases} 1 & x < \alpha \\ -\frac{x - \alpha}{\beta - \alpha} & \alpha \leq x \leq \beta \\ 0 & x > \beta \end{cases}$	
The monotonically increasing sigmoidal MF	$S(x; \alpha, \beta, \gamma) = \begin{cases} 0 & x < \alpha \\ 2 \left(\frac{x - \alpha}{\gamma - \alpha} \right)^2 & \alpha \leq x \leq \beta \\ 1 - 2 \left(\frac{x - \alpha}{\gamma - \alpha} \right)^2 & \beta \leq x \leq \gamma \\ 1 & x > \gamma \end{cases}$	
The monotonically decreasing sigmoidal MF	$S(x; \alpha, \beta, \gamma) = \begin{cases} 1 & x < \alpha \\ 1 - 2 \left(\frac{x - \alpha}{\gamma - \alpha} \right)^2 & \alpha \leq x \leq \beta \\ 2 \left(\frac{x - \alpha}{\gamma - \alpha} \right)^2 & \beta \leq x \leq \gamma \\ 0 & x > \gamma \end{cases}$	
ri-type MF	$\Pi(x; \beta, \gamma) = \begin{cases} S \left(x; \gamma - \beta, \frac{\gamma - \beta}{2}, \gamma \right) & x \leq \gamma \\ 1 - S \left(x; \gamma, \frac{\gamma + \beta}{2}, \gamma + \beta \right) & x > \gamma \end{cases}$	
Gaussian MF	$G(x; k, \sigma) = \exp \left(-\frac{(y-x)^2}{2\sigma^2} \right)$	

where σ is the standard deviation.

Pappis and Siettos (2014)

Establishing Weights of Indicators and Dimensions

The SIs weighting is a political process but is necessary like SIs selection for the SA Balkema *et al.* (2002). It must include entirely actors' interests which are impressed by the decision-making process. Then, the weights signifying an individual SI comparative significance must be demarcated. The weighting method selection is continuously debatable because it comprises a definite bias/subjectivity level (Nardo *et al.*, 2005). In short, there are three types/categories of weighting approaches; statistical, participatory, and equal weighting (Juwana *et al.*, 2012; Nardo *et al.*, 2005; Saaty & Tran, 2007; Saaty & Vargas, 2012) (Table 4). According to Lermontov *et al.*

(2009), the success of using fuzzy logic is always determined by the weighting of the SIs in the fuzzy set. The weighting method selection is at all times debatable because it includes some degree of bias (Nardo *et al.*, 2005). Many methods had been developed and each method has its advantages and disadvantages. The analytical hierarchy process (AHP) as stipulated in many studies was mostly used in attaining diverse weights for SIs (Molinos-Senante *et al.*, 2014).

Table 4: Weighting Approaches Categories

Approach	Description
Statistical	Use statistical analysis to assign weights to the factors, based on their overlapping information. Examples are “Principal Component Analysis (PCA), Factor Analysis (FA), Regression Analysis, Data Envelopment Analysis (DEA) and Unobserved Component Model (UCM)”. These approaches mainly benefit from deriving weights based on “an objective principle”. Though, the methods “must be sensibly deliberated because the results change with the removal of any control over the weighting process”.
Participatory	Assign weights grounded on the perceived importance of individual factors to the overall index or weights are estimated outside the evaluated units’ data. For example: “Budget Allocation (BA), Analytical Hierarchical Process (AHP), Revised Simons’ Procedure, and Con-joint Analysis (CA)”. The methods are frequently used as they are reflected more steadily over those made through direct assessments.
Equal Weighting.	Equal weight on each factor is assigned

More or less SIs may be correlated, meaning that they might measure the same aspect to either a part of the full extent. If this interrelation is high, then double- or over-counting one aspect of sustainability is probable. Such makes some weighting approaches less suitable for such cases, an example of which is the Equal Weighting Approach. The most common weighting method used in sustainability indicators is equal weighting, whereas the most common statistically-based method is PCA. Regarding the participatory methodologies, public opinion was mostly used for the assignment of weights (Vidal *et al.*, 2019). However, by not presenting weights that signify the stakeholders importance, the analyst must assume that each indicator has equal importance, which is an unspoken, illogical non-transparent valuation, and not frequently suggested. Moreover, researchers wish to prevent more the normalization and weighting political process, but these steps are crucial in SA.

Index Aggregation

Aggregation is the combination of parameters conferring to the fundamental theoretical outline. Aggregation methods that are used in the majority of sustainability indices development are the linear additive and the geometric aggregation methods. Each of these methods is suitable, based

on the dataset's characteristics (Lin *et al.*, 2006; Molinos-Senante *et al.*, 2014). The linear additive aggregation (or weighted arithmetic mean) is the most popular method used in sustainability and water quality indices (Juwana *et al.*, 2012; Vasanthavigar *et al.*, 2010). Furthermore, it is preferable when trade-offs between the indicators are not defined leads to the low value of one indicator is remunerated through another with high value. The geometric aggregation is more suitable when trade-offs among the indicators are present, or not enough information on the underlying interlinkages among the indicators exists. However, it does not account for full compensation of the trade-offs, and sensitivity analyses cannot be employed with errors of the indicators (Langhans *et al.*, 2014; Nardo *et al.*, 2008).

When the weights and fuzzy sets are known for each indicator, aggregation can be performed to quantify the fuzzy set of sustainability attributes. Aggregation means the sum-product of weights and fuzzy sets for each of the indicators under the sustainability attribute. In the formulas presented in Table 5, x_i denotes the indicator variable and w_i the associated weight, where $0 \leq w_i \leq 1$.

Table 5: Aggregation method

Method	Formula
Linear Additive	$X_i = \sum_{i=1}^n w_i x_i$
Geometric	$X_i = \prod_{i=1}^n x_i^{w_i}$

Index aggregation can follow consecutive steps (i.e. sub-indicators/variable – indicators – dimensions - final index). The same form of equations for indicators aggregation may be utilized, with some modification at diverse aggregation levels (Juwana *et al.*, 2012).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study conducted in Mwanza city. The city with two districts Nyamagana and Ilemela is Tanzania's second-largest urban center, with a total population of 706 453 people and an average of 5 people per household (National Bureau of Statistics [NBS], 2012). It is also among the quickest developing urban centers within Sub-Saharan Africa (SSA). The city is on the southern shores of Lake Victoria, in the northwest of Tanzania, and is well-known for its numerous rocky outcrops and ridges. It is estimated by the National Bureau of Statistics that just about 75% of the population live in unplanned and informal settlements in the city's outskirts on the steep stony mountains. Only 8% of the populations are served by sewers while 84% of this population is supplied with water services from MWAUWASA, which will lead to the increase of wastewater. Therefore, the OSSs or SSs at the household level in the city is inevitable, although the sanitation situation is complicated by the difficult terrain.

Diversity of water or sanitation service levels can originate in countries, provinces, or even single cities (Iribarnegaray *et al.*, 2012). For that reason, the research started by zoning a case study (Mwanza city) aimed at initial distinguishing spatial changes in the quality or equity of sanitation services. A city was divided into six zones as shown in Figure 4. These are zone C (Nyakato, Nyegezi, Nyamanoro, Ilemela, Kiseke, Kiloleli and Pasiansi) which has higher SSs/OSSs coverage was selected. Of the other zones, zones O (central area) and A (Capripoint, Isamilo), are served by a central sewer system, zone B (Bwiru and Nyakato block F and G) by semi-centralized systems, zone D (other planned areas) is largely undeveloped, and zone E (Igogo, Bugarika, Mabatini, Butimba, Igoma) comprises unplanned settlements with the semi-centralized sewerage system.

In this analysis, the critical location (study area) selected was named the 'area of concern' (Nyegezi) in zone C (Figure 4) to prevent dangerous values which can prejudice the valuation. Area has a population of nearly 12 000, located near an urban stream that discharges water to Lake Victoria, based on its fulfillment of the requirements for the selection area as shown in Table 6. Also, the selection of the area was based on the SSs' age, ecological situations, and settlement features.

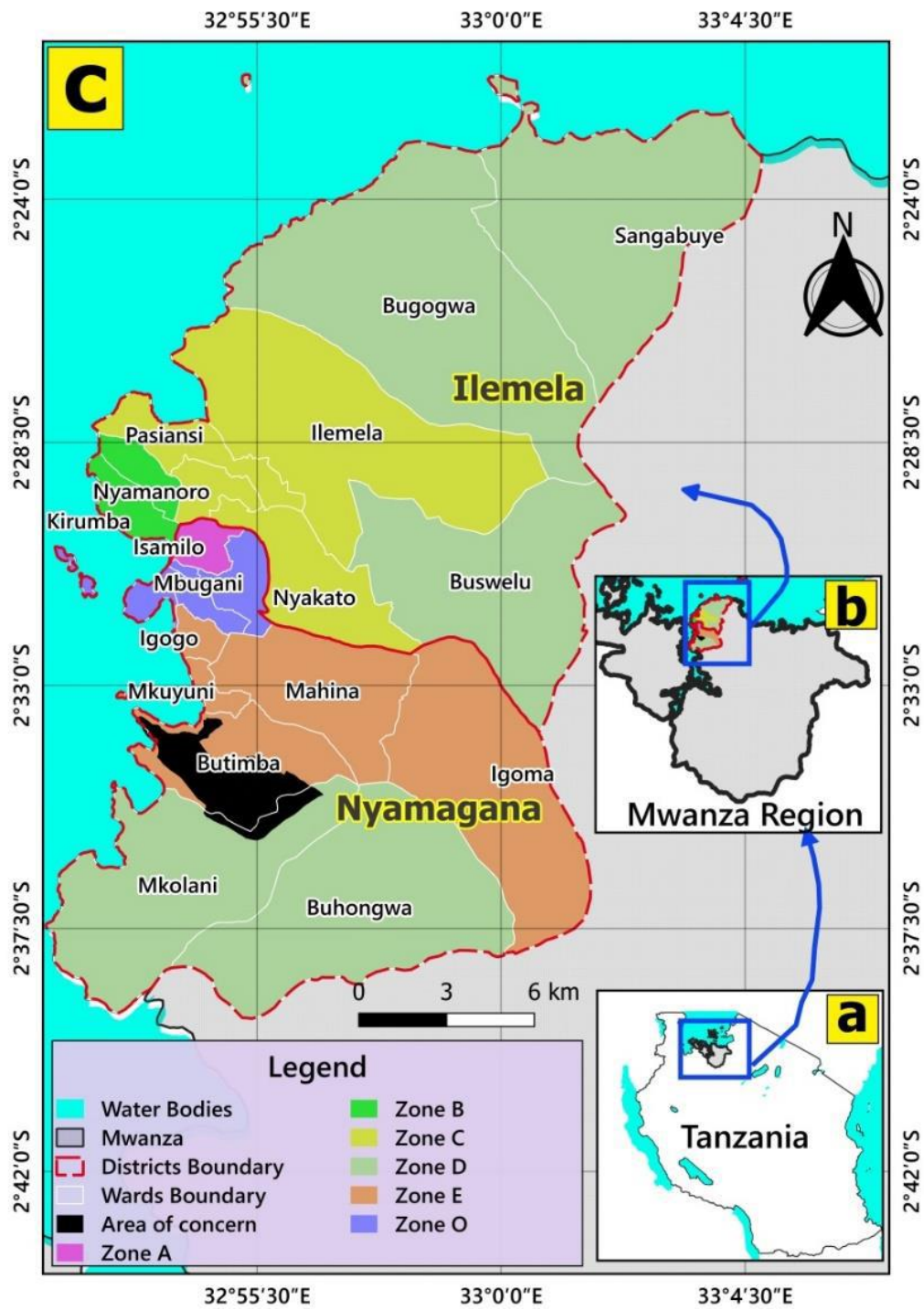


Figure 4: Mwanza City with six zones and area of concern

Table 6: Fulfilment of ‘Nyegezi Area’ to selection criteria

Criteria	Satisfaction
Natural features	Located in the gardening watershed and without sewer from MWAUWASA.
Water-associated conditions	Wastewater and waste are handled poorly. Blackwater is partly pre-treated and greywater is discharged freely to the environment.
Demography	Categorized in high-density settlements, with a population density of 2245 populations/km ² .
Amenability and engagement	The interested party is involved, who is too supportive and eager to exchange information of any sort and assist in collecting data process.
Vulnerability	In the center of the cities, an urban stream (river) is situated, essentially the point of entry of sewage and wastewater to the river.

To determine a region that is more susceptible to domestic wastewater pollution, the researcher performed a vulnerability analysis within the selected areas of the zones. Such was based on two approaches: (a) laboratory testing for the existence of E-Coli bacteria as a fecal pollution indicator for water samples; (b) A field study identifying zones with high exposures to household wastewater. Therefore, ‘*area of concern*’ (Nyegezi) was chosen, based on these extensive vulnerability assessment, as a critical study/vulnerable field aimed at SA of the SS and a pilot area within the framework of SSs in this dissertation.

3.2 Sampling Procedures and Sample Size

3.2.1 Selection of Household

A single random sample size technique was selected to define the total number of the population of interest. Interested residents are those who live in the city of Mwanza. However, entire residents could not be sampled because of time and budget restrictions. Then, the respondent's sample size (n) was determined when 1 was applied. The household was the sample size unit.

$$n = \frac{N}{(1 + Ne^2)} \quad 1$$

Where n is the sample size; N is the total number of the population; and e is the acceptance of probability of error (fit for 0.07, 0.05, 0.03, and 0.01 for a confidence level of 93%, 95%, 97%, and 99% respectively).

For household questionnaires, the sample size is obtained from Equation 1 So, in Mwanza City with N= 706 453 people with 5 people per household, according to the 2012 National census,

assume the acceptable probability of error, $e = 0.05$ or 0.03 with a confidence level 95% or 97%, thus the sample size:

$$n = 125 \text{ to } 222 \text{ households}$$

Hence, approximately 200 households must be assumed to present patterns of the target population at large in all income levels, social and educational levels in Mwanza City (Fig. 5)

For laboratory analysis, wastewater samples from 15 septic tanks with a soak-away pit were picked (Fig. 5). Furthermore, septic tanks were selected with usable holes which have been quickly unlocked as well as locked. The chosen households were coded after the screening process, and numbers were used to mark the sampling bottles. Triplicates from each of the septic tanks chosen were obtained at a two-week interval from wastewater samples. For water samples, two (2) sampling points in the urban stream were selected for sampling (Fig. 5).

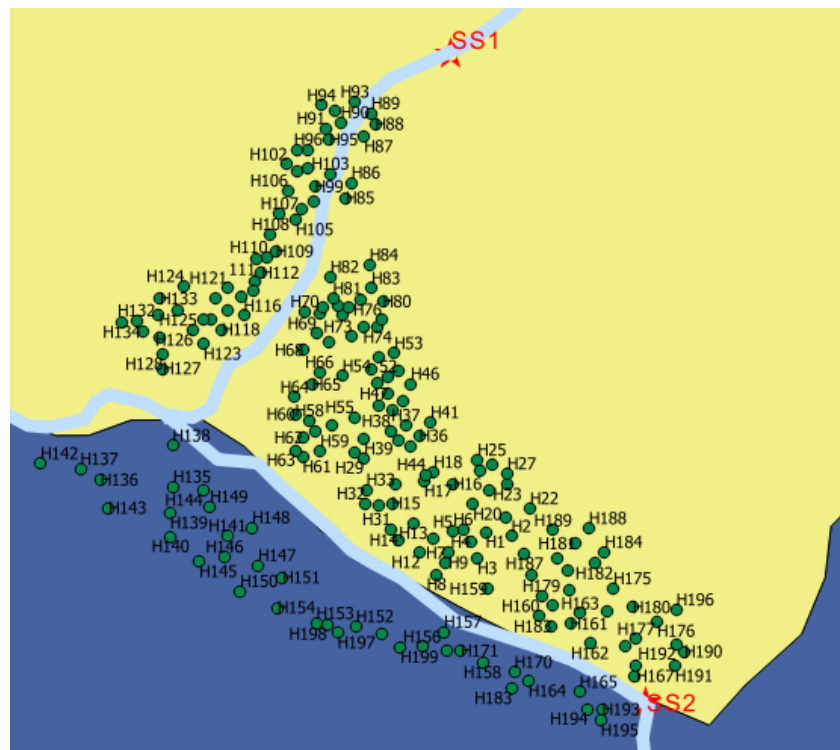


Figure 5: Spatial distribution of sampled households, septic tanks and urban stream

3.3 Fuzzy-based Indices Approach for Sustainability Assessment

The research centered on the second objective developing and applying a SA method called FIA for assessing the sustainability SS. The method was developed by researcher using the guiding principle for calculating an index and testing it on SS in the study area (Georgiou *et al.*, 2020; Nardo *et al.*, 2008; Organisation for Economic Co-operation and Development [OECD], 2008).

Six typical steps were as shown in Fig. 6. The FIA was tested on 200 households, 15 septic tanks and 2 sampling points on urban streams sampled in the study area. It enables the creation of a sustainability index depending on the study locality and objectives.

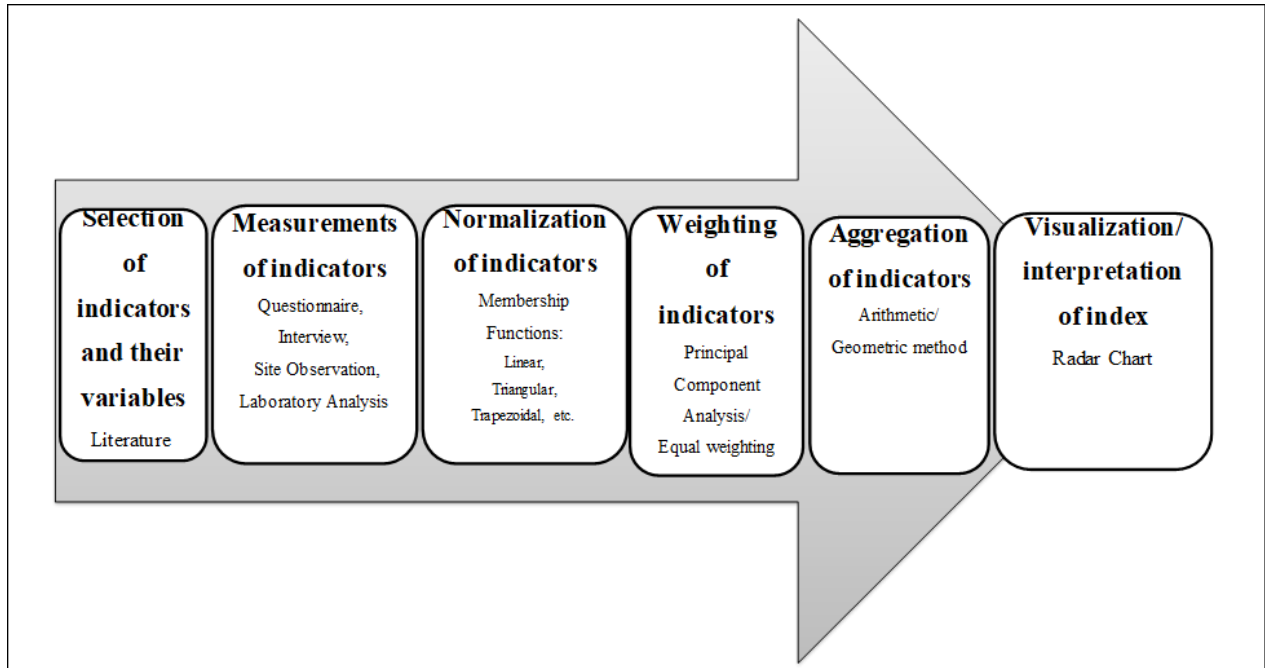


Figure 6: Methodological outline, Modified from (Georgiou *et al.*, 2020)

3.3.1 Selecting and Grouping of Sustainability Dimensions, Themes, Indicators and Variables

The relevant SIs was obtained from the comprehensive literature review and consultation with experts and stakeholders as per procedures shown in Fig. 7. Figure 7 denotes the cooperating process for the SIs development and their scoring orders (Chalise, 2014). These steps are: (a) Literature analyses to find out the SIs for assessing the wastewater treatment plants' sustainability some time ago; (b) Selection of the relevant SIs to be considered for the operating SS and to indigenous settings; (c) The lists provision of themes/issues, SIs, and variables summed in each dimension; and (d) Stakeholders (institutions, users) interviews aimed at gathering data (references) which may be used in supporting the selection of SI as well as scoring/rating scales. Moreover, the concise explanations, references, objectives from individually SI have been presented (Section 4.1.2). Because the sustainability study was intended to measure the effect of SS practices across a broad variety of parameters, then the qualitative and quantitative indicators had been utilized in the indicator's outline.

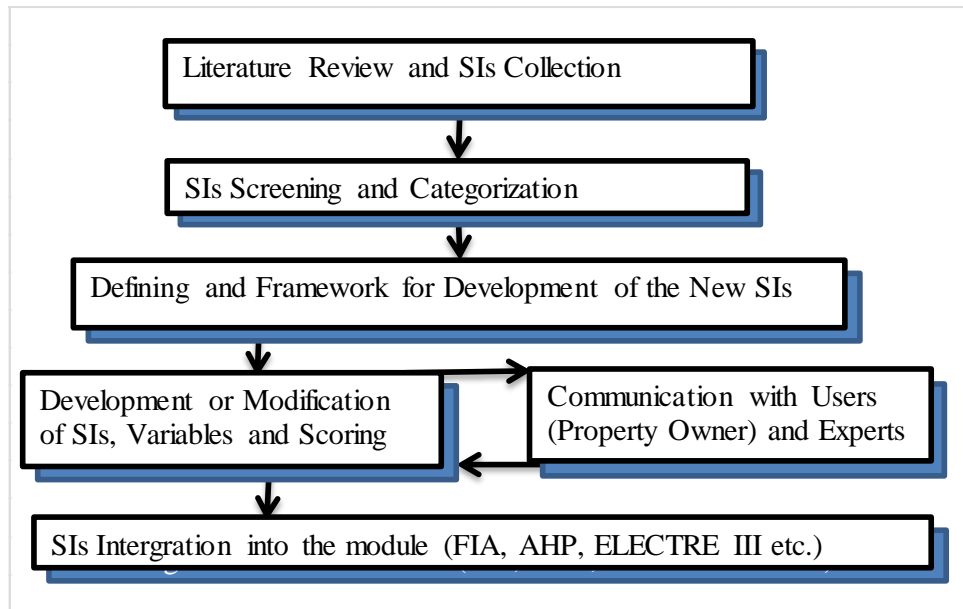


Figure 7: Cooperating processes for the sustainability indicators development and their scoring orders

3.3.2 Conceptual Framework for Assessing Sustainability of Septic System

The main step for the calculation of the sustainability index had been the selection of an adequate conceptual framework of relevant dimensions, themes, indicators and variables (Iribarnegaray *et al.*, 2012). This framework was established based on the most representative and pertinent set of parameters out of those generated from the literature review as well as discussion with stakeholders and experts.

3.3.3 Measurements of Indicators or Variables

In this study, each indicator/variable used to evaluate the system has its type of data (primary or secondary) and a wide range of information to be collected. The primary data have different methods termed ‘social survey’ (household survey, site observation, etc.) and ‘laboratory methods’ were implemented. For example, the primary and qualitative data mainly for the sustainability dimension of the SS were collected from the property owners through questionnaires, interviews, and site observation and managed by the researcher. Secondary data were amassed to match primary data to estimate SIs/ variables and indices using FIA. It commonly comprised reference/target/norm values from various literatures, particularly for water/wastewater quality, durability, capacity of SS indicators, etc. For this purpose, all data collection, interpretation, and analysis methods were significant stages.

(i) Interview

The interview has been carefully chosen as among of the most basic methods for collecting data because it provides an extensive diversity of data and views. However, there were three types of interviews (structured, semi-structured, and unstructured interviews)(DiCicco-Bloom & Crabtree, 2006; Walliman, 2006), that could be used.

In this study, semi-structured interviews have been utilized because they provided both flexible and targeted responses. The household members or staff from Mwanza Urban Water supply and Sanitation Authority (MWA-UWASA), Ward, and Lake Victoria Water Basin (LVWB) were interviewed. Preliminarily, it aims at identifying unsafe homes, obtaining a SS better picture based on operating/ monitoring practices, and collecting data to support SIs selection, calculation, and scoring.

(ii) Household Questionnaires

Further primary data were obtained through a survey using closed-ended structured questionnaires. A total of two hundred (200) households were systematically sampled. The questionnaires were intended to collect quantitative data (e.g., water use, quality of water, and wastewater) as well as qualitative data (for example, gratification level of using the water supply) for the entire SIs. In other words, they aimed to provide a detailed image of the study field or to classify SS's interruptions and defects based on the SIs situations. It presumed that the beneficiaries/users were the most relevant stakeholders apart from the organizations and professionals. Such could be due to their historical responsibilities like SS running, managing as well as eventually maintaining.

The questions are in sequence, starting from general information questions and progressively move into particular parts to make it comfortable for respondents during interview sessions. The questionnaire was divided into six sections (Appendix 1), beginning with the general information (age, level of educating, etc.), then with the supply of the respondents' sanitation status, and then with their reply to the existing SS. In general, the residential buildings SS assessment questionnaire focusing on the measurement of selected indicators was structured "as simple as possible", taking into account the average level of education in the local community.

(iii) Field Observations

It is the supportive technique for checking the questionnaires and interviews results. Checking has been essential for some causes:

- Sanitation isn't every time an easy thing to talk about. There may be a distance between the interviewer and the interviewee during key individual interviews and household questionnaires, which often makes it difficult for respondents to communicate their thoughts.
- Via their behavior rather than verbal contact, some respondents show their awareness of a subject better.

Therefore, observations may check if persons do not act as they say or mean (Walliman, 2006). In some SIs, experiential indications or records of direct observation and experience of researchers were the primary data source for study. In other words, it can be utilized as the balancing approach and key data collection strategy in a social survey. The method of observation used by the participant is based on the surveyor's involvement in the daily activities of the environment carefully chosen to see trivial facts linked to the variables to be observed. The survey was conducted in a case study area of the Nyegezi. Observed activities contain: local activities and living conditions of the community daily (Appendix 2). Such was achieved by visiting their homes that are planned and have insufficient sanitation services. There were likewise visits to the very contaminated drains and pools (the wells are therefore impracticable), all of that lie close to the homes.

(iv) Sampling and Laboratory Analysis

For the environmental sustainability assessment, measurable data (from the wastewater samples of 15 SSs nominated and water samples from two sampling points in urban streams) were collected using a built MWQZL sampling method (laboratory methods). Particulars on results for every sample from analysis events are shown in Appendix 3.

(v) Septic Tank Effluent Sampling and Analysis

Several toilets attached to the septic tank were flushed to check if the effluent was released to the soak pit before sampling for each septic tank. Then, on-site, the effluent was sampled and pH or T⁰C was assessed. A bottle with a sample was conserved as well as transferred into the laboratory to examine the BOD₅, COD, TKN, TP, TSS, and Total coliform using Standard Methods (America Public Health Association [APHA], 2012). The Mwanza Water Quality Zonal Laboratory (MWQZL) analyzed all samples of water and wastewater. It is not practical to examine laboratory samples, including 200 SSs, due to the expense of laboratory experiments plus the time limit. Furthermore, it was impossible to sample the effluent content from the septic directly since it was

connected to the soak pit, with underground pipes in most places. Therefore, the 15 STE or soak pit influent had been sampled at the soak pit inside the target watershed Fig. 8.



Figure 8: Sampling point of a septic tank effluent at soakaway pit

Anh (2014) suggested that the loadings between 10 AM-4 PM presented the maximum concentration, which may be originated from STE as there are great toilets recurrent usage, in case of hourly emission loadings from household wastewater. During 6-10 PM, the second-highest loadings were observed, whereby the main activities were toilet use and bathing/showering/washing. Wastewater samples were then taken at 10 AM-4 PM at each point of discharge (n=15) in this analysis.

(vi) Urban Stream Water Sampling and Analysis

As it was defined in Section 2.1.3 on the effect of nitrogen, phosphorus, pathogens, TSS and COD/BOD from the SSs, then the quality of the urban stream water (surface water source) nearby as the SIs will be analyzed. It is aimed to know whether the system serves the pollution of pollutants in the study area sustainably. However, the visibility of the algae concentration on the surface of surface water may also suggest contamination during the site inspection. This was also conducted aimed at verifying environmental hazards related to the sanitation systems.

In the upstream and downstream of the watershed, water was collected at two sampling points per week for two months. The samples were taken at these points in urban streams using the following laboratory sampling instruments: Beaker 1 L, Cooler box filled with ice cubes, Ethanol 70%, Catch sampler, Latex gloves, Notebook and pencil, Thermometer, Portable pH meter, 1000 mL plastic bottles, Plastic bucket volume 10 L, Measuring cylinder. Water samples for analysis were obtained using normal procedures to the sterile glass/plastic bottles. They were transported to the testing laboratory within 24 hours or checked on-site using different equipment depending on the

parameter concerned. The Standard Methods were adopted in analysis in the laboratory by COD, BOD5, SS, TKN, TP and Complete Coliform Counts (APHA, 2012).

(vii) Managing and Interpreting Data

The data (qualitative or quantitative data) were collected, managed and interpreted within different means. These data management and interpretation methodologies are summarized in Table 7.

Table 7: Data collection, management and interpretation methods

Data collection	Data management	Data interpretation
Interview	The tape recorder was sometimes used (for formal structured interviews) or extensive note was taken and a designed standard form. The record was carried out instantly after the interviews so that to avoid losing or forgetting information/data within Microsoft Word Files.	Using coding patterns as starting points to answer the questions related to Conditions; Interpretation; Strategies; Consequences etc.
Questionnaires	All the questionnaire forms, Picture of the respondent, and GPS coordinate were Filed	Data were processed using Microsoft excel
Direct observation	Using the fieldwork checklist with some questions to record the observation of the researcher during households’ survey and SS inspection. It contains findings, experiences, and problems that arise and records ideas for cross-checking, comparison, and refinement	The fieldwork checklist was presented as memo-writing
Sampling and Laboratory analysis	Using MWQZL standard form and notebook to record the results or data from measuring instruments/tools	Data were processed by using Microsoft excel in form of graphs, tables, etc.

(viii) Coding

All data were recorded into an Excel sheet and provided with codes. To evade misperceptions in data analysis, the data parts were screened and the codes of the various variables were marked.

3.3.4 Normalization of the Variables/SIs

In FIA, SIs under their variables are normalized, grouped by a fuzzy set theory, and processed by function to make quantitative and qualitative indicators comparable (Lermontov *et al.*, 2009). This is because SIs has different units. To evaluate the indicator value mathematically, matching fuzzy sets are attributed to verbal terms/variables based on the aim of a specific indicator by an author who is aware of different SS practices observed. Then, this study proposed to use the ‘linear

membership function' due to its simplest and few input data for fuzzy evaluation mode instead of the other membership functions.

Then from linear membership function, the assigned scores (AS_v) are converted into the normalized index (NI) or sustainability variable index (SVI_v) as follows:

$$SVI_v = \begin{cases} 1, & \text{if } AS_{btn,v} \geq AS_{max,v} \\ \frac{(AS_{btn,v} - AS_{min,v})}{(AS_{max,v} - AS_{min,v})}, & \text{if } AS_{min,v} < x_{btn,v} < AS_{max,v} \\ 0, & \text{if } AS_{btn,v} \leq AS_{min,v} \end{cases} \quad 2$$

Where $AS_{max,v}$ and $AS_{min,v}$ are the maximum and minimum scores correspondingly; v is a number of the variable categories per each indicator and $AS_{btn,v}$ is any input score lies between these two extreme thresholds.

3.3.5 Weighting Techniques of the SIs and Dimensions

In this study the 'new direct statistical-based approach' introduced by the author was used. It is a mathematical formula to weigh the importance of the indicators and dimensions taking into consideration entire population responses per each parameter (Equation 3 and Equation 6). The key benefit of such a method is that weights are under unbiased opinion. This is because the users' responses in term of the frequencies on specific indicators status were used and the number of SS to be evaluated are huge (n=200).

3.3.6 Aggregation Techniques of the Variables, Sustainability Indicators and Dimensions

The linear aggregation was used to consolidate individual variables into indicators into respective dimension indices and the overall index. The general SA, with FIA, is a step-by-step approach as follows:

(i) Step 1: VSI aggregated into indicator sustainability index (ISI)

Having computed the VSI_v and the frequencies of responses (N_v) for each variable, then indicators sustainability index (ISI_i) of the SS across the i^{th} indicator within a sustainability dimension can be determined by:

$$ISI_i = \frac{\sum_{v=1}^V VSI_v * N_v}{\sum_{v=1}^V N_v} \quad 3$$

For: $i = 1, 2, 3, \dots, I$ where i is the number of SIs; and $v = 1, 2, \dots, V$ where v number of variables within i^{th} indicator.

(ii) Step 2: ISI aggregated to form dimension sustainability index (DSI)

The weight of each indicator w_i was obtained from ISI_i calculated in Equation 3 as follows:

$$w_i = \log\left(\frac{1}{ISI_i}\right) \geq 0 \quad 4$$

After the weights of each SI (w_i) have been calculated, the social SO ($I=4$), environmental EN ($I=4$), economic EC ($I=3$), and technical TE ($I=7$) sustainability indices for SS can be computed individually as follows:

$$DSI_d = \frac{\sum_{i=1}^I ISI_i * w_i}{\sum_{i=1}^I w_i} \quad 5$$

Where, DSI_d is dimension sustainability index of the dimensions d ; $d=SO, EN, EC$ or TE ; for $i=1, 2, 3, \dots, I$ where i is the number of indicators in every dimension; ISI_i is the indicator sustainability index of i^{th} indicator and w_i is the weight of the i^{th} sustainability indicator.

(iii) Step 3: DSI aggregated to form general sustainability index (GSI)

By adopting the similar approach in step 2, the relative importance (weight) of each sustainability dimension w_d was attained as follows:

$$w_d = \log\left(\frac{1}{DSI_d}\right) \geq 0 \quad 6$$

And then, the GSI of SS can be computed as follows:

$$GSI_{SS} = \frac{\sum_{d=SO}^d DSI_d * w_d}{\sum_{d=SO}^d w_d} \quad 7$$

Where, w_d is the weight of each sustainability dimension; DSI_d is the dimension sustainability index; GSI_{SS} is general sustainability index of the SS.

3.3.6 Interpretation of the Indices

Results were offered in an easy and clear style through explanation to stimulate the anticipated responses and to certify that the indices were well acknowledged by its targeting users. Therefore

it was done using an attractive and manageable tool: The radar/spider diagram. Also, for classification/interpretation and decision-making purposes, the indices (I_s) obtained by SS were transformed keen on ‘sustainability scale’ (ranging from 0 to 1) with some ‘measures and actions’ recommended such as:

- $I_s \leq 0.25$ to be ‘unacceptable’ and fast aid and renewing actions are must,
- $0.25 < I_s \leq 0.50$ to be in ‘danger’ and correction measures are recommended,
- $0.50 < I_s \leq 0.75$ to be ‘good’ and optimization and alteration measures is suggested,
- $0.75 < I_s < 1$ to be ‘very good’ and checking and repairs are needed,
- $I_s = 1$ to be ‘excellent’ and monitoring is required (Iribarnegaray *et al.*, 2012).

The remark on instantaneous actions for a balanced system was set at 0.50. Bearing in mind that the goal of sustainability is to achieve a high level of sustainability for each SI, for the different sustainability dimensions, and, ultimately, for general sustainability.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Sustainability Indicators for Assessing Sustainability of Septic System in Mwanza City, Tanzania

4.1.1 Sustainability Indicators

Results of an all-inclusive review of literature in numerous screening levels which focused on wastewater treatment systems and discussions with individual experts are summarized in Table 8. Whereby, this practice generated about 50 initial set indicators with the standard indicator bolded. All SIs have been categorized under technical environmental, social, and economic dimensions as in Table 8. These will be applied as the earliest limiting point for building up the suitable and related basic SIs.

Table 8: Preliminary set of indicators for assessing sustainability from various kind of literature

Dimensions with their Indicators
Social dimension (n=14)
Public acceptance ^{1,2, 3,4} Aesthetics ^{1, 2,4} Public Health risk ¹ <ul style="list-style-type: none"> • Infection risk of complete system use⁴ • Exposure risk to dangerous constituents; heavy metals, medical residues, particular other organic compounds⁴ Coverage ¹ Participation ^{1, 3} Occupational health and safety ¹ Local job creation and diversity ¹ Staff requirements ¹ Stimulation of sustainable behaviour ¹ Employee satisfaction ¹ Expertise ¹ Awareness ^{1, 3,4}
Environmental dimension (n=8)
Energy use ^{1,3} Global warming potential ^{1,4} Removal of BOD, TSS, TN, TP and FC ¹ Land area ^{1, 3,4} Quality of effluent and sludge ¹ Potential recycling/reuse/recovery (nutrients, energy, or organic materials) ^{1,4} Sludge production ^{1, 3} Natural resources utilization (water and raw materials) ^{1, 3,4}
Economic Dimension (n=10)
Capital ^{1, 3,4} Maintenance and /or operation costs ^{1, 3,4} Tariff ¹ Cost effectiveness ¹ Affordability ¹ <ul style="list-style-type: none"> • Capacity to pay – user (% of available income)⁴ Ensure economic sustainability of the utility ¹ <ul style="list-style-type: none"> • Local development⁴ • Reception to pay (percent available income)⁴ • Comfort (personal safety, odor, noise, appeal, age, gender, and revenue needs)⁴
Technical dimension (n=18)
Building, and operation (O)& maintenance (M) complexity ^{1,4} <ul style="list-style-type: none"> • Possibility of use of local building skills⁴ • Use of local operational and maintenance expertise⁴ • Easy system surveillance⁴ Reliability ^{1,3} Durability ^{1, 3,4}

Dimensions with their Indicators

Robustness¹

- i. Robustness of the system; risk of failure, failure effect, structural stability⁴
- ii. System robustness; shock load, system abuse effects ⁴
- iii. Strength against extreme circumstances (e.g., drought, flooding, earthquake, etc.)⁴

Flexibility/adaptability/solidity (high groundwater level, geologies, etc.) – to user requirements and existing environmental conditions.^{1,3,4}

Improvement, extension, or modification of the scope of future development¹

Amount of wastewater treated as a percentage of total wastewater volume.¹

Actual equivalent persons (PE) as a design PE¹

Pollutant load generated by the WWTP (per inhabitant connected; per catchment area; per population density)¹

Level of treatment¹

Compatibility with existing system⁴

¹(Cossio *et al.*, 2020) ²(Bisschops *et al.*, 2019), ³(Balkema *et al.*, 2002) and ⁴(Malisie, 2008), n = number of indicators

It is often problematic to use standard indicators, either due to the availability of data or due to the system's relevance. The standard indicators' viability and significance must thus be validated in a given setting, and local indicators developed to evaluate severe aspects of the system to attain sustainability (Freebairn & King, 2003). The diverse researches are not comparable, without modifications and definitions of SIs concerning local environment and objectives to be full filled due to their different purposes, scopes, and terminology (Cossio *et al.*, 2020). Then, some adjustments were brought into the typical indicators to get used to local settings and FIA.

A collection of SIs is built in this dissertation based on the "integrative approach" for SD. The fullness of a sustainability concept involves the creation and calculation of many different dimensions. The number of SIs must be reduced concerning the aims, time limitations, and difficulty of collecting all information from entirely 50 SIs to take decisions. Therefore, regarding the four (4) sustainability dimensions, 18 sets of indicators were used in this dissertation (Table 9), which takes into account the following selection criteria of a good indicator (Nardo *et al.*, 2005; Waas *et al.*, 2014):

- In place of SD, SI must meet the least possible obligation for a device. Though the number is small, the greatest critical dimensions of SS must be determined.
- Key issues to be addressed in the study area (Theme) (e.g., performance, financial, social mindset, awareness level of users/operators, health status, etc.).
- Data obtainability in the research's field. Collection of indicators should use data available to avoid "measuring the immeasurable".'

The indicators and their variables had been picked out to evaluate the theme (rules) gratification based on their significance. These all indicators established in Table 9 are more all-inclusive and flexible. Indicators also can be employed for a variety of uses. Technical indicators are many because technical dimension was considered a new aspect then, in most studies were not evaluated. Also, the nature of SS in the study area is highly associated with operational (technical) problems.

Table 9: General categories of selected sustainability indicators (n=18) for sustainability assessment of the septic system in this Study

Social (n=4)	Environmental (n=4)	Economic (n=3)	Technical (n=7)
<ul style="list-style-type: none"> • Exposure chances to the wastewater by users • Public awareness for septic tank management • Aesthetics based on nuisance level • Community support for SS 	<ul style="list-style-type: none"> • Access to enough water supply to operate the system • Quality of septic tank effluent • Water quality of the Stream, Main River, or lake in the city • Compatibility of SS with the surrounding environment 	<ul style="list-style-type: none"> • Operation and maintenance cost • Capacity to sustain the system • Level of Contribution of the system to local economic development 	<ul style="list-style-type: none"> • Durability • Risk of failure of system • Adaptability to flow fluctuation or user needs • Upgradability • The operation and maintenance level required • Availability of local materials • The capacity of existing SS

4.1.2 Descriptions and Justifications of the Selected Sustainability Indicators

The SIs were more defined and justified in this section individually once again by the author. This was prepared ready to outline the methods by which the system results were categorized, and keep away from misinterpretations with the stakeholders in the data collection. After defining indicators, an appropriate method of evaluation for each indicator was established: how to evaluate a specific indicator? Then ranking/scoring technique (e.g., with scale 1 to 3 for ordinal variables and 1 and 2 for dichotomous variables) is essential, whereby small number and large number presents a low (inferior variable) and higher (superior variable) fulfilment of the indicator objective respectively (Seleman, 2012). Such was obtained by comparing the system needs to be sustainable to the selected variables (targets) against SIs (local circumstances). The majority of rating scales are local dependent (rule, insight, attitude), as clarified in the “remarks” and that indicator aims to attain sustainability of the system. If this scale is used for a different case study, it is necessary to adjust for the local context, especially when setting threshold values. Indicators had been measured through the measurement of variables preferably chosen to firmly comply with the conceptual framework. This section gives a comprehensive explanation and argument of the justification of

the parameter selection (dimension, theme, indicator, and variable). Then, rating description and rating values as well as the detailed assessment methods for each indicator to a case study area are shown in Table, 10, 12, 13 and 14.

(i) Social Dimension

Table 10 presents the definition summary of the social dimension in terms of theme (n=3), indicators (n=4), variables, and data required gathered from household questionnaires which reveal the users’ view after the system usage, and other details needed when evaluating social sustainability. All variables are qualitative and should be transformed by on-site scoring in “dimensionless quantitative variables.

Table 10: Descriptions and justifications of social dimension parameters

Theme: Health and safety
Public health and safety associated with the treatment activities of the system are very significant. Becoming safe from the toilet to disposal (or recycling) due to the exposure risk into contaminants or harmful constituents, the procedure must be harmless using the minimal potential for public risk. This includes the safe treatment and recycling process; the reduction of the risk of health disease occurrence (e.g., diarrheal); the overall system hygiene status, particularly if an interface is established with users or maintenance technicians; as well as the effectiveness of the regulation of public health issues, e.g. the reduction of open cases of defecation (Hashemi, 2020).
SI: Exposure Chances of Users to Wastewater (SO₁)
This indicator assesses the possible health effect while carrying on SS for household members and maintenance technicians. The assessment is based upon the household survey and visual observations of the system on the users’ exposure to insects and wastewater that leads to diseases like Diarrhea; Worms; Cholera; Typhoid; Eye diseases, and Dysentery. The sanitation system must generally generate a physical fence among polluted wastewater and the user. It evades emissions of odor and still water that leads to mosquito nursing sites.
Objective: Minimization of exposure chances to wastewater (Low exposure chance)

Data required	Unit	Remarks	Score
The number of systems showing the exposure chances to the wastewater or insects to be; <i>Low (SO₁₁)</i>	Number –semi-quantitatively	System reduces the contacts among users or maintenance technicians in wastewater and the risk of insect breeding through all system features.	3
<i>Moderate (SO₁₂)</i>		Various system features need contact among users/maintenance technicians and wastewater, and an insect reproductive risk occurs.	2
<i>High (SO₁₃)</i>		Contact among user/operator and wastewater is necessary for all system features. Insect reproduction is a systematic risk.	1

Justification for Indicator

Health threats related to sanitation arise primarily through persistent pathogenic species (viruses, bacteria, helminths, and protozoa) in excreta. Such can lead to infectious diseases (diarrhea and intestinal worms) when excretes are not correctly accumulated, treated, conveyed, and implemented. Therefore, any OSS must protect human health and provide sufficient barriers to potential exposure to pathogens. Nevertheless, the possibility of contracting an infectious disease can be present while working with the sanitation system. This situation made exposure chances of users to wastewater an essential social indicator. In this study, the risk refers to the severity of exposure to raw or pre-treated wastewater that can lead to disease throughout the system. Several potential exposures chances to sanitation systems are shown in (WHO, 2002).

Table 11: Presents parts of sanitation system and potential exposure

SS parts	Likely exposures
Toilet (user interface)	During and after cleaning (use)
Treatment system (septic tank)	During maintenance; In case of process failure; Direct contact with the treatment process.
Discharge (soak-away pit)	Water contact; use of contaminated groundwater as the source of drinking water; Insect or wild animal contamination contact
Rest product handling	Emptying of accumulated rest products/sludge
End product use	Use to arable soil; Ingesting of wastewater fertilized vegetables.

Theme: Awareness

This is described as the level at which groups of individuals are capable of recognizing, coping with, and reacting to problems such as systems practices, costs, and benefits associated with their wastewater systems. It promotes social characteristics that lead to a public feeling based on the presence of best understanding of the scheme, interests, openness, and involvement of all users, hygiene actions of the recipients, acceptance, satisfaction, etc. In general, decentralized wastewater treatment systems require further awareness and chipping in from local occupants. They are accepted by individuals who are aware of their aims and benefits, including economic ones (Capodaglio *et al.*, 2017). This theme may be measured by judgmental surveys or, ultimately, user statistics of service-related complaints.

SI: Public Awareness of Septic Tank Management (SO₂)

It assesses the public knowledge of the system's management. The assessment is based on a household interview on the understanding of the system's wasteful function. The better public understands the treatment programs, the more trust in the associated SS operations and the greater the degree of advantageousness in the system. It is crucial when public health and security problems (typhoid trends) are at risk.

Objective: Maximization of public awareness (*Yes*)

Data required (Variables)	Units	Remarks	Score
A number of respondents understanding the role of desludging: <i>Yes (SO₂₁)</i>	Number	No. of HH understand the role of frequent desludging	2
<i>No (SO₂₂)</i>		No. of HHs do not understand the roles of frequent desludging	1

Justification of Indicator			
<p>It is a common social sustainability indicator as it determines how complex it will be for property owners to recognize their responsibility for the facility's operation as planned (user-friendliness). They need to understand what basic measures need to be taken to monitor a proper function, such as desludging or sampling the handled waste, so that they can do it themselves or hire a service. Unfortunately, Kihila and Balengayabo (2020) reported that public awareness of septic system best practices is not known even though it is the oldest system. Such makes the indicator more pertinent than others but, sensitivity was not a well thought-out subject in the setting of this study.</p>			
Theme: Impact on Local Community			
<p>It denotes the people and SS relationships. Above all, the theme observes if the system's problems and welfares are reasonably widespread or the level of participation of stakeholders in the process. It assesses the contributions the system makes to the city economy. Examples of social benefit are the formation and influence of jobs and valued services to the public economy. Based on local culture and historic buildings, the system should be appropriate and not add an offensive picture to the city.</p>			
SI: Aesthetic Based on Nuisance Level (SO₃)			
<p>It referred to the calculated nuisance level/extent derived from noise, odor, visual impact, insects, and other pests created by the device to determine whether beauty environments are maintained or not. What are the levels of common nuisances currently used for sanitation facilities?</p> <p>Objective: Minimization of nuisance level (low level)</p>			
Data required (Variables)	Unit	Remarks	Score
A number of household members reported complaints these levels of nuisance factors (smell, flies/cockroaches and other vermin, greywater pollution incidents, etc.):	Number	Number of households having experienced nuisance factors: `	
<i>High level (SO₃₁)</i>		> 1 week/ month	1
<i>Medium level (SO₃₂)</i>		1 day to 1 Week/month	2
<i>Low level (SO₃₃)</i>		< 1 day/month	3

Justification of Indicator			
<p>Septic systems can be a source of objectionable odors, flies/cockroaches, etc. Numerous studies have concluded that there are many odor-related symptoms for complaints of individuals living close to wastewater treatment plants and/or waste sites. Then this indicator is essential for the system sustainability as it is stated as the standard indicator. However, checking on-site if swales, ditches, and infiltration field/pit offer aesthetical green areas and to what extent is another measure of aesthetic level (site observation).</p>			
SI: Community Acceptance for the Septic System (SO₄)			
<p>It refers to the acceptance by users for repeated use and maintenance of SS. The steps of cultural sanitation in society should reflect acceptability. Therefore, it may also be referred to under the principle/norms of society (habits, religion, and tradition) as a percentage of individuals happy about the use and reuse of the system (Hashemi, 2020).</p> <p>Objective: Maximization of public acceptance (High)</p>			
Data required (Variables)	Unit	Remarks	Score
No. of HHs who responded with this level of acceptance; <i>High (SO₄₁)</i>	Number-Semi-Quantitative	No of HHs with very strong public acceptance /support as all features are okay	3
<i>Medium (SO₄₂)</i>		No of HHs/user who is uninterested to the system. Not all features are okay but, modification is required to increase acceptance	2
<i>Low (SO₄₃)</i>		No of the user is rejecting the system. All features are against social norms.	1
Justification for Indicator			
<p>Centralized systems, which are aware of the constant 'out of view' processes under the supervision of one authority responsible for their control, have been accepted in public as a de-facto need. But, It is not always so clearly defined in decentralized systems. For example, end-user(s) is responsible for systems management in the case of systems such as SSs and probably would like not to be. Then, the public preference or acceptance for a system becomes a key indicator because it is one of the indicators that define SS's lasting sustainability. The acceptability of society shall depend on the assessment of the system's value (for example, reduced health and ecological issues, economic benefits); its observance of society's values (i.e., appropriateness to religion and customs); and its anticipated socio-cultural effects (i.e., ease,</p>			

confidentiality, respect). Bear in mind that over time, how things are perceived and their consequent acceptance will alter. However, the current SS that has been installed and operated in the community must achieve an acceptable level (a preference percentage).

(ii) Environmental Dimension

Table 12 presents the definition summary of three (3) themes, four (4) indicators, variables, and data required gathered from household questionnaires which reveal the users’ view while using SS, from laboratory/site observation, or other details needed when evaluating environmental sustainability. Through on-site analysis using the score, all variables should be translated into dimensional and quantitative variables.

Table 12: Descriptions and justifications of the environmental dimensions parameters

Theme: Resource Consumption			
It means that natural resources required for operating SSs are indicated. This aim at to assess the resources’ sustainable usage. However, in this study, the energy (electricity, fossil fuels), land, or materials (chemicals) required in operating the system (septic tank system) is neglected except for water during the operation phase. Hence, resource consumption has been matched using a satisfactory verge for assessing its sustainability.			
SI: Water Use to Operate the System (EN₁)			
It means that extra amounts of freshwater required for proper system operation and other hygiene practices are used for sustainable use. Wastewater generation and other water volumes (e.g., freshwater used into flush toilets) can meet the system's water requirements. In this study, however, just extra water consumption for the system operation is considered.			
Objective: High enough water availability for the system operation.			
Data required (Variables)	Unit	Remark	Score
No. of HHs with water use and available for toilet flushing are; <i>High (EN₁₁)</i>	Number- Quantitative (liter/household. day)	This amount is enough for a septic system of greater than 60 l/HH. D (Low health risk).	3
<i>Medium (EN₁₂)</i>		Enough water from the water service provider for the system to operate of 40 – 60 l/HH. D (Medium health risk)	2

<i>Low (EN13)</i>		System requires this amount of additional water < 40 l/HH. D and is usually preferred but, the system cannot well operate (High Health Risk).	1
Justification for Indicator			
<p>The most key sustainability metric is water usage. According to many kinds of literature, insufficient access to sufficient quantities of water affects the population’s life quality and/or implementation of water-based OSSs (such as septic systems). For example, when an in-house connection is available, costly systems like cistern-flush toilets connected to the conservative sewage or septic tanks and soak away are theoretically possible. The system’s operational water quantity is a minimum of 40 liters per household per day (URT., 2020). Note that the drinking water availability and water under the functionality of the SS are different all over the place.</p>			
Theme: Impact from the System			
<p>Such included indicators to reflect the system impacts comprising environmental and land use impacts resulting from system weaknesses and personal conduct. The effects focus on water pollution indicators that result from personal ingesting and cultural conduct, whether direct or indirect, often hindered. Improvements in water quality have been regarded as the most significant factor in avoiding such water-related diseases (Waddington <i>et al.</i>, 2009). Generally, all pollutants need to be addressed for various recipients, including water, soil, and air.</p>			
SI: Water Quality of the Urban Stream in the City (EN2)			
<p>It defines the water condition to its appropriateness for specific use (drinking or swimming). It is based on physical, chemical, or microbiologic parameters.</p>			
Objective: Minimization of waste product in water sources (Good quality).			
Data required (Variables)	Unit	Remarks	Score
Total number of tested water samples having;	Number - Quantitative	Must be assessed for the specified quality of wastewater discharge standards, of all fundamental parameters	
<i>Good Quality (EN21)</i>		Raw water is qualified for recreation, irrigation and fishing.	2
<i>Poor Quality (EN22)</i>		The water does not meet the standard as raw water is not qualified for the purposes.	1
Justification for Indicator			
<p>At-risk aquatic and terrestrial systems eutrophication and contamination should be prevented by the sanitary system (Oladoja, 2017). To ensure that the specific practices adopted are substantially reducing water source pollution, water quality analysis in conjunction with</p>			

improved sanitation practices is critical. In urban areas, the common source of pollution is likely to be human and animal waste. Preventive steps implementation, including better sanitation and regular water quality monitoring, can help direct adequate and efficient water quality management.

SI: Compatibility of SS With the Surrounding Environment (EN₃)

This indicator relates to the suitability of the correct functionality of the device to the local environmental situation. It focused on determining whether the device is located in rock soil, higher groundwater table, etc.

Objective: Maximizing the use of the system in a suitable location (High compatibility)

Data required (Variables)	Unit	Remarks	Score
Number of SS whereby the level of compatibility is; <i>High (EN₃₁)</i>	Number- Quantitative (%)	All features (soil and rock type, water table, and other necessary elements) are matched for the system’s functioning.	3
<i>Medium (EN₃₂)</i>		Groundwater table level low or Infiltration rate likely to be low (gravel/rocky and clayed soil).	2
<i>Low (EN₃₃)</i>		Groundwater table level high or Infiltration rate likely to be high (gravel/rocky and clayed soil).	1

Justification for Indicator

The physical environment's geological soil composition with hard rock, a high-water level, and loose soil contributes to the weak OSSs implementation or operation. In areas with a low water table and soils of moderate to high permeability, pit latrines and septic tank-soak away pits may be installed to allow the required treatment to occur. Pits tend to overflow in areas with high water tables during the rainy seasons, which may need regular emptying, which can be very expensive. Public health is also threatened with water flowing freely in the environment that people are exposed to. For such areas, septic tanks or latrines must be combined with technologies such as constructed wetlands or subsurface drains. In low permeability areas, it is recommended to use a lateral subsurface drain connected to the soak-away pit (URT., 2020). Then, for the system sustainability, these are significant parameters.

Theme: Watery Waste Discharge from System

The majority of the water utilized in residential buildings is dumped. The quality and amount of the water produced by the treatment systems have different effects on the environment. This study is based on the quality of wastewater discharged from the system ignoring the quantity

aspect. Other significant themes like solid waste (sludge) and gaseous discharge representing the output from the system are out of the scope of this study. However, the themes can be considered in the future in terms of their quality, quantity and the possibility of re-use for purposes other than disposal (environmental pollution).

SI: Quality of the Septic tank Effluent (EN₄)

It measures the quality of effluent (liquids) released from the system. Local regulations/guidelines with effluent quality standards are applicable including, BOD, COD, TSS, TN, TP Fecal E-coli, etc., and they should be considered for this indicator evaluation (Kamami, 2011; Muga & Mihelcic, 2008).

Objective: Minimization of wastewater parameters concentration (Good Quality).

Data required (Variables)	Unit	Remarks	Score
Number of samples showing these categories; <i>Good Quality (EN₄₁)</i>	Quantitative (%)	Below the applicable local limits and system contains and treats waste	2
<i>Bad Quality (EN₄₂)</i>		Not meeting applicable local limits or system is not containing or treating waste	1

Justification for Indicator

The quality of system-generated waste is a SI of every operating system (Bahar *et al.*, 2017). Effluent consistency represents the treatment system efficiency in terms of technological and ecological dimensions (Kazora & Mourad, 2018). Wastewater must be processed and disinfected to comply with a regulatory standard or with a legal requirement to defend human health and the environment for a particular reason. To safeguard soil fertility and public health, qualitative and quantitative effluent requirements must preserve or even increase the quality of the receiving water.

(iii) Economic Dimension

Table 13 presents the definition summary of the economic dimension with one (1) theme, three (3) indicators, variables and data required, gathered from Questionnaires that reflect the users’ opinion after experiencing the system, and other details needed when evaluating economic sustainability. Both of the variables listed are qualitative that should be converted by the on-site analysis to measurement-free quantitative variables.

Table 13: Descriptions and justifications of economic dimensions parameters

Theme: Life Cycle Costs			
It involves an estimate of how much the systems would cost the property owners for the one-time installation. Also, what this installation and maintenance would cost the property owners annually over the lifespan of the facilities. Capodaglio <i>et al.</i> (2017) reported that the homes/publics ability in paying system is a common challenge.			
SI: Operation and Maintenance (O& M) cost (EC₁)			
It refers to the system's annual cost for (a) collecting and transporting black water, urine, and septic tank bubbles, (b) electricity, consumables (chemicals, P-filters) and mechanisms (pump change), and (c) control operations, comprising sampling and examining of effluents. This study only focused on the ability of most households to fund the waste charges of the system.			
Objective: Maximizing capacity/willingness to pay for standard sludge discharge charges (<i>Yes</i>)			
Data required (Variables)	Unit	Remarks	Score
The number of households willing to pay for existing desludging charges by service providers of; <i>No (EC₁₁)</i>	Number – TZS/HH	Willingly to pay $\leq 50\ 000$ which is not enough for the services	1
<i>Yes (EC₁₂)</i>		Willing to pay Between 50 000 -200 000 and even $\geq 200\ 000$	2
Justification for Indicator			
An important indicator for sustainability is the capacity to pay for sanitation among users. Users must pay for the water needed to flush the toilets and drain the septic tank of accumulated solids annually. Each two to three years, the tank must be drained depending on the design (URT, 2009). The calculation of operating, repair, and disposal costs for the septic system constructed are difficult to perform as the frequency of these acts and the site of disposal from one household to another differs significantly.			
The building, emptying, and faecal treatment should be accessible at the speed that everybody may manage to pay for without losing their capability to access additional basic needs, e.g., food, accommodation, education, and health services. The expense of storing and transporting (desludging) the black water, faeces, and septic tank sludge involves emptying scheduling frequencies and wastewater discharge charges that differ nationally. Hence, an illustrative			

average charge had been utilized for the study area. In the case of Mwanza city, the costs can roughly be estimated from 50 000 to 200 000TZs for emptying the septic tanks.

SI: Capacity to Sustain System Long Term Repair and Replacement (EC₂)

It evaluates the community's ability to finance a comprehensive plan for lasting system restoration or renewal. It usually depends on the economic status of the community.

Objective: Maximization of capacity to sustain the system (High)

Date required (Variables)	Unit	Remark	Score
No. of HHs that the plan for lasting restoration or renewal are; <i>Highly (EC₂₁)</i>	Number	Usual homeowner plans the expenses and has the finances	3
<i>Moderate (EC₂₂)</i>		Usual homeowners do not plan the expenses and have the finances.	2
<i>Low (EC₂₃)</i>		Usual homeowners do not plan the expenses and have no finances.	1

Justification for Indicator

Lasting renewal/restoration has been a homeowner's responsibility and requires money. Such typically involves blinding or leakage of the disposal fields. Therefore, this indicator is essential to bring sustainability to the system.

SI: Level of System Contribution to Local Economic Development (EC₃)

It refers to the level of the economic contribution of the systems through reuse to water supply protection, local culture, and financial gain in the stability of society (water, energy, and nutrients reuse potential). How cool and beneficial it is to use the system as viewed by the users.

Objective: Maximization of system contribution to local development (High).

Data required (Variables)	Unit	Remarks	Score
The number of households benefited from the use of the system at; <i>Highly beneficial (EC₃₁)</i>	Number-semi quantitative	Material can be reused and users' wishes (material-anything from system leads to money)	3
<i>Slightly beneficial (EC₃₂)</i>		Material can be reused but dweller does not need	2
<i>Low/no benefit (EC₃₃)</i>		Material cannot be reused as well dweller does not need	1

Justification for Indicator			
Several technologies bring economic benefit from resources recoveries that make them sustainable now how about the existing septic system. Then, this indicator is important to know the sustainability of the system.			
<i>Slightly beneficial (EC₃₂)</i>		Material can be reused but dweller does not need	2
<i>Low/no benefit (EC₃₃)</i>		Material cannot be reused as well dweller does not need	1
Justification for Indicator			
Several technologies bring economic benefit from resources recoveries that make them sustainable now how about the existing septic system. Then, this indicator is important to know the sustainability of the system.			

(iv) Technical Dimension

Table 14 presents the definition summary of the themes (n=4), indicators(n=7), variables, and data required gathered from household questionnaires which reveal the end-users views while using SS, site observation, and other details needed when evaluating technical sustainability. Through on-site analysis using the score, all variables should be translated into dimensional and quantitative variables. It also assesses the current system design using the functional approach to risk analysis.

Table 14: Descriptions and justification of the technical dimensions parameters

Theme: Performance
It measures the SS's flexibility/adaptability to changes in environment and season, shocking charges, etc. It is a key measure of sustainability, as it inspires continuous upgrading and novelty, allowing for upcoming ecological and technical change (Agudelo <i>et al.</i> , 2007; Balkema <i>et al.</i> , 2002). The system's performance measurement can be achieved efficiently by (1) offering consistency, reliability and effectiveness-oriented measures, (2) having a goal-setting process and including a routine monitoring and reporting process, etc. In addition, this theme was suitable for understanding the service's current quality, predicting potentially restricted access, and recognizing investing areas.
SI: Durability of the system (TE₁)
It means estimating the SS's remaining lifespan. Such focused on the average age of septic tanks compared to ordinary lifetime figures. Design life notes that before it must be replaced or

undergo extensive rehabilitation, how long the facility is supposed to last. This will illustrate whether or not the device is a design for extended service life and the degree to which robust materials have been defined about the local climate.

Objective: Minimization of old malfunction system in the society (below 12 years)

Data required (Variables)	Unit	Remarks	Score
The number of septic tanks that have a lifetime of: <i>Below 12 years (TE₁₁)</i>	Number	A fresh system expected to work effectively	3
<i>Between 12 to 20 years (TE₁₂)</i>		At a normal state, the systems expected to work effectively without replacement or major rehabilitation	2
<i>Above 20 years (TE₁₃)</i>		At state that required either replacement or major rehabilitation	1

Justification for Indicator

Durable systems may serve, although unforeseen events such as disturbances occur suddenly in the dropping temperature. The evaluation should be based on the SS's short or long-term durability within the society concerned. The SS lifespan has been recorded to range from 12 to 20 years.

SI: The Capacity of the Existing Septic Tank System (TE₂)

This indicator refers to the design demands and construction skills w.r.t local requirements (URT, 2009). It can contribute to the system's quality/ability evaluation to bear shock loads/seasonal effects or to the potential for overflow depending on the sizes of septic tanks and household size installed.

Objective: Maximization of capacity/quality of the system (more than 5m³)

Data required (Variables)	Unit	Remarks	Score
Number of septic tanks having the volume ranges of; <i>>5m³ (TE₂₁)</i>	Number	The systems can full serve the 15 users although it is over design according to 2012 census with approx. 5 people per household	3
<i>2.0 to 5 m³ (TE₂₂)</i>		The system that is sufficient for 1 to 15 users	2
<i><2 m³ (TE₂₃)</i>		System cannot serve the user demand and is under design	1

Justification of Indicator

The capacity of the septic tank should be sufficient for the waste settlement or floatation depends on the rate of flow of liquid through the tank. It is related to the retention time (URT, 2009). Storage space required for the sludge and scum is largely a function of the time interval between desludging. The data in Table 15 below for several years in Tanzania, to provide the septic tank sizes commonly used. It has been used in this study to formulate numerical ranges for assessing the system capacity.

Table 15: Septic tank sizes, adopted from (URT, 2009)

Septic tank size (depth is from top water level)					
Type	All wastes number of users	Dimensions			Volume
		Length (cm)	Width (cm)	Depth(cm)	V, (m ³)
1	1 to6	210	60	150	2
2	7	260	75	170	3
3	15	300	90	170	5
4	30	350	105	180	7
5	40	400	120	180	9

Theme: System Robustness

In this study, two indicators defined robustness: the risk of system failure and flow variations adaptability. Due to the more severe consequences, "the risk of failure" was considered more important (2/3) than its "adaptability to fluctuating flows" (1/3) (Vidal *et al.*, 2019).

SI: Risk of Failure of System (TE₃)

This refers to the system's potential to experience a technological challenge that might affect its treatment capacity. Failure was described as the lack of adequate functioning of the system operating under normal conditions, both partly and fully. The indicator was assessed qualitatively using three variables: low, medium, and high robustness.

Objective/Target: Minimization of the possibility of the failures (low failure level)

Date required (Variables)	Unit	Remarks	Score
The number of septic tank systems showing different failure levels;	Number	It is based on the risks level of the soil-based treatment units (Soak pits) or clogging of the media in terms of the number of failures/ year that are;	
<i>High (more than twice/year) (TE₃₁)</i>		Not being constructed correctly, which is a common problem and high failure occurs	1
<i>Medium (Twice/year) (TE₃₂)</i>		Slightly constructed properly but still showing failure signs	2
<i>Low (once/ year) (TE₃₃)</i>		Properly constructed/managed	3

Justification for Indicator

This indicator was used as a relevant indicator because of technical issues such as mechanical failures technical systems may malfunction. The following risks can be considered the risk of the soak way pits not being constructed correctly and the risk of filter clogging, etc. depending on the system units assessed (Palme *et al.*, 2005). Then, these actions must be diminished, or

SSs should be able to recover in absence of extra expense or exertion (Balkema <i>et al.</i> , 2002).			
SI: Adaptability to Fluctuations of Flow or User Needs (TE₄)			
It referred to the SS's ability to handle or adjust to influent variability. Example increased average water usage due to higher user presence or absence times while the system is not in use and the inflow efficiency. It also can be assessed regarding the climate change and site condition (e.g., changes in temperature) in study areas ((Vidal <i>et al.</i> , 2019).			
Objective: Maximization of adaptability possibility (Yes)			
Data required (Variables)	Unit	Remarks	Score
No. of systems that can function without the sign of failure are;	Number	Systems may be modified to the requirements comparatively simply because they are considered the basic requirements for existing infrastructures.	
<i>Yes (TE₄₁)</i>		No. of system that may handle high loads; flows above design criteria; installation or connection is easy, and a minor adjustment is required.	2
<i>No (TE₄₂)</i>		No of a system that may not handle high loads; flows above design criteria; installed to the new system; and only requires major adaptation	1
Justification for Indicator			
It is a significant SI as it facilitates limitless development and creativity, considering upcoming ecological and technical changes (Agudelo <i>et al.</i> , 2007; Balkema <i>et al.</i> , 2002). Note; In the case of the soak-away pit, the adaptability depends on the design and local situation.			
SI: Upgradability of the System (TE₅)			
It relates to the possibilities for users to expand or duplicate their system in the future to achieve overall targets based on past operating experience or any confusion arising using local financial and geographical circumstances as a technique. It means that, after the SS construction and operation, owners can manage their system.			
Objective: Maximization of upgradability possibility (High possibility)			
Data required (Variables)	Unit	Remarks	Score

No. of septic tanks that Future expansion possibility is; <i>High (TE₅₁)</i>	Number	Future expansion is possible. Add hygiene facilities, modifies the septic system to overcome additional hydraulic load, etc.	3
<i>Medium (TE₅₂)</i>		Future expansion is slightly possible. Allow only some of modification to take place	2
<i>Low (TE₅₃)</i>		Future expansion is not possible due to space limits, financial and willingness, or the new system needed.	1

Justification for Indicator

In the future, along with community growth, the system should be able to be updated and foreseeable using predictable managing tactics over a specified time (Balkema *et al.*, 2002). Construction of a completely new sanitation facility is not always necessary as the current system can be updated or the new system can be combined with the existing one. In some cases, existing sanitation facilities represent social and cultural priorities in the community or local economic and technical capabilities for sanitation improvement (Brikké *et al.*, 2003). Where existing community facilities are not in compliance with basic hygiene standards, the update must be taken into account first. A new technology/system should be installed if an update is not appropriate or if the places have no sanitation services. From an economic point of view, it is necessary to have a new system well-matched with a current system so that costs can be saved.

Theme: Technical Complexities

It determines how far systems are adopted and the ability of people to maintain their use. It involves the availability of materials, system coverage, local builder capacity to build the system without a deep contractor from the professionals/officials, and compulsory additional new technology needed for proper use. Then, it is necessary to determine the system's simplicity. Domestic wastewater treatment systems for households or communities should be user-friendly, technically easy and healthy, and never depend on external fuels, chemicals, or electricity.

SI: Operation (O) and Maintenance(M) level (TE₆)

It relates to the complexity of carrying out the precise acts required for operating and maintaining the facilities. Either way, inconveniences of the requisite acts, including sludge removal and filter replacement (sands or gavels in soak away pit) or chemical frequency

provisioning, are assessed. Then this study is based on the evaluation of the normal size sludge removal interval of the existing system compared to the common frequency from the literature, which is 2 to 3 years.

Objective: Minimization of technical complexity (Low non-desludging interval).

Data required (Variables)	Unit	Remarks	Score
The number of systems in HHs that, the non-desludging interval is; <i>High (TE₆₁)</i>	Number-Semi-quantitative	No of the tanks not emptied in more than six (6) years. Assumed all features showing some problems during the operation of the system in last years	1
<i>Moderate (TE₆₂)</i>		No of tanks with 3 to 6 years and assumed slightly functioning	2
<i>Low (TE₆₃)</i>		No. of tanks emptied in less than three (3) years and assumed that all systems are working properly and no problems have been observed	3

Justification for Indicator

SSs must be maintained because if this is not done, they will become a source of pollutant release. The maintenance needed for a SS is being governed by its design. It should function with minimal maintenance requirements, as any disruption will have detrimental environmental impacts. The system should have safe and sound controls to mitigate effects due to system maintenance.

SI: Availability of Materials Locally for Minor Problem Fixing (TE₇)

It relates to the availability of procurement of materials/services during operating processes and the likelihood of repairing minor issues within a reasonable period of repair. Technologies can use components and spare parts that are locally sourced and can be easily bought and transported.

Objective: Maximization of the possibility of obtaining the materials locally (High chance).

Data required (Variables)	Unit	Remarks	Score
No. of HHs responded to the availability of local materials and the possibility to repair within a reasonable time as;	Number	Necessary materials are obtainable and possible the problem may be resolved within 4 hours of notification	3

<i>High (TE₇₁)</i>			
<i>Medium (TE₇₂)</i>		Necessary materials are slightly obtainable and possibly the problem can be solved in 4 to 6 hours after it is first notified.	2
<i>Low(TE₇₃)</i>		Necessary materials not are obtainable, and the problem may be solved over six hours of the first notification.	1
Justification for Indicator			
<p>Repairs often include fixing minor device issues (for example, blockage, slight cracking, slight replacement parts contravention) to ensure that contaminants and other pollutants are removed effectively. The availability of materials and human capital are strongly affected by this within a reasonable time to repair the system. That way, the availability of materials is one of the basic SIs used in this research.</p> <p>Every community will have different reasonable times according to their understanding of how necessary it is to make sure the system works again, their ability to react to the issue, and their access to their closest service. In this analysis, the probability of repair is semi-quantitatively defined. If the problem may be resolved within 4 hours after its first notification, then a high potential is obtained. The 4-hour norm is extracted from interviews with nine (9) local builders in Mwanza city. It involves the length of regularly required spare parts acquisition and the time used to meet the service resources.</p>			

The SIs are meant to determine how to achieve sustainability. In this segment, these SIs chosen and updated are complete and versatile and may be utilized in several uses like planning and designing new systems, enhancing and updating the current system, etc. It should be noted that the concept of sustainability or SD refers to an interrelationship between environmental, economic, technical, social dimensions, etc. Since depending on the focus and perception of the study all the indicators are in some way related to each other. Then, it means that the indicator inclusion in one dimension is merely a classification process, but does not mean that it doesn't come from another dimension. For example, in indicators such as the generation of odors and noise (nuisance), that might instead be either environmental or social indicators.

4.2 Sustainability Level of the Existing Septic Systems in Mwanza city, Tanzania

4.2.1 General Household and Septic System Information in Mwanza City, Tanzania

The selection of the study area was designed to be more concentrated on the city residential area, which mainly comprises several family residential units, followed closely by the single-family units (Fig. 9). Roughly, the business/commercial houses are also present in the study (residential) area (Fig. 9). In the field of study, the SS's mean age ranged between 5 and 30 years (Fig. 10), while the residences' mean age was over, between 10 and 40 years (Fig. 11).

It was shown that some households connected their wastewater into the drainage system certainly allowed their wastewater to flow freely through the environment. Some drain their tank content into the public drains during heavy rain, causing unfriendly smell and muddy conditions (Fig. 12). It was presented that household wastewater, specifically gray water, was not all joined with a SS. In addition, in particular, ventilated improved toilets, pour flush toilets, and septic tank and soak away removal systems were the most frequent OSSs used in the study area (Fig. 13). The numbers of people in the households interviewed range from 1 to 20, with an average of 7 in each family (Fig. 14). Most respondents were housewives, senior citizens, youth, and children from morning to noon, so the majority of them surveyed. Over half were female (Fig. 15). The participants' age was graded from 18 to 84 years, and their average age was 38 years (Fig. 16). The occupation, income, and educational background describe the Mwanza city respondents (Fig. 17).

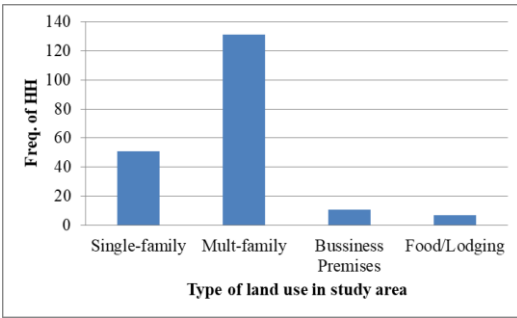


Figure 9: Land use pattern of residential area of the City of Mwanza

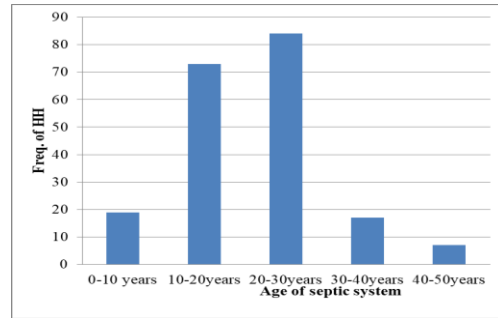


Figure 10: Respondent's rating of the age of average septic system

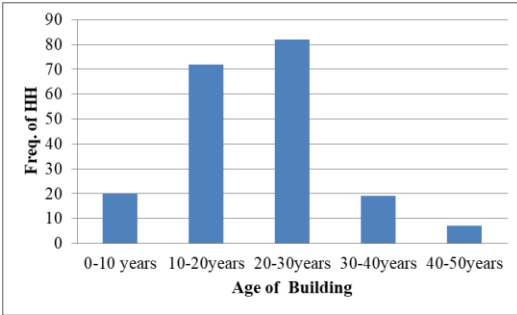


Figure 11: Average age of residential buildings in the study area

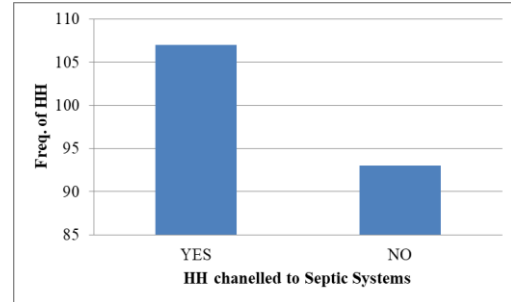


Figure 12: Premises with wastewater channelled to toilet system

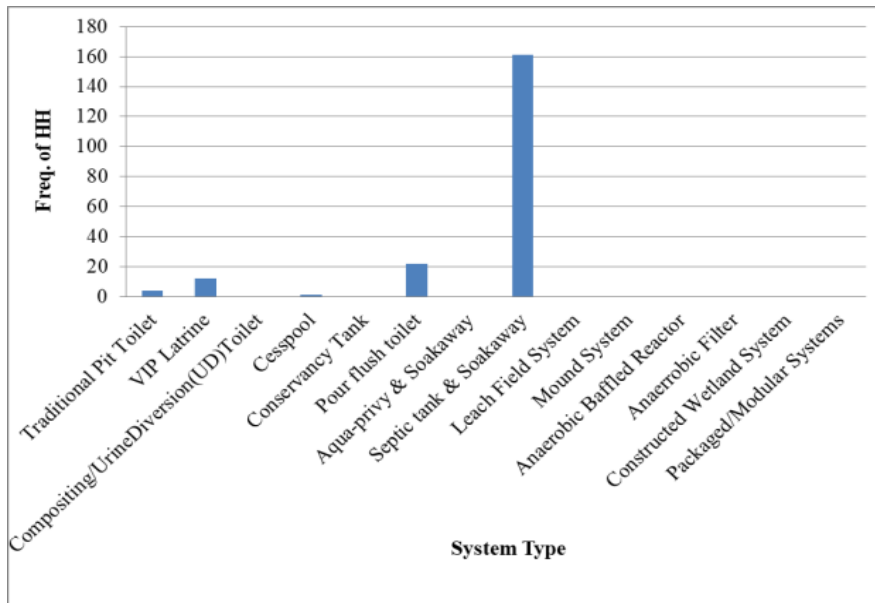


Figure 13: Common decentralized wastewater treatment system

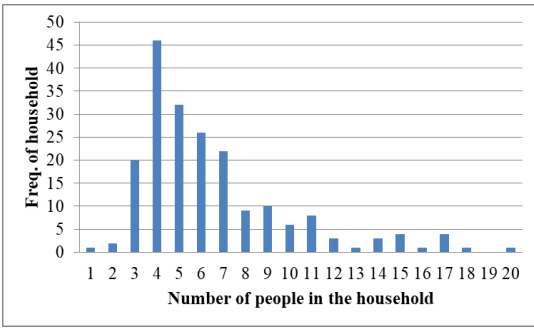


Figure 14: Distribution of the number of people in the household

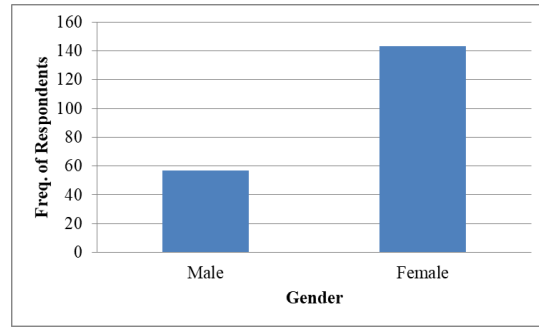


Figure 15: Gender distribution

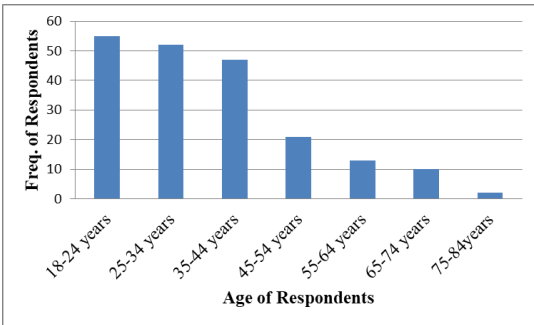


Figure 16: Age of respondents in study area

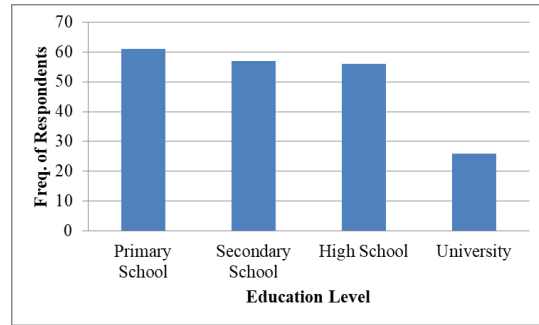


Figure 17: Respondent's education level

4.2.2 Measuring Separately the Selected Sustainability Indicators

This section included the various semi-structured interviews, site observations, and laboratory analysis results and calculations underlying the evaluations of all indicators regarding environmental, social, economic, and technical dimensions for the SS.

(i) Social Indicators Evaluation

The household (social) survey was conducted to identify public perception and experience about the septic system on issues like health and safety, its operation and management, awareness, etc. The random sampling/comfort samples for interviews were used to select 200 households, and all the critical residential buildings with SSs were selected evenly for the survey (asking questionnaires). The questionnaire sample is contained in Appendix 1. Next comments were taken from the results of the survey (questionnaire):

Evaluation of Exposure Chances to Wastewater by Users (SO₁)

The findings from the household survey shown in Figure 18 that about 103 of 200 HHs (51.5%) septic systems have no exposure likely chances to wastewater by users, and the septic tank is somehow operating well. Hence, users are unable to contact their wastewater every day because a

septic tank is a structure underground. Only 50 of 200 HHs have exposure chances to wastewater and insects. Contact might have occurred if the septic tank is emptied after 2 to 3 years. The emptying methods were either done manually or using sewage trucks. When done manually, the contents of the facilities are buried, which presents a greater risk to human health. When done by sewage trucks, the contents were also discharged into waste stabilization ponds which are not enough if each one emptied the system per regulation. Such practice may also present a greater risk to human health.

Evaluation of Public Awareness of Septic Tank Management (SO₂)

Figure 19 presents that almost all interviewees (i.e., 180 of 200 HH or 90%) responded that they do not comprehend the regular desludging function. Such may be simply understood from long non-desludging intervals (14.2 ± 4.9 years) investigated in the Nyegezi area (Mwanza city). Also, almost all STs in the study area were observed not to have a manhole to access. Hence, this situation may prevent frequent desludging. Because of the failure to know, households frequently build a large ST that costs a long service. In a household, septic tanks are discharged grey and toilet wastewater, their average sizes are large (approx. 4.2 m^3), and they are even greater than U.S. standards.

Evaluation of Aesthetics-based on Nuisance Levels (SO₃)

Figure 20 shows the findings from a household survey that the system supports the aesthetically at low nuisance level with 168 of 200 (about 84%). It is because there is enough water for flushing the toilet and the use of detergents/chemicals in toilets. Also, 16% of SSs have some issues accountable for the presence of odor problems like: Poor design and construction (which exposes the contents to the environment), flooding, erosion and water-logging hazards, poor operations, maintenance and management and over-stretching of the capacity of the systems. It was seen the raw waste was released to the environment from the system because the system has suffered physical damage Fig. 21.

Evaluation of Community Acceptance for the Septic Tank System (SO₄)

The social survey has been done in the study area for determining a fulfillment/acceptance level from SS daily users. It may be utilized as a basis for future improvements in the design and management of SSs. For a calculation of the need and acceptability of SSs to be used again and again and the findings, were about 66% accepted (highly) by households' owners (Fig. 22). It is because SSs present the most commonly used OSSs in Tanzania (URT., 2020). Moreover, other

studies reported that: (a) because it was regarded as easy to build and improve; (b) because of its convenience, low cost, long history of use, and low complexity and (c) because the local builder can construct main household as well as a SS or toilet without special training. In a society, the system's popularity provides some sense of its acceptance by a society that affects its social adaptability (Dunmade, 2002). However, some state that they accept the system due to the absence of other alternatives for comparison in the selection of the system. Therefore, the SS may be understood as simply accepted from a social perspective. Few (about 34%) highlighted a need to improve the system performance with some suggestions: Connecting the septic to the drain system; constructing septic tanks with consideration of the soil type; connecting sanitary facilities to the sewerage system; providing disposal facilities; separating flows; connecting the sanitary flows to the environments. Such answers show that few members of the community are capable of identifying shortcomings in sewage treatment and disposal, but they are not all technically sound and sustainable for improvement.

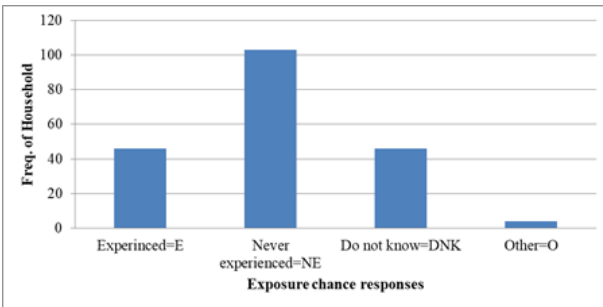


Figure 18: Exposure chances of users to wastewater

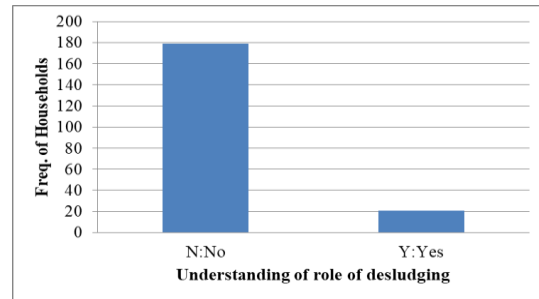


Figure 19: Public awareness of the role of desludging (n=200 HH)

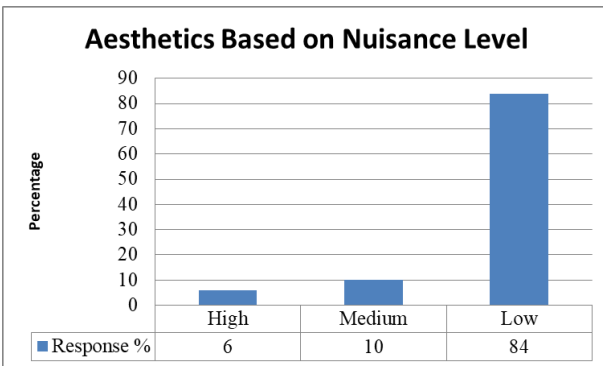


Figure 20: Aesthetics-based on nuisance levels



Figure 21: Physical damage of the system with the first-hand release of raw sewage

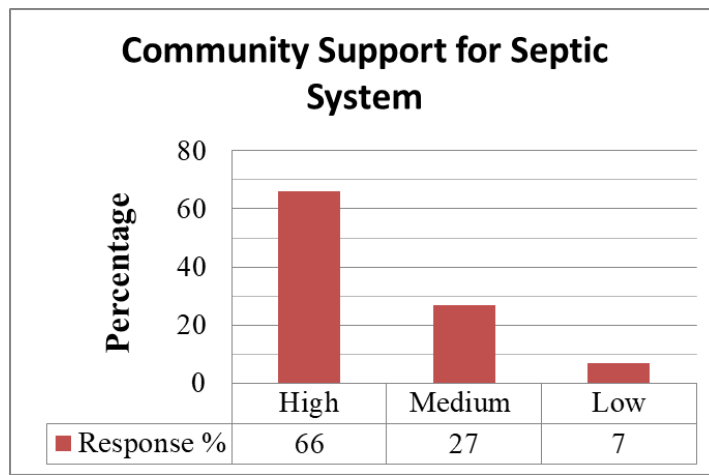
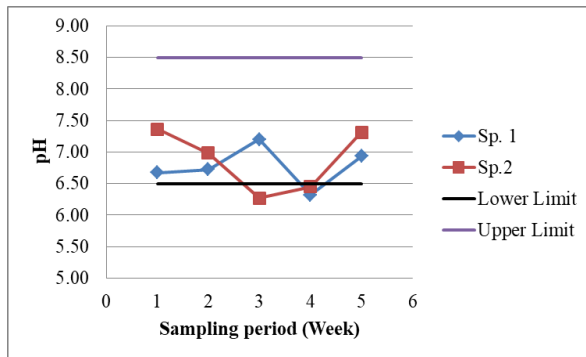


Figure 22: Acceptability of the existing system by users

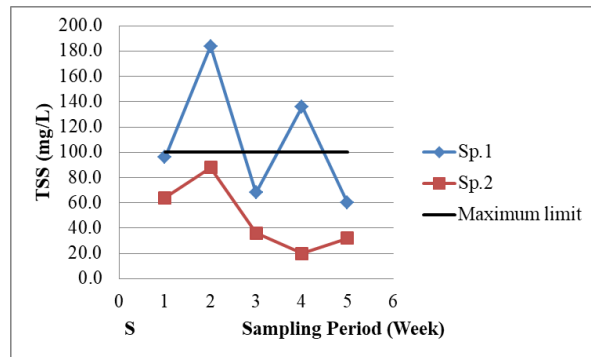
(ii) Environmental Indicators Evaluation

Evaluation of Water Quality Change of Urban Water Stream (EN₁)

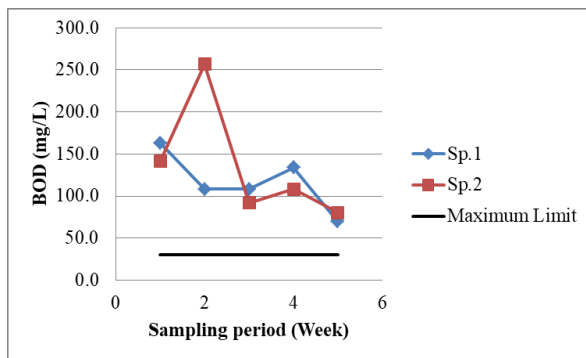
The results of the physical, chemical and microbiological quality of the carefully chosen urban stream show that the following parameters: pH, TSS, BOD, COD, nitrates, phosphates, FC, meet the standard of wastewater discharging in the environment (TZS 860:2006) (Fig. 23, (a- g); Appendix 3).



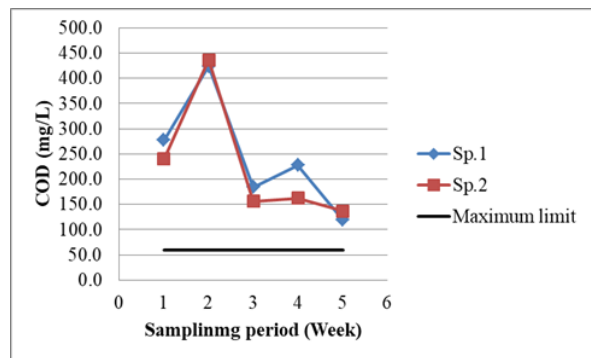
(a)



(b)



(c)



(d)

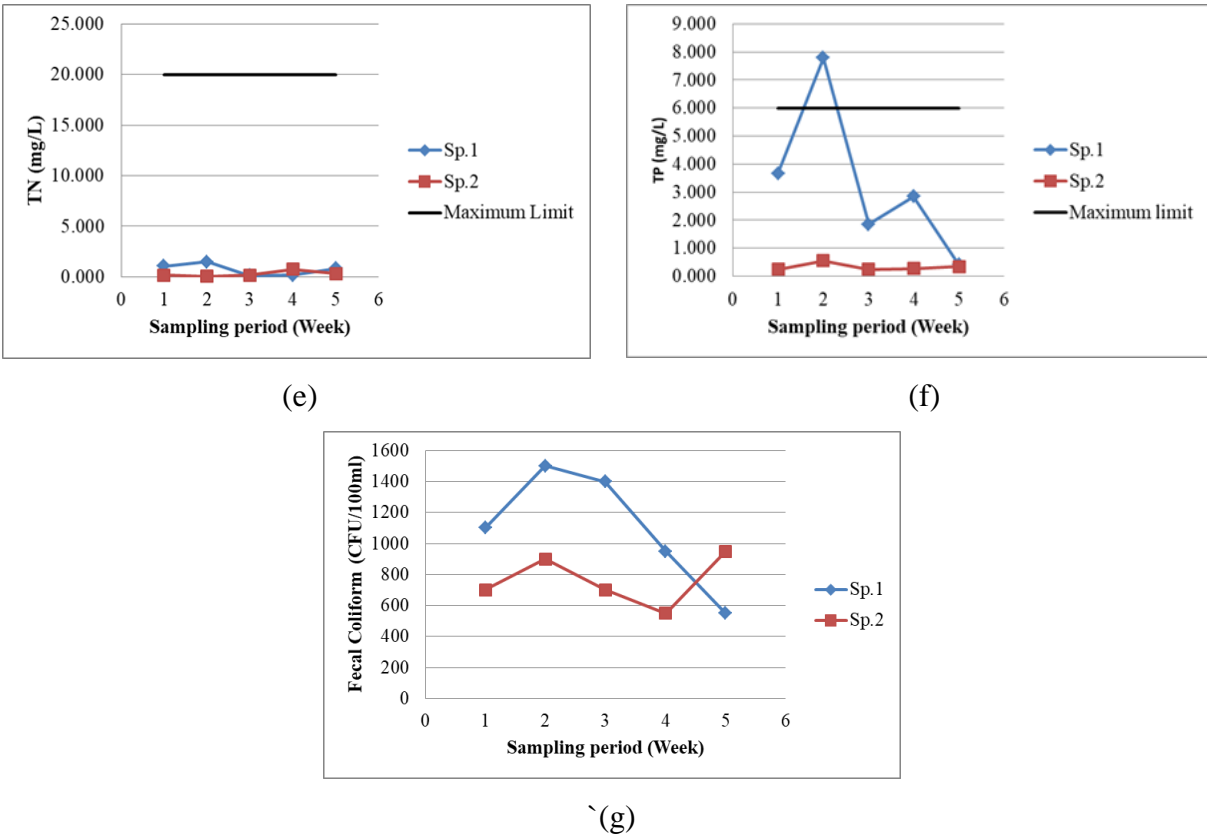


Figure 23: Typical (a - g) results of the urban stream water sample analysis

Generally, variations observed in these parameters' graphs are due to discharge variations in the streams from households located near the urban stream. Table 16 presents the results summary of the seven (7) parameters of water quality parameters for two (2) sampling sites that were compared with wastewater discharge standards into water sources.

Table 16: Summary for water quality from urban stream

Parameters	pH	COD (mg/L)	BOD (mg/L)	TC (FCU/100 mL)	TSS (mg/L)	TP (mg/L)	TN (mg/L)
This study ranges.	6.3-7.4	118-437	69.3 -256.8	500-1500	20-184	0.25-7.79	0.07-1.49
Permissible limits TZS 860:2006.	6.5 -8.5	60	30	10,000	100	6	20
No. of tested Samples passed.	7	0	0	10	8	9	10
No. of tested samples failed	3	10	10	0	2	1	0

COD=Chemical Oxygen Demand, BOD=Biochemical Oxygen Demand, TC=Total Coliform, TSS=Total Suspended Solid, TP=Total Phosphorus and TN=Total Nitrogen

Water sampling is conducted from two monitoring sampling points, two (2) samples in each week for five (5) weeks (n=10samples due to budget limitation). As shown in Table 16, the stream was seriously not polluted according to 70 tested samples as 44 of 70 (63%) do meet (not polluted) and 26 of 70 (37%) do not meet (polluted) the national standard for BOD, COD, TN, TP, TSS, pH and

FC. To truly determine if SS (sanitation) practice) are effective in reducing water contamination at the source the regular monitoring will be necessary. The study could conclude that wastewater released in the field of study (freshwater) can be ended up when: Developing knowledge on the impact of wastewater discharge on the quality of water in Tanzania has been given special attention, treating waste water before entering the stream, used to irrigate the garden, wash machinery, etc., enhancing home maintenance practices and water effluent management encourages water usage reduction without lowering hygienic standards, preventing wastewater production and developing new clean processing methods and wastewater treatment.

Evaluation of Septic System Effluent Quality (EN₂)

The performance of the ST depends on the features of the wastewater, O&M of STs, for instance, custom or chemical uses, etc. Through the evaluation of the SS sustainable performance, the effluent quality data in septic tanks were collected in Mwanza city.

Table 17 matches the STEs quality attained from this study of 15 isolated households with the literature's typical data.

Table 17: Summary of quality of septic tank effluent (n=15)

Parameters	pH	T C	TSS- mg/L)	BOD- (mg/L)	COD- (mg/L)	TKN- (mg/L)	TP- mg/L	TC(CFU/ 100 ml)
This study ranges	6.6- 8.3	22- 27	19-720	77-1800	89-3525	2-81.2	1.2- 32.9	1.00E+05 - 3.50E+08
(Swann, 2008)	-	-	50-90	140-200	-	25-60	10-30	10 ³ to10 ⁶
(Crites & Tchobanoglous, 1998)	-	-	40-140	150-250	250-500	50-90	12-20	-
(USEPA., 2002)	6.4- 7.8	-	40-350	46-156	-	19-53	7.2-17	-

COD=Chemical Oxygen Demand, BOD=Biochemical Oxygen Demand, TC=Total Coliform, TSS=Total Suspended Solid, TP=Total Phosphorus and TN=Total Nitrogen

Immediately after the samples were taken from the STs, pH and T were commonly measured. The pH values vary considerably between 6.6 and 8.3 from one sample point to another due to the water usage habits of different users. The STE had higher concentration values of COD, BOD, N, P, coliform bacteria (TC). They were suspended due to the irregular desludging of septic tanks that can continue polluting the water sources if inappropriately treated. Note that for water to flush in the pour flush toilet, phosphate detergents contained in the monitoring septic tank's effluents lead to high concentrations and differences in phosphates. The difference in the condition of the flow tanks was shown to be enormous in quality (minimum and maximum) as presented in Table 17.

On other hand, in the Septic Tank Effluent (STE), around 60% of tested samples (n=90) met the required limits from the literature.

The contaminated effluent may be clarified as anaerobic digestion has not decomposed organic matter efficiently due to low septic residency time. It is also clear that the settlement process in septic tanks was very limited, with large quantities of sludge in the effluent being transferred. In the second chamber of the septic tanks, an extreme sludge accumulation should be present because of poor desludging reported (non-desludging interval 14.2 ± 4.9 years) that leads to the possibility of short circuit flow of the wastewater. This has been demonstrated using laboratory results as the key practical issue. In order to protect the water environment, prevent potential health risks and also improve the quality of effluent which can enable compliance with the waste disposal requirements, additional treatment or modification and/or improved household wastewater is essential in addition to existing ST installation.

Evaluation of Water Use to Operate the System (EN₃)

Figure 24 presents the water consumption for flushing the toilet, where each household consists of 7 family members. Depending on the type of toilet installed in the family, water consumption for flushing the toilet varies greatly. At least 40 liters of waste disposal per day per household is suggested or presumed to allow maximum benefits for on-site excretion and sewerage system for greywaters and all sewage after wastewater disposal (Monvois *et al.*, 2010). It has been noticeable that the mean daily water consumption per household in Mwanza was 85% above the minimum value, which means that there was a small health risk. The large water consumption in the field was apprehended to mean high flush volumes and frequencies of toilets due to higher water availability. However, this has an impact on sustainable water use that requires minimum water consumption. The lifestyle effect on water consumption, per-household water consumption for toilet flushing, and other hygiene practices is positively correlated to household size (Fig. 25). In this study, a strong tendency was never detected (the relationship was not statistically strong as $R^2=0.0218$) despite the high distribution of household sizes in target households. The waster consuming behaviors are slightly good and improved, expecting hygiene practices. However, water use reduction for the operating system through water serving facilities/automation and control is suggested.

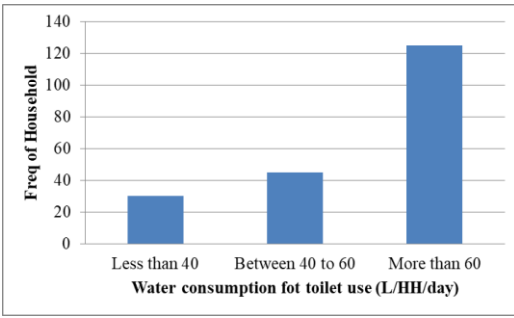


Figure 24: Water consumption for toilet flushing

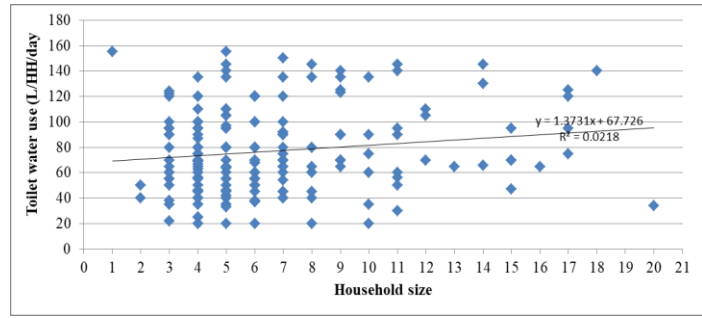


Figure 25: Daily average consumption of water per capita for various household sizes

Evaluation of Compatibility of Septic System with the Surrounding Environment (EN4)

It was found that in places where water tables are higher, where the ground is loose and gravely rocky (combined), people dig out shallow pits (septic tanks and soak pit) of about 7 feet or less which provide poor sanitary facilities as presented in Fig. 26. In comparison to the health ministry guidelines that advise 12 feet pit depth, this depth is insufficient. In these areas, the overland flow of onsite waste is probable to put the surface water at risk, especially during heavy rainstorms. It accepts that quite substantial amounts of contaminants can reach the surface waters of this area. Such demands for pit-reinforcement training and an appropriate site so that to protect equally public and environmental health. In areas with deep, permeable soils, septic tank-soil absorption systems can be used. Also, in areas with shallow soils, a limiting condition, very slowly, or very highly permeable soils, more complicated onsite systems will be required. Then in that fact, these are suggested:

- (i) The SSs need excavating work. When the soil is rocky, the building cost will rise. The pit must be increased to guarantee a small volume tank (micro-septic tank) to lower costs. Such restriction implies that the emptying incidence stays satisfactory with facilities that need a small amount of water (urine-diverting, dry toilets, etc.).
- (ii) For the soak away pit, if the groundwater table is high, especially if it is below 3 meters from the base of the pit, the risk of contamination increases. Where an identified risk of contamination is presently caused by closeness to the groundwater table, the waterproof pits must be used or the option of using the small or conventional sewage system must be studied.

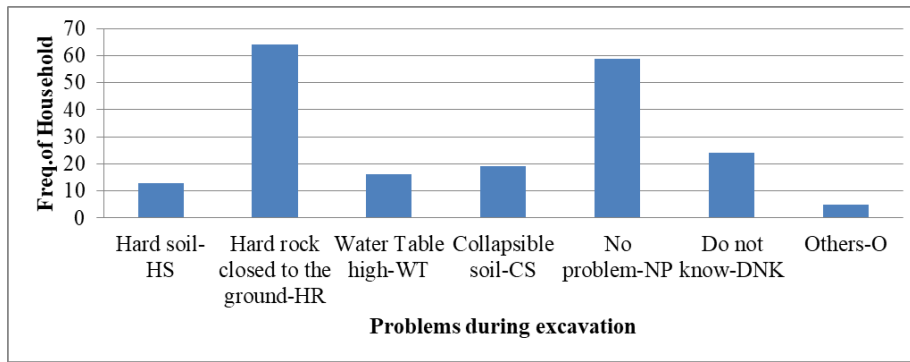


Figure 26: Problems during the excavation of pits observed by house owners (n=200)

(iii) Economic Indicators Evaluation

Economic sustainability is viewed as utilizing different plans to best use existing resources to achieve accountability and helpful stability in the long term. The investment/working costs must be assessed based on experiences and prices derived from the building/operating of such systems in Tanzania to classify the most economical SS plans and measured remedy choices for existing failing systems.

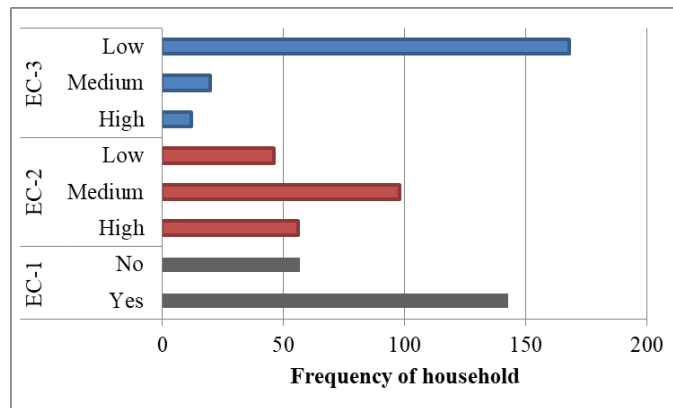


Figure 27: Survey results for economic sustainability indicators evaluation

Evaluation of Operation and Maintenance Cost (EC₁)

A survey that assesses the ability goes in hand with the willingness of the local population to pay for emptying the system (operational cost) was performed by the author in the area. According to service providers, the common prices are between TZS-50 000 and 200 000 for desludging of the tank (every 2 to 3 years). Nearly all interviewees were prepared to pay for emptying the system, except 57 persons (Fig. 27). Even 15 out of 200 people were willing to pay higher costs if necessary to operate and maintain the system successfully. It is a great condition for the treatment system's economic sustainability.

Evaluation of Capacity to Sustain Existing System (EC₂)

Figure 27 shows, that the users have a medium capacity to sustain the system (98 of 200 or 49%) due to the presence of some plan to take care some of minor repairs and maintenance. This is also due to the socio-economic status of the users most of them having a medium income.

Evaluation of Contribution Level of System to Local Economic Development (EC₃)

The fundamental data from the questionnaire regarding payment will extend only to what users saw as an advantage or importance. Figure 27 shows the 168 of 200 (84%) users have low benefits from SS. It is because there are no reuse practices implemented in the study area. Therefore, additional funding or resource recovery will continuously be required to guarantee the sustainability of the services.

(iv) Technical Indicators Evaluation

From the prior researcher or user knowledge and highest practices, the best qualitative technical indicators are measured. Then, Fig. 28 presents the results from the site observations by the researcher (author) and households' survey (users) of the septic system in the study area.

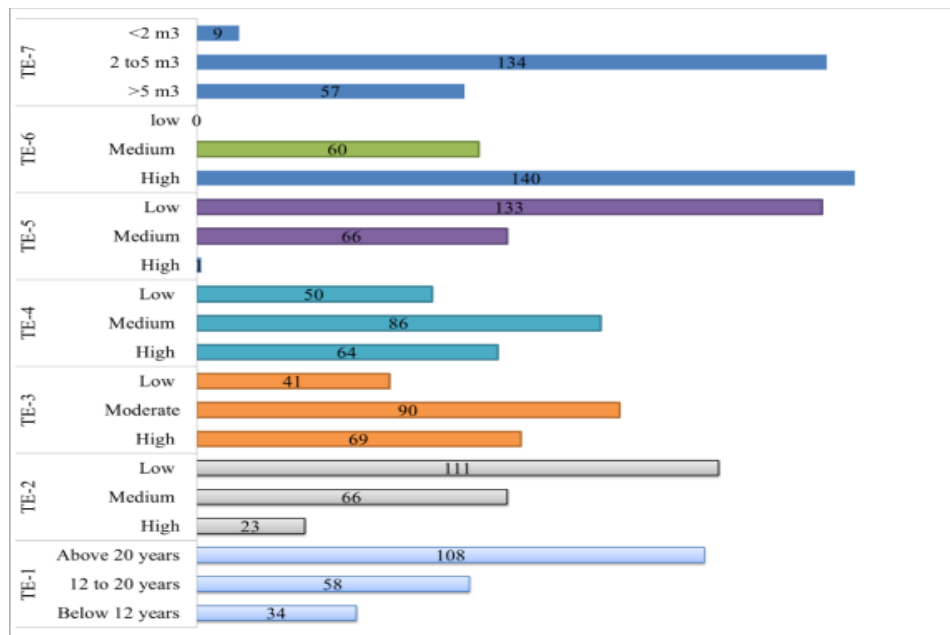


Figure 28: Overall results of technical sustainability indicators evaluation of existing septic systems

Evaluation of Durability (TE₁)

Almost 54% of septic tanks were more than 20 years (Fig. 28) since their construction. The average life span is of 21.5 ± 8.7 years, then, means that it is expected to have limited performance (high

rate of failure) even though some seemed to work suitably despite being out of design lifetime (12 to 20 years). In many studies durability (age) can play a role in the failure rate of septic tanks: For example, the risk factors increasing by 5 for 10-29 years and by 12 for 30 and above years of septic systems. In similar (Capps *et al.*, 2020) reported that almost 70% of the OWTS presented potential environmental risk due to their age (25 years or older). The densities and ages of SSs, therefore, cause severe environmental as well as human health problems.

Evaluation of Risk of Failure (TE₂)

Figure 28 presents that 111 of 200 (56%) SSs were having a low risk of failure (high robustness). Given that, they usually function well when the filter material/soil is well designed and loaded as the main risks (Siegrist *et al.*, 2000). The other respondents stated that there are problems such as the lack of water and the frequent overflowing of raw waste during the rainy season. The interview with the ward health official confirmed that challenges and disorganized means for emptying and desludging are done as an option.

Since SS can comply with public health and environmental standards without a complex design, the SS-fit is entirely used. Though, when it is poorly applied, it may generate health problems. The inventory showed that effluent was on the absorption area of the system in some buildings visited. The absorption area was also shown to be surface damp. The results of this study were also compatible with (Kihila & Balengayabo, 2020) in their study, where they characterized the most common ST issues to include: cracks, deteriorations, and damages of different levels, leakages, and exposures of contents to the environment. Such issues, as stated by them were due to a lack of basic operations and maintenance.

Evaluation of Adaptability to Flow Fluctuation or User Needs (TE₃)

In Fig. 28, 41 of 200 septic systems (at soak pits) were found to have dilution problems (low adaptability), indicating that the sealing layer was not appropriately constructed. Hence, the technical function of these sand filters was different from that expected from a standard design. The 90 of 200 have shown adequate hydraulic function (medium adaptability). Whereas, 69 of 200 SSs had to cope with higher hydraulic loads and poorly treated effluent from the septic tanks that lack frequent desludging leading to higher sludge accumulation and low retention time of the wastewater in the tank (high adaptability).

Evaluation of Upgradability (TE₄)

The upgradability is medium, or it is marginally impossible to expand the system (Fig. 28). The evaluation results also revealed a lack of sufficient and particular regulatory standards for SSs in the study area. Such a situation creates quality obedience checking too hard for regulators to perform. It was shown that the deprived and insufficient regulatory/design standards of the SS effectively limited the implementation of additional innovative SS technologies.

Evaluation of Operation and Maintenance Level (TE₅)

Nearly every SS was left to operate at the expense of nature as the main finding of this assessment process. Also, it was noted that the level of maintenance or septic tanks' desludging situation was low by 133 of 200 (66.5%). The SSs are out of the required desludging time of 2 or 3 years (URT, 2009) (Fig. 28). Even if septic tanks operated for 14.2 ± 4.9 years (Table 19), most of them have not emptied so far. Because of a lengthy operation without desludging by the user, sludge was over-accumulated in the septic tanks. The sludge accumulation reduces the hydraulic holding time for a septic tank, a significant factor in the settling performance and anaerobic digestion. Then, septic tanks' performance in the area under study will be limited. The study also showed that common SSs had not been properly operated and maintained in their conditions (from 10 to 30 years). Of those who have full septic tanks, just 66 of 200 HH have emptied septic tanks, but 1 of 200 HH have just given up and built a new tank or have not done anything. Each SS was subject to maintenance deficiencies and had its disruption at various steps. There were also flaws in routine health/sanitation inspections: Very few SSs have been examined by environmental health/sanitation officials in the previous five (5) years. The evaluation results presented that the regulator did not conduct routine health inspections to enhance the quality of operations and management of SSs in the field of study.

Evaluation of Availability of Local Materials for Minor Fixing (TE₆)

Figure 28 presents that the availability of the materials is high because of the easy availability of hardware shops in the vicinity within 4 hours. It was proven in Table 18, showing the travel time or distance and kind of that materials or service.

Table 18: Material and services accessible in the study area

Place	Traveling time	Accessibility
Bohongwa and Mkolani, the Nyegezi nearby small business center	±7.8 km, ±20 minutes driving	Materials like concrete (cement, gravel, sand), brick, block, stone, steel, PVC pipes and fiber, Spare parts dealers
Mwanza city, Business center	±10.2 km, ±30 minutes driving	All materials and services are obtained in the above location. Service is for vacuum truck for desludging.

Evaluation of the Capacity of Existing Septic Tank System (TE₇)

The septic tanks' structure based on dimension, number of users, and number of chambers outlined in, Table 19 were good because they met the (URT, 2009). The STs were big (i.e. 4.2 m³ of approx. Seven (7) people per household) because most users frequently reflect big ST defines proper performance. Such dimension is higher than the U.S. or European standard ST (3m³), having five (5) people per household. A positive correlation between the number of users and volume of ST (size) was observed but did not show clearly the trend ($R^2=0.0112$) (Fig. 29). The STs were built mainly from practice. No difference in system dimensions utilized between individual and multi-household units was observed from visual observations. Bearing in mind that the SSs cannot be left to homeowners to operate and manage the way they like, architects and engineers (artisans or builders) cannot be left to design and construct whatever they wish without observing any standards.

Table 19: All septic tanks' characteristics (n=200)

Septic tanks quality	No. of users	Non-desludging interval	Volume (m ³)
Minimum	1	3	1.28
Average	7	14.2	4.2
Maximum	20	23	18
Standard deviation	3	4.94	2.36
Medium	5	15	3.6
Requirements (URT, 2009)		2 or 3 years	>2

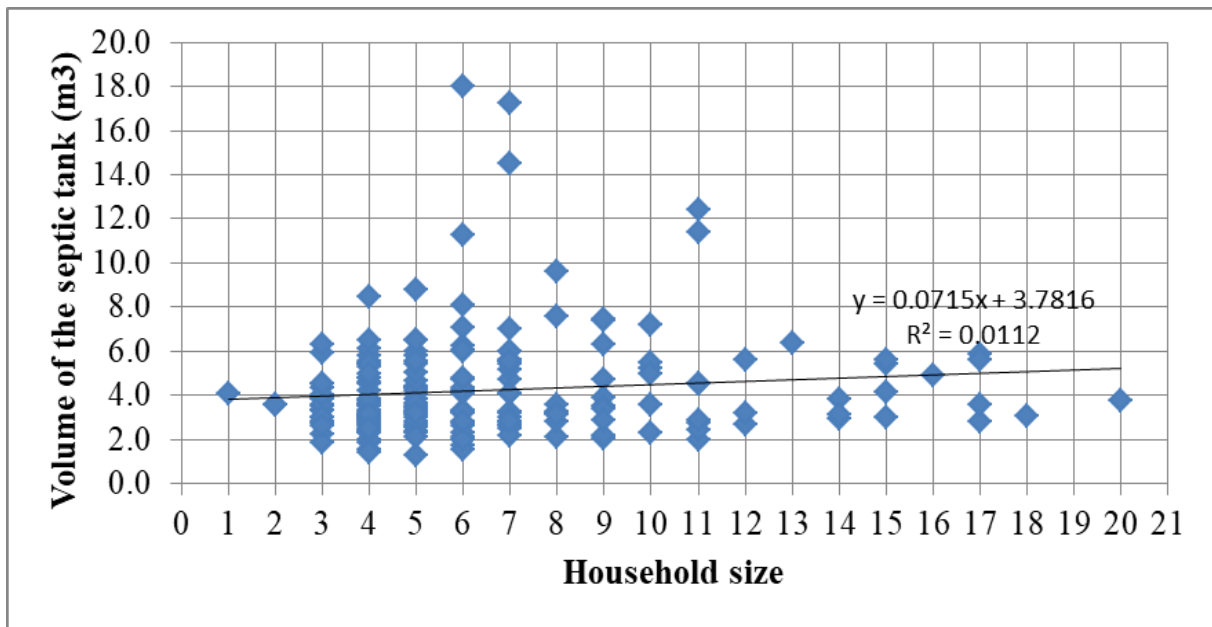


Figure 29: Volume of individual septic tanks to different household sizes

4.2.3 Fuzzy-based Indices Approach for Assessing the Sustainability of Septic System

(i) Conceptual Framework for Assessing Septic System Sustainability

Figure 30 demonstrates a conceptual structure developed for evaluating the SS sustainability potential in Mwanza city, Tanzania symbolized as an inverted tree diagram. However, each parameter is being computed depending on the parameters of the previous level. It is sole and more locally modified equal to the current ones (Iribarnegaray *et al.*, 2012; Malisie, 2008). In other words, the framework differs depending on: (a) the number and type of discrete variables/indicators/dimensions, (b) indicators' distribution in dimensions, and (c) indicators' weights. These frameworks' changes were clarified by the context-specific of sustainability idea because using a framework which is not adapted to the study contexts could result into failure in sustainability improvement program.

This framework contained eighteen (18) most pertinent and typical SIs. The indicators carefully chosen from the fifty (50) identified valid indicators grounded mostly on their data measurability and availability. The two or three variables were categorized into respective indicators. The indicators were characterized in four dimensions as economic, social, technical and environmental dimensions with three, four, seven, and four indicators respectively. Then these dimensions are aggregated into GSI, termed as septic system sustainability index (SSSI). The arrows at any level show aggregation processes of the parameters. The equations, which include the weights of the

parameters, were used to obtain the indices. For example, the indicators were obtained from the aggregation of various variables evaluated depending on the linguistics words used.

In this framework, the sum of SIs used is less than those provided by the literature review. Such can be clarified using a statement that it is developed for RSA on differing to full sustainability assessment (FSA) that offers extra information with a huge amount of SIs (Cossio *et al.*, 2020) . If the framework users raise their allegiance to OSSs’ sustainability potential, they may increase extra-understanding using the FSA perspective.

On the other hand, if a conceptual structure is valued, diverse structures are potential depending on the local situation and the accessibility of dependable info/data Fig. 33. Parameters were carefully chosen at all levels so that every variable, indicator, or theme/dimension may ultimately be measured as a relatively autonomous sustainability measure. Parameters (i.e., variables and indicators) may vary all over the place and the time for a similar context provided that the conceptual framework's integrity is observed. Such exceptional feature makes the FIA very flexible and adaptable to various conditions while maintaining its theoretic stability. It is not the approach weakness, as it may seem at, first sight, instead, the flexibility of the calculation process and the dynamic character of the index are debatably amongst its strengths.

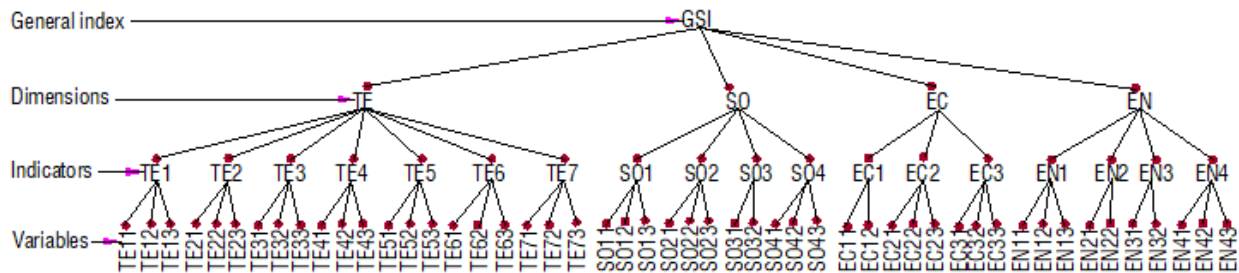


Figure 30: Conceptual framework, see parameters codes in Table 20

Such a section discusses the results of the FIA application in SA of SS that were used to help the decision-making process for the selected study area. Computation was performed using a Microsoft excel.

(ii) Measurement of Indicators

Table 20, columns 4 and 5, presents the summary of all numerical values of each SI and variable used to obtain sustainability indices regarding the case study. In other words, it represents the responses of the septic system owners and the results of laboratory analysis. Qualitative data are from survey questionnaires and field observation. Quantitative data are from urban water/septic tanks effluent sampling and laboratory analysis to know the number of samples passed or failed

concerning the local water uses quality and discharge limits standards were collected by the researcher. Raw data for each indicator were straightforward converted into the total populations (N) responded to and frequencies/rate of recurrences (N_v) per variable. These numerical values ought to be modified for each situation and also vary over time.

(iii) Normalized Sustainability Variables

In this study, the variable is whether ‘dichotomous or ordinal’. Suppose, for ordinal variable, the i^{th} indicator, public awareness for septic tank management has three (3) variables: High, medium, and low (Table 20, column 3) with assigned scores/ranks (AS_v) of 3, 2, and 1 (Table 20, column 6) respectively. These scores depend on an objective of SI to the SS sustainability fulfilment. This indicator aims to obtain a high awareness level. Once the variables are made unidirectional, normalization is carried out using Equation 2 for ordinal/binary variables as per conditions rules. However, with Equation 2, $AS_{max,v} = 3$, $AS_{btn,v} = 2$, and $AS_{min,v} = 1$, and the normalized values SVI_v are 1, 0.5, and 0 (Table 20, column 7) respectively. Hence, the equation is used for obtaining normalized values of all variables termed as the degree of membership or sustainability variable index (SVI_v) ranges 0 to 1. It depends on the type or number of variables being analyzed. Here SIs were represented by a unit-less value ranging from 0 to 1 so as, the units applied and fluctuations range while quantifying a SI doesn’t impact the answers of sustainability (Molinos-Senante *et al.*, 2014; Munda, 2005).

(iv) Weights of the Parameters

The weighting of the parameters as the key and complicated step was undertaken simply with equations (Equation 4 and Equation 4 for w_i and w_d , respectively). It is a suitable approach as the weight is provided regarding the responses’ frequency of the existing situation. For example, higher weights were to most worse-performing factors or vice versa (Table 20, columns 9 and 11). It is not surprising that the social dimension is the least important one for the understanding of the sustainable SS (Table 20, column 11). Without a doubt, in past alike studies, social tendencies also appear to have shown that social dimension is less significant during choosing, planning, or understanding the sustainable wastewater treatment system (Molinos-Senante *et al.*, 2014; Muga & Mihelcic, 2008; Plakas *et al.*, 2016).

(v) Sustainability Indices

Once the N , N_v , AS_v , SVI_v , w_i , and w_d , were assigned and computed as shown in Table 20, the next step was to calculate or aggregate the sustainability indices for each indicator (SII_i),

dimension (SDI_d) and overall (GSI_{SS}) of SS sustainability using Equation 3, Equation 5 and Equation 7.

Table 20: Input data for indicators, dimensions, and general sustainability indices evaluation of septic systems

1	2	3	4	5	6	7	8	9	10	11
Indicators	Variables	N	N_v	AS_v	SVI_v	SII_i	w_i	SDI_d	w_d	GSI_{SS}
Social dimension-SO										
Exposure chances to wastewater by users SO_1	High- SO_{11}	200	50	1	0					
	Medium- SO_{12}		47	2	0.5					
	Low- SO_{13}		103	3	1	0.63	0.20			
Public awareness for septic tank management- SO_2	High- SO_{21}	200	145	3	1					
	Medium- SO_{22}		24	2	0.5					
	Low- SO_{23}		31	1	0	0.79	0.11			
Aesthetics based on nuisance level - SO_3	High- SO_{31}	200	12	1	0					
	Medium- SO_{32}		20	2	0.5					
	Low- SO_{33}		168	3	1	0.89	0.05			
Community support for septic tank system- SO_4	High- SO_{41}	200	132	3	1					
	Medium- SO_{42}		54	2	0.5					
	Low- SO_{43}		14	1	0	0.80	0.10	0.73	0.14	
Environmental dimension-EN										
Access to enough water supply to operate the system- EN_1	Low- EN_{11}	200	30	1	0					
	Medium- EN_{12}		45	2	0.5					
	High- EN_{13}		125	3	1	0.74	0.13			
Quality of septic tank effluent- EN_2	Good- EN_{21}	90	45	2	1					
	Bad- EN_{22}		45	1	0	0.50	0.30			
Water quality of the stream, river, or lake in the city- EN_3	Good- EN_{31}	70	27	2	1					
	Poor- EN_{32}		43	1	0	0.39	0.41			
Compatibility of septic system with surrounding environment- EN_4	High- EN_{41}	200	115	3	1					
	Medium- EN_{42}		25	2	0.5					
	Low- EN_{43}		60	1	0	0.64	0.2	0.51	0.29	
Economic dimension-EC										
Ability to pay for desludging charges- EC_1	Yes- EC_{11}	200	143	2	1					
	No- EC_{12}		57	1	0	0.72	0.1			
Capacity to sustain system - EC_2	High- EC_{21}	200	56	3	1					
	Medium- EC_{22}		98	2	0.5					
	Low- EC_{23}		46	1	0	0.53	0.28			
System input Level to local development - EC_3	High- EC_{31}	200	12	3	1					
	Medium- EC_{32}		20	2	0.5					
	Low- EC_{33}		168	1	0	0.11	0.96	0.26	0.59	
Technical dimension-TE										
Durability- TE_1	≤ 12 yrs. - TE_{11}	200	32	3	1					
	12 to 20 yrs- TE_{12}		45	2	0.5					
	≥ 20 yrs - TE_{13}		123	1	0	0.27	0.6			
Risk of failure of system- TE_2	High- TE_{21}	200	23	1	0					
	Medium- TE_{22}		66	2	0.5					
	Low- TE_{23}		111	3	1	0.72	0.1			
Adaptability to flow fluctuation or user needs- TE_3	High- TE_{31}	200	69	3	1					
	Medium- TE_{32}		90	2	0.5					
	Low- TE_{33}		41	1	0	0.57	0.2	0.50	0.30	

0.42

1	2	3	4	5	6	7	8	9	10	11
Indicators	Variables	N	N_v	AS_v	SVI_v	SII_i	w_i	SDI_d	w_d	GSI_{SS}
Upgradability- TE_4	High- TE_{41}	200	64	3	1					
	Medium- TE_{42}		86	2	0.5					
	Low- TE_{43}		50	1	0	0.54	0.3			
Operation, and maintenance level required- TE_5	High- TE_{51}	200	1	1	0					
	Medium- TE_{52}		66	2	0.5					
	Low- TE_{53}		133	3	1	0.83	0.1			
Availability of local materials- TE_6	High- TE_{61}	200	140	3	1					
	Medium- TE_{62}		60	2	0.5					
	Low- TE_{63}		0	1	0	0.85	0.1			
The capacity of existing septic tank system- TE_7	>5 m ³ - TE_{71}	200	57	3	1					
	2 to 5 m ³ - TE_{72}		134	2	0.5					
	<2 m ³ - TE_{73}		9	1	0	0.62	0.2			

Note that: N_v =response frequencies per specific variable, N=total of response frequencies, AS_v =assigned scores per variable, SVI_v = sustainability variable index, normalized values or degree of membership per variable, SII_i = sustainability indicator index, w_i and w_d =weights for the indicators and dimensions, SDI_d = sustainability dimension indices, GSI_{SS} =general sustainability index

(vi) Representation and Interpretation of the Indices

Finally, the representation or interpretation of these indices was done also in this sub-section.

General Sustainability (GSI_{SS})

The result for the GSI was 0.42 of the whole SS in the city (Table 20, column 12). It is lower than the 0.50 verge and is in the danger range. The SS is already running with an unsustainability performance. Then, improvement actions should be highly suggested. This finding reveals the recent sustainability situation as it was informed over a sequence of studies as for OSSs issues in Tanzania (Lyimo *et al.*, 2007). The existing SS is facing a large number of restrictions to its sustainability within the study area. These restrictions are aging, poor maintenance, non-desludging of the system (Kihila & Balengayabo, 2020).

Sustainability Dimension Index (SDI_d)

Figure 31 (b) presents SDI_d from Table 20, column 10 in a radar diagram that may provide information on the sustainability of the whole system in the study area. It is essential to identify the failures to obey the standards/sustainability scales, enable faster outcomes transmission toward related stakeholders, and spread results to wide spectators. For example, the social sub-index presented the highest value 0.73 (good state), the technical sub-index is 0.51 (good), followed by environmental 0.50 (danger state), and the lowest was the economic dimension with 0.26 (danger state). The first two dimensions mean that the optimization and transition/corrective are recommended. The last two mean that immediate relief and restorative measures/procedures are recommended. The least is an economic dimension that complies with many reports that many

OSSs, such as soil treatment systems like SSs, are not sustainable in terms of economics because the reuse practices are limited (Hashemi, 2020). Moreover, the verge value at 0.50 (as a thick line) was added to explain if parameters' sustainability index is below acceptable verge value. Then, improvements are obligatory. For example, the economic is below while social and technical are above and environmental at the balance of verge value. These results highlight the issues of those social and technical dimensions alone are not enough to guarantee the sustainability of the SS.

Sustainability Indicator Index (SII_i)

- **Social Indicators**

All social indicators were above an acceptable verge value fixed at 0.50 see Fig. 31 (a). The aesthetics based on nuisance level (SO₃) offered the highest index 0.89, followed by community acceptance for SS (SO₄) with 0.80, public awareness for septic tank management (SO₂) with 0.79 (all are in excellent range) while, the exposure chances of wastewater by the user (SO₁) presented the lowest index 0.63 (in good state). The reasons for the SO₁ to have the lowest index than others could be attributed to lack of handwashing facilities, lack of appropriate disposal facilities, and greywater-free discharge to the environment in some residential buildings in the study area (Kihila & Balengayabo, 2020).

- **Environmental Indicators**

Some of the environmental indicators (One half) were above an acceptable verge value see Fig. 31(a). Access to enough water supplies to operate the system (EN₁) presented the highest value, 0.74 (good), followed by compatibility of SS with the surrounding environment (EN₄) 0.64 (good). Quality of septic tank effluent (EN₂) with 0.50 is at balance state or in danger state, which complied with the report by Kihila and Balengayabo (2020) that the septic tanks understudy in their status do not meet effluent discharge limits. In other words, septic tanks release significant amounts of pollutants to the environment exceeding the allowable limits. The water quality of the stream/main river/lake in the city (EN₃) has an index value of 0.39 and is in an unacceptable or dangerous range. Similarly, the issue of water pollution was reported elsewhere (Kashaigili, 2010; Maganga *et al.*, 2002) and is also among the main challenges in many water sources in Tanzania. Then, the current operation and regime of the septic tanks cannot be used as a standalone treatment of the existing treatment arrangement to improve the STE quality, which may allow compliance to the discharge requirement and protect the quality of water.

- **Economic Indicators**

The indicators (two out of three) were above acceptable verge value (Fig. 31 (a)). Ability to pay for desludging charges (EC_1) showed the highest index, 0.72 (good), followed by the capacity to sustain system (EC_2) with 0.53 (good), and system input level to local development (EC_3) showed the lowest index 0.11 (unacceptable range). The reasons for EC_3 to have the lowest value could be the absence of resource recovery practices and many SSs, which are built for three significant aims, collection, treatment, and disposal of wastewater (URT, 2009). Furthermore, water is highly available (84% of water coverage) at a low or reasonable cost in the study area. Therefore, the latter indicator could lead to the low economic sustainability of SS in the city.

- **Technical Indicators**

The majority of technical indicators (six out of seven) were above an acceptable verge as presented in Fig. 31 (a). Note that: The availability of local materials (TE_6) presented the highest value 0.85 (excellent), followed by operation and maintenance level required (TE_5) with 0.83 (excellent), risks of failure of the system (TE_2) with 0.72 (good), the capacity of existing septic tank system (TE_7) with 0.62 (good), adaptability to flow fluctuation or user needs (TE_3) with 0.57 (good), upgradability (TE_4) with 0.54 (good) and the lowest is durability (TE_1) with 0.27 (danger). The reason for TE_1 to have the lowest value is due to the higher desludging interval (more than 20 years). A similar cause could be supported by Brikké *et al.* (2003) and Capps *et al.* (2020) that aging SS is a common problem (found around the globe).

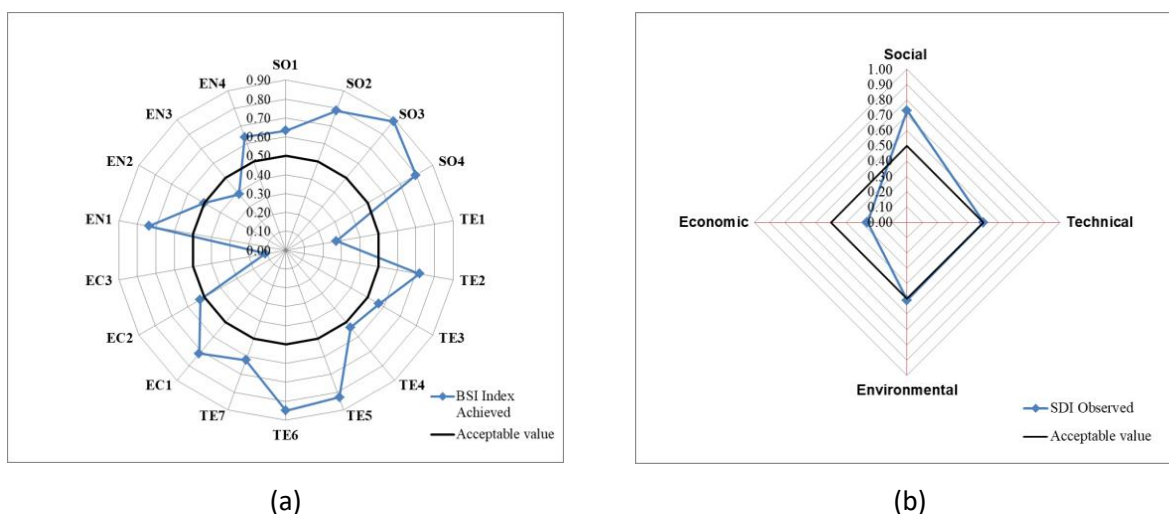


Figure 31: Sustainability indices in radar chart diagram: (a) sustainability indicators and (b) dimensions

It is the first time the GSI was calculated for SS in Mwanza city. Therefore, sustainability tendencies or potential situations are too soon to be identified and predicted. Building these

situations can be essential to clarify the track toward sustainability. In the evaluation process in Tanzania, especially in so-called developing countries, data accessibility and dependability are critical. The more data, the more actual the index is. The data absence or unreachability also indicates that the management system is quality and transparent. This is why the index must be measurable, although data is not easily accessible as policymakers decide anyhow, with or without data. The lack of data can disturb the calculation of particular topics. However, data must not inhibit the computation of the index because the purpose of this calculation, regardless of the beginning, is to develop/improve the quality of SS management.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Meanwhile, the first objective of the study was to identify SIs for SSs' assessing sustainability potential. Several studies have developed SA with a series of SIs in the field of the wastewater treatment system. However, from the time-to-time majority of SIs are too global to reflect local wishes, less relevant in the setting of Tanzania's sanitation system than in other settings, and are not fixed universally to assess the sustainability of systems. Then, in this research, 18 out of 50 relevant SIs, which may be utilized in decision-making or operations were selected and characterized in environmental, social, economic, and technical dimensions for assessing the sustainability of SS. These indicators demonstrate the significance of matching the series of SIs to the particular sanitation system's features being studied.

Regarding the degree of sustainability of the SSs using FIA as a decision tool (second and third research objectives), $SIGI_{SS}$ of 0.42 (scaled 0–1) has been established or computed of Mwanza city's SS within northern Tanzania. Such value is within the danger range, lower than an acceptance verge of 0.50, then instant actions are required for SS. Economic and environmental fell in danger range and others (technical and social), fell in the good range. It indicates that SSs should be supported with funding and legislation for their research and development (R&D). In other words, such a study finds that SS is socially very beneficial in the city. Then, much effort has to be performed on other dimensions. The SA of SSs in Mwanza city using FIA permitted an all-inclusive analysis for understanding the existing systems' weakest points. It also, proposes for actions/measures to improve. Therefore, fuzzy-based sustainability indices are simple, flexible, stable and reliable indexing systems and could be used as suitable tools for assessing the sustainability of other OSSs and case studies.

5.2 Recommendations

5.2.1 Improvement of Septic Systems in Rocky Areas

Evaluation of sustainability of SSs in urban areas (Mwanza city, Tanzania) and their GSI paves a way for system improvement. Then, it is essential to look into indicator values to comprehend the result or importance of the life-threatening indicator. The requirement for particular strategies (like

awareness, discharge-free, etc.) to promote SS improvements is highlighted by these life-threatening indicators as follows:

- (i) Socially the system is in a good range. All indicators are in excellent range then monitoring and maintenance are suggested by users or health officers on any complaints. Except for the exposure chances indicator, the system is in good range then ‘optimization and transition procedure is must like behavior change in hygiene practices.
- (ii) Environmentally, the system is in danger range. The water consumption and compatibility are in a good range, then, the optimization and transition measures (i.e., the use of water serving toilet facilities, encourage the cluster system, etc.) are recommended. The septic tank effluent quality and water quality from the urban stream are in danger, and the ‘corrective measures like adding the new system, stop free-discharging the waste, etc.’ are suggested.
- (iii) Economically, the system is slightly in danger range. The system contribution to the local economy is in unacceptable range, then, relief and restorative actions are must like inserting the recovery of nutrients or energy that in the end knowingly decreases the entire system's operating and maintenance costs. The capacities of the user to sustain the system and O&M in terms of ability to afford the desludging charges are slightly and fully respectively in good range, then the optimization and transition procedures are must like the presence of cheap repairs materials or improvement of the social-economic situation.
- (iv) Technically, the system is in a slightly good range. Indicators: (a) durability is in danger range then corrective action is recommended; (b) risk of failure, adaptability, upgradability, and capacity are in good range then optimization and transition procedures are suggested; and (c) O&M level required and availability of the materials are in excellent range then monitoring and maintenance of the system is required.

5.2.2 Recommending Usage of Fuzzy-based Indices Approach

Without a doubt, the “conceptual framework” applied in this research must be simply applied to other OSSs, by adjusting some of its constituents specifically in developing countries where OSSs are diverse.

FIA is appropriate for addressing complex decisions with ambiguities, for instance, supreme sustainable indicator/dimension/technology ranking. It will help answer the question of how to

reliably evaluate the sustainability of OSS to encourage a transformation towards a sustainable system and to comprehend the numerous interdependencies between the evaluation elements/parameters. FIA is logical and complex enough to enable vital evaluation and surveillance of the city's whole SS. It is believed to be helpful in the conceptual coherence and efficiency of SS evaluations. Also, it is helpful to classify the course of action and upgrading strategies by constructing the GSI with locally relevant SIs. But, measuring a GSI in a whole city is an appropriate way of disseminating the results to a wider public and communicating clear messages to politicians. Its simplicity is accompanied by data from the four dimensions and eighteen SIs, each of particular variables casing the various pertinent challenges. Then, the index will be of use to “service providers, control agencies, research teams and grassroots organizations”, who wish to evaluate SS from a sustainable viewpoint. Sustainability is variable and dynamic between a people which mean the FIA proposed is subject to change. Hence, FIA can be improved based on the sustainability aims and changing aspects to remain adapted to the situation being considered.

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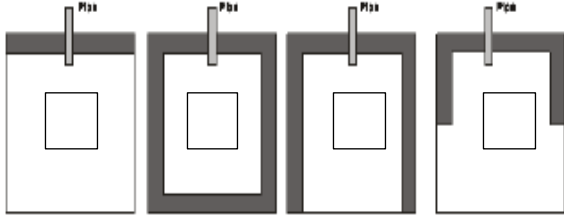
APPENDICES

Appendix 1: Household questionnaire for measuring sustainability indicators

Table A1: Indicates summary of survey questionnaire scripts, site observation checklist, laboratory analysis, durations, and topics

Participants	Interested topic	Expected duration	Estimated number of participants
Appendix 1: Sustainability Indicators Survey Questionnaire Scripts			
Household Members	Sustainability indicators measuring	15 - 30min per script	At least 200
Appendix 2: Site Observation Checklist			
Researcher, users, and ward public health officials	The existing situation of the system	1 month	34 households
Appendix 3: Sampling and Laboratory Analysis			
3.1: Author and two assistants	Results of urban stream water quality	2 months	n=10 sampling points
3.2: Author and two assistants	Results of septic tank effluents	2 months	n=15 households

	<p>NELSON MANDELA AFRICAN INSTITUTION OF SCIENCE AND TECHNOLOGY (NM-AIST)</p> <p>SUSTAINABILITY POTENTIAL FOR SEPTIC SYSTEMS IN RESIDENTIAL BUILDINGS; A CASE STUDY OF MWANZA CITY, TANZANIA</p> <p><i>Questionnaire Sheet</i></p> <p><i>Questionnaire Design and Copyright by Author, NM-AIST</i></p>
Questionnaire number: Date / / 2020	
S/N	QUESTIONS/RESPONSES
PART A: LOCATION AND RESPONDENT INFORMATION (IDENTIFICATION)	
A1	What is the measured coordinates? Latitude (N/S): Longitude (W/E):
A2	Ward:
A3	Street:
A4	Date:
A5	Gender: Male/Female
A6	Age: <input type="checkbox"/> 18-24 <input type="checkbox"/> 25-34 <input type="checkbox"/> 35-44 <input type="checkbox"/> 45-54 <input type="checkbox"/> 55-64 <input type="checkbox"/> Over 65
A7	What is your occupation?
A8	How many individuals are in your house?
PART B: THE EXISTING SEPTIC SYSTEMS CHARACTERISTICS	
B1	When did you construct your first septic system?

B2	What local available material do you use to construct septic tank? <input type="checkbox"/> Cement at what price/ 50Kg bag <input type="checkbox"/> Aggregates Tshs <input type="checkbox"/> Stones Tshs..... <input type="checkbox"/> Mesh at what price/square meter <input type="checkbox"/> Price per brick/block..... Tshs <input type="checkbox"/> Iron sheet Tsh/sheet														
B3	What is the level of availability of manor repairs materials? <input type="checkbox"/> High <input type="checkbox"/> Medium <input type="checkbox"/> Low														
B4	Do you have a septic tank of, 														
B5	What do you think of a septic tank that is not cemented on its base? <input type="checkbox"/> Good, because it will not be full <input type="checkbox"/> Good, because the dirt quickly infiltrates into the ground <input type="checkbox"/> Not good, because it contaminates soil and groundwater <input type="checkbox"/> Do not know														
B6	Is there a problem with your septic tank? <input type="checkbox"/> Yes <input type="checkbox"/> No														
B7	If there is, what's the problem? <input type="checkbox"/> Septic tank simply full <input type="checkbox"/> Septic tank collapses <input type="checkbox"/> Septic tank clogging <input type="checkbox"/> Septic tank odorous														
B8	What is the frequency of maintenance activities done on a septic system in the last year? <input type="checkbox"/> Once /never, <input type="checkbox"/> Twice, <input type="checkbox"/> More than twice,														
B9	Type of sanitation facilities <input type="checkbox"/> Normal cistern-flush <input type="checkbox"/> Pour flush <input type="checkbox"/> Water-saving cistern-flush <input type="checkbox"/> Others														
B10	Please respond, the questions below if you use pour flush toilet B10.1 How to flush B10.2 Number of a bucket used	<input type="checkbox"/> By bucket <input type="checkbox"/> By valve <input type="checkbox"/> 1 bucket <input type="checkbox"/> 2 buckets <input type="checkbox"/> 3 buckets <input type="checkbox"/> 4 bucket <input type="checkbox"/> 5 buckets <input type="checkbox"/> More													
B11	Shape of septic tank	<input type="checkbox"/> Rectangular <input type="checkbox"/> Cylindrical													
B12	No of chamber	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> Do not know													
B13	Material	<input type="checkbox"/> Concrete <input type="checkbox"/> Other													
B14	Year of construction														
B15	Influent to septic tank	<input type="checkbox"/> Blackwater <input type="checkbox"/> Greywater													
B16	What were your septic tank (ST) and soak pit (SP) dimensions?	Length (m) Breadth (m) Depth (m)	<table border="1"> <thead> <tr> <th></th> <th>ST</th> <th>SP</th> </tr> </thead> <tbody> <tr> <td>Length (m)</td> <td></td> <td></td> </tr> <tr> <td>Breadth (m)</td> <td></td> <td></td> </tr> <tr> <td>Depth (m)</td> <td></td> <td></td> </tr> </tbody> </table>		ST	SP	Length (m)			Breadth (m)			Depth (m)		
	ST	SP													
Length (m)															
Breadth (m)															
Depth (m)															
B17	Please indicate if a septic tank has been emptied:	<input type="checkbox"/> Yes <input type="checkbox"/> No													
B18	If the septic tank has been emptied, please list the latest desludging.														
B19	Reason for desludging	<input type="checkbox"/> Clogging <input type="checkbox"/> Bad odor <input type="checkbox"/> House rebuild/repair													

B20	How do you contact the desludging service	<input type="checkbox"/> Commercial <input type="checkbox"/> Neighbour/local people <input type="checkbox"/> Other (indicate)
B21	Do you think the desludging fee is:	<input type="checkbox"/> Expensive <input type="checkbox"/> Acceptable <input type="checkbox"/> Cheap
PART C: USERS AWARENESS, OPINION, AND USABILITY OF THE SYSTEM		
C1	Do you have the plan level for long-term repair and replacement in terms of expenditures? <input type="checkbox"/> Highly <input type="checkbox"/> Medium <input type="checkbox"/> Low	
C2	Do you think system operation and maintenance require an external contractor at this level? <input type="checkbox"/> Highly <input type="checkbox"/> Medium <input type="checkbox"/> Low	
C3	Do you think Septic System (SS) simply had benefits to the treatment systems of domestic wastewater? <input type="checkbox"/> Highly <input type="checkbox"/> Medium <input type="checkbox"/> Low	
C4	Have you ever expanded the system?	Yes /No
C5	If the answer to question 4 is no, what is the reason for not upgrading the system? <input type="checkbox"/> Financial problems <input type="checkbox"/> Technical limitations of the system <input type="checkbox"/> Still functioning properly <input type="checkbox"/> Having not been interested	
C6	If yes to question no 4, what is the future expansion possibility of the system regarding user needs variations? <input type="checkbox"/> High <input type="checkbox"/> Moderate <input type="checkbox"/> Low	
C7	If yes to question no 4, what is the possibility of the system to function regarding flow fluctuation and user needs variations? <input type="checkbox"/> High <input type="checkbox"/> Moderate <input type="checkbox"/> Low	
C8	Have you ever experienced any failure level (elevated loadings and flow) above the design criteria? <input type="checkbox"/> High <input type="checkbox"/> Medium <input type="checkbox"/> Low/Never	
C9	Do you think that availability of local materials and the possibility to repair within a reasonable time (4 hours) are; <input type="checkbox"/> High <input type="checkbox"/> Medium <input type="checkbox"/> Low	
C10	Do you think that the current septic tank system could be a big plan for your wastewater treatment? <input type="checkbox"/> Yes <input type="checkbox"/> No	
C11	If the reply for question 4 is no, what are the reasons for that? <input type="checkbox"/> Having odor production <input type="checkbox"/> No inhabitants served <input type="checkbox"/> Not to bear seasonal effects <input type="checkbox"/> Not comply with designed inflow	
C12	If yes to question no 4, what are acceptable levels related to the sanitation facility currently used? <input type="checkbox"/> High <input type="checkbox"/> Medium <input type="checkbox"/> Low	
C13	Do you know the effect of regular desludging? <input type="checkbox"/> Yes (Indicate) <input type="checkbox"/> No	
C14	Do you know to which the sludge goes? <input type="checkbox"/> Yes <input type="checkbox"/> No	
C15	If regular desludging is required, are you willing to comply with it? Why? <input type="checkbox"/> Yes (Indicate) <input type="checkbox"/> No (Indicate)	
C16	If you concern about the price, how much can you pay for that? <input type="checkbox"/> 50,000TZs <input type="checkbox"/> 50,000-100,000TZs <input type="checkbox"/> 100,000-150,000TZs <input type="checkbox"/> 150,000-200,000TZs <input type="checkbox"/> 200,000TZs	
C17	What is your suggestion on the frequency of desludging? <input type="checkbox"/> Once every year <input type="checkbox"/> Once, every 2year <input type="checkbox"/> Once, every 3years	
C18	Will you join the free desludging strategy?	

	<input type="checkbox"/> Yes <input type="checkbox"/> No
C19	Water discharge Greywater to: <input type="checkbox"/> Drainage <input type="checkbox"/> Open water bodies <input type="checkbox"/> Others (Indicate) Septic tank effluent connection: <input type="checkbox"/> Drainage <input type="checkbox"/> Open water bodies <input type="checkbox"/> Soak pit <input type="checkbox"/> Others (Indicate)
C20	Possibility to sample septic effluent or to access the septic tank and its effluent <input type="checkbox"/> Yes <input type="checkbox"/> No
C21	Do you experience any smell or any air pollution incidents from the system? <input type="checkbox"/> Yes <input type="checkbox"/> No
C22	If yes to question 21, what nuisance level do you experience? <input type="checkbox"/> High level <input type="checkbox"/> Medium level <input type="checkbox"/> Low level
C23	Do you experience exposure to wastewater in any of these actions? <input type="checkbox"/> During and after use/During cleaning/During maintenance/In case of process failure/Direct contact with treatment process/Contact with treated water/Using contaminated groundwater as a drinking water source/Contact with contaminated insect or wild animals/Emptying of collected rest products (sludge)/Application on arable land/Consumption of vegetable fertilized with wastewater <input type="checkbox"/> Never experience <input type="checkbox"/> Do not know <input type="checkbox"/> Others. Specify
PART D: ENVIRONMENTAL CHARACTERISTICS OF THE AREA	
D1	What problem do you face when excavating a pit <input type="checkbox"/> Hard soil <input type="checkbox"/> Hard rock close to the ground <input type="checkbox"/> Water table high <input type="checkbox"/> Collapsible soil <input type="checkbox"/> No problem <input type="checkbox"/> Do not know <input type="checkbox"/> Others specify
D2	If encountered any problem, how did you address it? <input type="checkbox"/> Line the pit <input type="checkbox"/> Excavate shallow pit <input type="checkbox"/> Elevate the pit.. <input type="checkbox"/> .Other specify....
D3	How deep do you excavate a pit before you get water (reach water table level) m or ft
<i>Thank you! for your cooperation</i>	

Appendix 2: Site observation checklist

Design-related aspects

1. Is there a ground-water table near the surface?
a) Yes, at what depth? Depth: meters b) No
2. Is the soil rocky?
a) Yes b) No
3. Observe the direction of grey water (Tick the most appropriate)
a) Channeled to the toilet pit b) Directed outside the bathroom to soak away pit c) Directed outside to the ground
4. Is there odors:
a) From sewers? b) In toilets? c) In any tank or chamber? d) At effluent (soak pit)?
5. Estimate the total area occupied (footprint) [square feet]
6. Is it possible for a desludging vehicle to access the sludge compartments?
a) Yes b) No c) Not sure
7. Is there access for sampling before/after each system component?
a) Yes b) No (specify on next page) c) Not sure (specify on next page)
8. Please describe where access for sampling is/may be difficult or not possible and why
9. Access possible for unauthorized persons?
a) Yes b) No (fence, locking door, guard, etc.) c) Not sure
10. Does the installation you see (technology configuration & design) correspond with what you are told?
a) Yes, everything appears to be according to the information available b) No, observations differ (specify on next page)
11. What differences do you observe?
12. Any peculiar design features, potential design or construction errors, or other observations?
a) Yes (Please note your observations) b) No

Infrastructure condition

1. Any remarks regarding construction quality?
a) Yes, (What remarks?) b) No
2. Any visibility of relevant corrosion of concrete or metal parts or other damage?
a) Yes (What corrosion problems or damage do you observe? What implications does this have on the functionality?) b) No or insignificant
3. Any signs of damage?

- a) Yes (What signs?) b) No
4. Any abnormal water discharge somewhere?
 - a) Yes (Where? How severe is it? What could be the reason and what implications does it have?) b) No
 5. Any water logging?
 - a) Yes (Where do you observe water logging? How severe is it? What could be the reason and what implications does it have?) b) No
 6. Any abnormal water stagnation?
 - a) Yes (Where do you observe water stagnation? What could be the reason and what implications does it have?) b) No
 7. Any cracks that may indicate leakages or risks for future leakages?
 - a) Yes (Where do you observe cracks? How severe are they? What implications do they have?) b) No (or insignificant cracks)
 8. Any adverse conditions of manholes/control openings of sewers/tanks?
 - a) None b) Absent/stolen c) Stuck (cannot be opened) d) Broken e) Severely corroded f) No handle g) Covered by dirt (invisible, cannot be opened) h) Not sure, could not see manholes/control openings j) Other

Operational aspects

1. Do you see the reason why the system has failed and is not operational? Do you think it is a permanent or a temporary failure?
2. Are all parts of the system operational?
 - a) Yes b) No c) Not sure
3. Which parts of the system are not / may not be operational? Do you see the reason why?
4. Can you observe people throwing greywater from the kitchen, laundry, cleaning, and bathing on the street / into storm drainage or using it for gardening?
 - a) Yes b) No
5. Any compartments with the presence of algal growth?
 - a) Yes b) No

Appendix 3: Results of laboratory analysis for Mwanza City. Tanzania

Table A: Results of water quality of 2 sampling points in vicinity of urban river or stream in the Mwanza City

No. of Weeks (W)	Sampling Site (SS)	Location (GPS)		pH	Temperature (°C)	TSS (mg/l)	TN (mg/L)	TP (mg/L)	Ammonia-N (mg/L)	COD (mg/L)	BOD (mg/L)	Fecal Coli (CFU/100mls)
		Lat	Long									
W1	SS1	-2.5967	32.7381	6.67	23.0	96.0	1.065	3.670	<0.03	277.6	163.3	1100
	SS2	-2.5917	32.9107	7.36	24.6	64.0	0.180	0.247	<0.03	240.2	141.3	700
W2	SS1	-2.5967	32.7381	6.72	23.1	184.0	1.493	7.790	0.023	424.3	108.3	1500
	SS2	-2.5917	32.9107	6.98	23.1	88.0	0.068	0.545	0.063	436.6	256.8	900
W3	SS1	-2.5967	32.7381	7.20	24.0	68.0	0.113	1.845	0.030	184.1	108.3	1400
	SS2	-2.5917	32.9107	6.27	25.1	36.0	0.182	0.247	<0.03	156.1	91.8	700
W4	SS1	-2.5967	32.7381	6.32	23.3	136.0	0.163	2.835	0.066	227.5	133.8	950
	SS2	-2.5917	32.9107	6.45	25.0	20.0	0.732	0.267	0.018	162.5	108.3	550
W5	SS1	-2.5967	32.7381	6.93	24.9	60.0	0.827	0.404	<0.03	118.7	69.3	550
	SS2	-2.5917	32.9107	7.31	23.0	32.0	0.323	0.345	<0.03	136.5	80.3	950

Table B: Results of STE quality for 15 septic tanks at Nyegezi, Mwanza city

S/N	HH number	Location		Sampling Date	pH	Temp °C	TSS (mg/L)	BOD5 (mg/L)	CODcr (mg/L)	TKN (mg/L)	TP (mg/L)	Total coliform (CFU/100ml)
		Lat	Long									
1	26	-2.5951	32.9209	16/4/2020	7.78	25	34	240	446	25.9	5.6	1.10E+05
2	20	-2.5934	32.9211	17/4/2020	7.17	27	24	160	332	28	6	2.00E+05
3	1	-2.5913	32.9161	18/4/2020	8.3	25	190	400	628	7	32.9	1.20E+07
4	5	-2.5908	32.9193	18/4/2020	8.2	23	42	200	300	18.2	3.9	3.00E+07
5	6	-2.5907	32.9195	18/4/2020	7.3	24	28	140	228	20.3	4.1	1.00E+05
6	114	-2.5872	32.9158	20/4/2020	7.5	23	44	320	532	22.4	4.8	8.40E+06
7	85	-2.5935	32.9171	20/4/2020	8	23.4	162	1800	3525	32.2	6.9	8.00E+06
8	12	-2.5922	32.9168	20/4/2020	7.1	25	720	920	1775	8.1	5.6	3.50E+08
9	8	-2.5889	32.9166	20/4/2020	7.41	22.3	189	200	276	68.6	14.5	1.00E+06
10	133	-2.5963	32.9168	20/4/2020	7.88	26	242	350	480	81.2	17.2	2.10E+06
11	36	-2.591	32.9216	21/4/2020	7.94	22	303	320	422	42	8.7	2.00E+06
12	2	-2.5914	32.9172	21/4/2020	6.8	24.5	50	150	268	12	21	1.90E+06
13	3	-2.5942	32.9168	21/4/2020	7.6	23	79	360	655	28	6	1.00E+07
14	25	-2.5899	32.9219	24/4/2020	6.6	24	89	165	234	3	2.2	5.10E+05
15	128	-2.5943	32.9176	25/4/2020	7.9	25	19	77	89	2	1.2	4.00E+05

RESEARCH OUTPUTS

(i) Publication

Salvatory, S., Machunda, R. L., & Mwamila, T. B. (2022). An Evaluation of Sustainability Potential of Existing Septic Systems: A Fuzzy-Based Indexing Approach. *Sustainability*, 14(9), 5526.

(ii) Poster Presentation