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An Evaluation of Sustainability Potential of Existing Septic Systems: A Fuzzy-Based Indexing Approach

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Abstract: In this study, a fuzzy-based indexing approach (FIA) is developed based on a conceptual framework regarding social, environmental, economic, and technical dimensions to evaluate the overall sustainability potential of existing septic systems (SSs) of around 200 Tanzanian residential buildings in Mwanza city. FIA required the following six steps: selecting, measuring, normalizing, weighting, and aggregating the sustainability indicators (SIs) or dimensions, as well as interpretation of the indices similarly to conventional sustainability indices to aggregate the four sustainability dimensions. In total, 18 SIs were selected based on a literature review. Input data obtained for each indicator were from the social survey and laboratory analysis. The results showed that the entire SSs in the city had a general sustainability index (GSI) of 0.42. The index fell on the verge of the "danger" category, indicating that corrective measures are needed. In conclusion, FIA is simple and transparent, it provides a both theoretical and practical basis for sustainability evaluation, does not require vast quantities of data, and does not demand an advanced computer software package. Moreover, FIA is a proper method to evaluate and improve SS sustainability in the city or provide the information to decision makers, designers, and researchers to scrutinize the decision possibilities in a multidimensional manner.

Keywords: fuzzy-based indices; septic systems; sustainability indicators

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1. Introduction

Sustainability is an important concept in the selection, planning, design, implementation, and maintenance of efficient wastewater treatment systems for their fully intended use [1]. Additionally, sustainability may and will be defined differently by diverse people, but what is clear is that it commonly comprises the four sustainability dimensions—namely, environmental, economic, technical, and social dimensions [2–5]. However, it is challenging to evaluate since it is a naturally ambiguous and contradicting concept, and it involves the several considerations of multiple dimensions to make a conclusion [1,6]. Hence, the development of various methods for evaluating sustainability is significant to capture the complexity of this concept.

Sustainability evaluation (SE) of existing onsite sanitation systems (OSSs) is crucial in recent years to achieve the "6th Sustainable Development Goal" by 2030 and the "City of Future Novel Concept" [1,4,7]. However, Waas et al. [6] defined SE as "*any process that purposes to (1) Contribute to a better understanding of the meaning of sustainability and its contextual interpretation (interpretation challenge); (2) Integrate sustainability issues into decision-making by identifying and assessing (past and future) sustainability impacts (information-structuring challenge); and (3) Promote the growth of sustainability objectives (influence challenge)*". Such definition is based on the three challenges facing the decision-making process from a sustainability perspective. Several studies stated that comprehensive, practicable methods for SE are fundamental factors in supporting decision makers in building a sustainable sanitation system by understanding the different sustainability dimensions and trade-offs between indicators. However, such methods have shortcomings concerning (1) inherent preferences when defining the indicators' weights and ranking, (2) completeness, (3) uncertainty, (4) processing of fuzziness, and (5) representation of results [8]. To overcome these limitations, it was stated that the fuzzy logic approach could be an appropriate, universal, and efficient method to evaluate sustainability because of its capacity to match individual experience and deal with unclear circumstances wherever old calculation is inefficient [9–11]. For example, the fuzzy logic approach has been applied in the evaluation of the level of sustainability in sectors such as water [12], construction [13], agriculture [14], management [15], transportation systems [16], and energy [17], among others [10,11]. However, to the best of the authors' knowledge, and based on the reviewed literature, the approach has not been used to evaluate or compare the sustainability of OSSs specifically by combining the fuzzy logic and sustainability indexing method.

Most OSSs comprise septic systems (SSs), pit latrines, or ventilated improved pit latrines (VIPs), according to Kihila et al. [18], and they are highly associated with ecological pollution, human health dangers, and functional problems in many countries [19]. Additionally, it is not clear in several areas of the literature how sustainable such systems are, specifically in terms of extent, effect, and corrective measures. As a result, extensive efforts have been undertaken globally in recent decades to install and upgrade OSSs or define and quantify service system sustainability [8]. In other words, such systems are aspirants for process optimization, re-evaluation, and improvement based on sustainability (a recently concerned concept). In this study, a detailed SE was undertaken on septic systems (SSs) since it is the most common and historical OSSs in urban and suburban areas of developing countries, including Tanzania [18,20]. Moreover, SSs have been used for new housing structures and are reflected as future, innovative, and cheap alternatives to pit latrines inside the OSSs ranking. Generally, as stated in many studies, the SS is suitable at the household level because it does not consume any energy to operate, is easy to design, and is cheap to construct and maintain [21,22].

Therefore, in this paper, the description, development, and application of an SE method, called the fuzzy-based indexing approach (FIA), was carried out to evaluate the sustainability potential of SSs regarding sustainability dimensions in residential buildings in Mwanza city, Tanzania. With the discussion of the sustainability concept and its adaptation to particular problems and settings, this study can assist decision makers, specialists, representatives, and researchers to improve future SSs. Additionally, it can validate the theoretical framework by evaluating the actual case study that contributes to the fulfillment of extra sustainable SSs in the city.

2. Materials and Methods

2.1. Region of Study

Mwanza city is on the southern shores of Lake Victoria, in northwestern Tanzania, and is well-known for its numerous rocky outcrops and ridges (Figure 1). The city is Tanzania's second-largest urban center, with a total population of 706,453 people and an average of 5 people per household [23]. Only 8% of the population is served by sewer networks for carrying domestic wastewater. Due to this factor, OSSs are used commonly in residential areas even though they do not comply with national standards. Furthermore, multiple discharges of raw sewage into the city's rivers have been found, and sewage reuse activities, whether raw or treated, are few and informal.

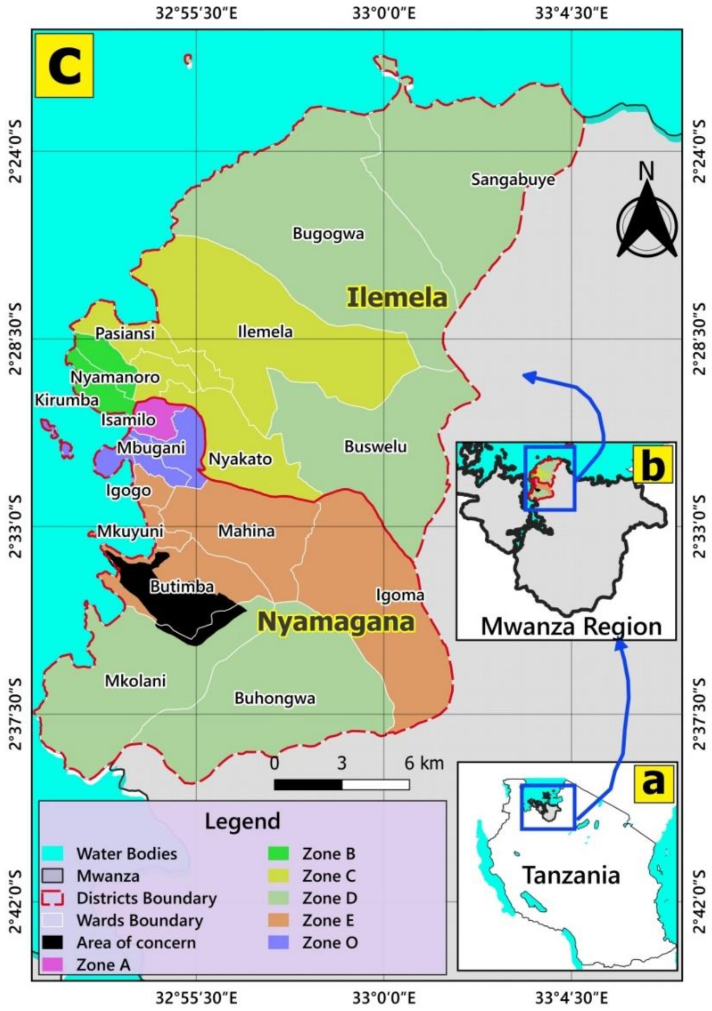


Figure 1. Location of the study area (Mwanza city) related to (**a**) Tanzania, (**b**) Mwanza region in northwestern Tanzania, and (**c**) the specific study area in zone E.

The city was divided into six zones to illustrate the general distribution of sanitation systems in the city, as shown in Figure 1. For example, zones O and A are served by a central sewer system, whereas zone B and C by semi-centralized wastewater treatment systems; zone D is largely undeveloped, and zone E comprises unplanned settlements. However, for this study, a single location known as an "area of concern" inside zone E was chosen since it has a greater SS/OSS coverage.

2.2. Septic System Description

Globally, 70 more diverse OSSs may be present and appropriate for definite site situations [24]. In African countries, including Tanzania, over 60% of sanitation systems are OSSs [25,26]. The commonly used systems are septic tanks and soak-away pits, pit latrines, and ventilated improved pits (VIP) [27]. Additionally, the most common and historical OSS in urban and suburban areas is the SSs (combination of a toilet, septic tank, and soak-way pits) [18,20]. It might be much better to note that SSs have many definitions or categories [28,29]. However, in this paper, SS was defined as the "oldest self-collected, belowground OSS used to collect, store, and treat domestic wastewater, which consists of user inference, distribution systems, septic tank, and soak-away pit", as shown in Figure 2 [30]. Households are the wastewater source that discharge waste to the final two units. Wastewater without reuse was disposed to soak pit, which has impacts on ground and surface water. In agreement with Muga and Mihelcic [29], operational phase of SS was selected and was critical in this study, compared with phases of planning, design, and construction during the SS life cycle. The reason is that this phase represents the considerably higher length of the life cycle and exerts higher environmental effects.

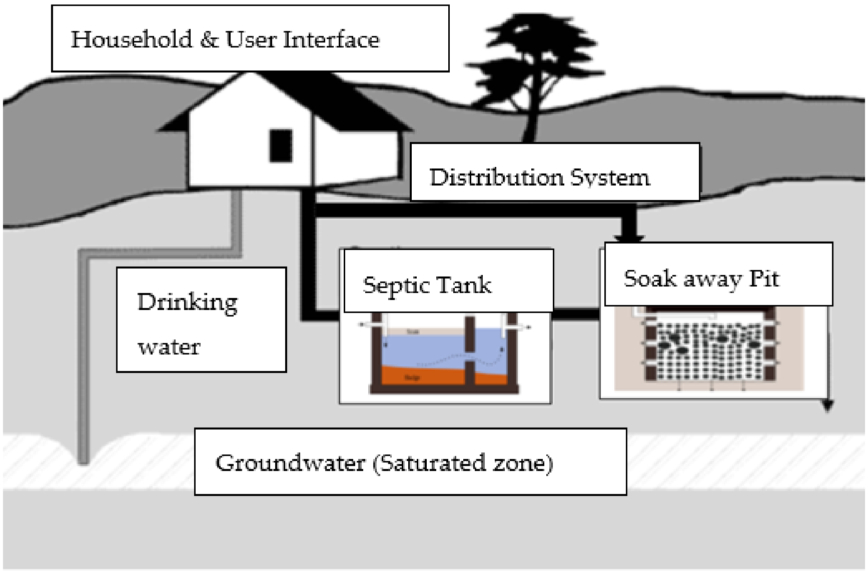


Figure 2. Typical septic system.

2.3. Conceptual Framework

The "five-dimensional" plan proposed by Cossio et al. [3], which defines sustainability as a conceptual framework within which the social, environmental, technological, and economic aspects of development can be openly discussed, following Balkema et al. [2], was used to apply the concept of sustainability to this case study. The elements are intricately linked and difficult to manage in a piecemeal fashion. This conceptual framework, by assigning explicit relevance to aspects, is arguably especially appropriate for dealing with the social, environmental, economic, and technical differences that are central to the understanding of sanitation systems in relation to water resources pollution.

2.4. Development of Fuzzy-Based Indexing Approach for Sustainability Evaluation

According to Iribarnegaray et al. [29], decision makers can give consideration to measured indicators. Failure to identify and measure core characteristics of a management system's sustainability will make these aspects almost invisible. In this study, An FIA was developed in an attempt to insert numbers to specific system sustainability and to carefully take into account vague aspects of sustainability [31,32]. FIA can provide indices to comprehend the SS, detect weak points, create upgrading and optimization plans, etc.

FIA requires six steps, similar to conventional sustainability indices (Figure 3), to aggregate the economic, environmental, technical, and social indicators [4,33]. The steps were modified from the conventional sustainability indices developed by Georgiou et al. [33] and Molinos-Senante et al. [8], as well as the fuzzy logic approach [17].

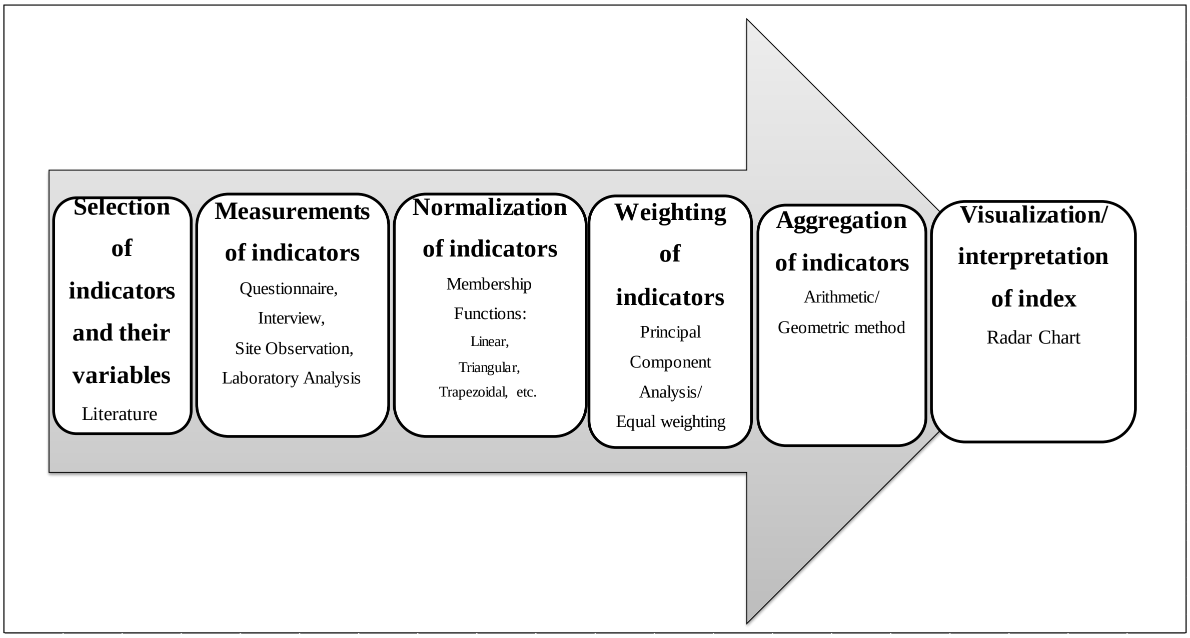


Figure 3. Methodological outline.

2.4.1. Selecting the Sustainability Indicators (SIs)

As a first step, there is a wide-ranging set of SIs in the literature according to the study's goals and scope [2,3,8,34]. Additionally, many studies suggest that the SI must be characterized by, but not limited to, (1) easiness, (2) scope, (3) measured estimations (4) capacity to catch the patterns, (5) affectability to fluctuations, and (6) convenient, recognizable proof-of-execution patterns. Based on these selection criteria, and with help of experts, 18 indicators were selected to implement the FIA for the needs of the SE (Table 1). These indicators, shown in Table 1, were classified under four sustainability dimensions, along with their code and aim.

Table 1. Sustainability indicators selected for evaluating the sustainability of the SS: H = high; M = medium; L = low; Y = yes; N = no; G = good; P = poor.

Dimension (Code)	Indicator (Code)	Unit or Variable	Aim
Social (SO)	Exposure chances to the wastewater by users (SO1)	H-M-L	Low exposure
	Public awareness for septic tank management (SO2)	H-M-L	High awareness
	Aesthetics based on nuisance level (SO3)	H-M-L	Low nuisance level
	Community support for SS(SO4)	H-M-L	High support
Environmental (EN)	Access to enough water supplies to operate the system (EN1)	H-M-L	High access
	Quality of septic tank effluent (EN2)	G-B	Good
	Water quality of the stream, river, or lake in the city (EN3)	G-P	Good
	Compatibility of SS with surrounding environment (EN4)	H-M-L	High compatibility
Economic (EC)	Ability to pay for desludging charges (EC1)	Y-N	Yes
	Capacity to sustain system long term repair and replacement (EC2)	H-M-L	High
	System input level to local development (EC3)	H-M-L	High input
Technical (TE)	Durability (TE1)	Years	Less than design life
	Risk of system failure (TE2)	H-M-L	Low risk
	Adaptability to flow fluctuation or user needs (TE3)	H-M-L	High adaptability
	Upgradability (TE4)	H-M-L	High
	Operation and maintenance level required (TE5)	H-M-L	Low level
	Availability of local materials (TE6)	H-M-L	High
	The capacity of existing SS (TE7)	m^3/household	High enough size

Indicators were quantified through the measurement of two or more variables. When more than two variables were needed, we preferably selected three in order to strictly follow the conceptual framework. Therefore, these established indicators and variables are more all-inclusive and flexible and are used for a variety of uses.

2.4.2. Measuring the SIs

Information on each SI was measured or collected using the social science methods (household survey, semi-structured interview, site observations, and literature review) or laboratory analysis.

A brief description of how indicators were measured; the significant sources of the input data, and assumptions are given below:

a. All social indicators were evaluated qualitatively or using a scoring system with a three-point ordinal scale. For example, "exposure chances to the wastewater by users" was measured by the number of households representatives' responses to assigned variables (high, medium, or low). Data were obtained from a household survey using a questionnaire.
b. Environmental indicators, "quality of septic tank effluent" and "water quality of the stream, river, or lake in the city" were measured quantitatively in the laboratory and then summarized into several samples that met the local standards or not. The other two indicators in this category—"access to enough water supplies to operate the system" and "compatibility of SS with surrounding environment"—were determined by counting the number of households' responses concerning their assigned variables using a questionnaire.
c. All economic indicators were calculated qualitatively or using a scoring system. For example, "ability to pay for desludging charges" was determined by the number of households' responses concerning the assigned variables (yes or no). Input data were obtained from the questionnaire.
d. All technical indicators were measured qualitatively or using a scoring system. For example, "durability" was captured or measured by counting the number of households' responses to the assigned variables (more than 20 years, between 12 and 20, or less than 12 years). Data were obtained from the household questionnaire and site observation.

Information was then analyzed using a new modified FIA in steps 3 to 6, developed from a fuzzy logic and a conventional sustainability indexing approach.

2.4.3. Normalization of SIs

The SIs under their variables were standardized and grouped by a fuzzy set theory and processed by membership function to make quantitative and qualitative indicators that are comparable and free from scale effects [35]. Thus, the indicators/variables were presented without units even though they have different units. For this study, the "linear membership function" was used, due to having the simplest and few input data for fuzzy evaluation mode, compared with the other membership functions [12,17,36,37]. From the linear membership function, the assigned scores (AS_v) were converted into the normalized index (NI) or sustainability variable index (VSI_v) as follows:

$$VSI_v = \begin{cases} 1, \ \text{if } AS_{btn,v} \geq AS_{max,v} \\ \dfrac{(AS_{btn,v} - AS_{min,v})}{(AS_{max,v} - AS_{min,v})}, \text{if } AS_{min,v} < x_{btn,v} < AS_{max,v}. \\ 0, \ \text{if } AS_{btn,v} \leq AS_{min,\,v} \end{cases} \quad (1)$$

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

2.4.4. Weighting Techniques of the SIs and Dimensions

The success of using the fuzzy logic approach is always determined by the weighting of the SIs [35]. The weighting method selection is always controversial, as it includes a certain degree of bias [38]. There are many methods, and each method has its advantages and disadvantages. The analytical hierarchy process (AHP) was commonly used in attaining diverse weights for SIs as stipulated in many studies [6,8,9]. However, in this study, the "new direct statistical-based approach" was introduced and used by the authors. It is a mathematical formula to weigh the importance of the indicators and dimensions considering the entire population responses per each parameter, as defined in Equations (3) and (5). The key benefit of such a method is that weights are determined with an unbiased opinion. The reason is that the users' responses under the frequencies on specific indicators status were used, and the numbers of SS to be evaluated are considerable.

2.4.5. Aggregation Techniques of the Variables, SIs, and Dimensions

Aggregation is the combination of parameters conferring to the fundamental theoretical framework. There are two methods of aggregation—arithmetic and geometric. Each approach is appropriate, depending on the characteristics of the datasets [8,39]. In this paper, an "arithmetic method" was selected and modified. The method combines fuzzy set theory and weighting technique and is the most common method applied in relation to water quality and sustainability indices [40]. Additionally, it is suitable when trade-offs among the SIs are not well-defined, whereby one SI with a low value is compensated by another SI with a high value. Then, the fuzzy-based indices of indicators, dimensions, and the entire system were computed using 3 steps:

Step 1; VSI aggregated into indicator sustainability index (ISI)

Having computed VSI_v and the frequencies of responses (N_v) for each variable, ISI_i of the SS across the ith i indicator within a sustainability dimension can be determined by

$$ISI_i = \frac{\sum_{v=1}^{V} VSI_v \ * \ N_v}{\sum_{v=1}^{V} \ N_v} \tag{2}$$

For i = 1, 2, 3 . . . I, where i is the number of SIs; and v = 1, 2 . . . V where v number of variables within i th indicator.

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 (2) as follows:

$$w_i = \log\left(\frac{1}{ISI_i}\right) \geq 0 \tag{3}$$

After the weights of each SI (w_i) were 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:

$$DSI_d = \frac{\sum_{i=1}^{I} \ ISI_i * w_i}{\sum_{i=1}^{I} \ w_i} \tag{4}$$

where DSI_d is dimension sustainability index of the dimensions d; d = SO, EN, EC or TE; for i = 1, 2, 3 . . . I, where i is the number of indicators in each dimension; ISI_i is the indicator sustainability index of i th indicator, and w_i is the weight of ith sustainability indicator.

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

Adopting a similar approach to that in step 2, the relative importance (weight) of each sustainability dimension w_d was attained as follows:

$$w_d = \log\left(\frac{1}{DSI_d}\right) \geq 0 \tag{5}$$

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

$$GSI_{SS} = \frac{\sum_{d=\mathrm{SO}}^{\mathrm{d}} DSI_d * w_d}{\sum_{d=\mathrm{SO}}^{\mathrm{d}} w_d} \tag{6}$$

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

2.4.6. Interpretation of the Indices

Results were offered in an easy and clear style through explanation to stimulate the anticipated responses and to confirm that the indices were well recognized by its targeting users. Therefore, it was performed by using a favorable and manageable tool called the radar/spider diagram [41]. Additionally, for interpretation and decision-making purposes, the indices (I_s) obtained by SS were transformed by using a "sustainability scale" (ranging from 0 to 1) with some "measures and actions" recommended, such as the following:

1. $I_s \leq 0.25$—"Unacceptable"; fast aid and renewing actions are a must;
2. $0.25 < I_s \leq 0.50$—"Danger"; corrective measures are recommended;
3. $0.50 < I_s \leq 0.75$—"Good"; optimization and alteration measures are suggested;
4. $0.75 < I_s < 1$—"Very good"; checking and repairs are needed;
5. $I_s = 1$—"Excellent"; only constant monitoring needed for supervising [42].

The remark on immediate actions for a balanced system was set at 0.50 [41], 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.

3. Results and Discussion

3.1. Conceptual Framework for Evaluating SS Sustainability

Figure 4 shows the conceptual framework with the general sustainability index (GSI) (first level), different key dimensions (second level), related indicators (third level), and variables (fourth level). Each upper level is computed using the lower level. Parameters (variables, indicators, themes, or dimensions) are carefully chosen, and they are relatively independent sustainability measures. If the framework is appreciated, diverse outlines are probable depending on the local situation and the information availability. Variables and indicators can change from one place to another and from time to time for a similar location if the framework integrity is respected. This exceptional characteristic depicts that the FIA is tremendously adaptable to diverse situations while conserving its theoretic robustness. This is not a method's weakness, as it may seem at first glance, but according to [42], it is possibly one of the method's strengths.

Table 2. Input data for indicators, dimensions, and general sustainability indices evaluation of SSs.

1	2	3	4	5	6	7	8	9	10	11
Indicators	**Variables**	**N**	N_v	AS_v	VSI_v	ISI_i	w_i	DSI_d	w_d	GSI_{SS}
SOCIAL DIMENSION-*SO*										
Exposure chances to wastewater by users (SO_1)	High SO_{11}	200	50	1	0	0.63	0.20	0.73	0.14	0.42
	Medium SO_{12}		47	2	0.5					
	Low SO_{13}		103	3	1					
Public awareness for septic tank management- (SO_2)	High SO_{21}	200	145	3	1	0.79	0.11			
	Medium SO_{22}		24	2	0.5					
	Low SO_{23}		31	1	0					
Aesthetics based on nuisance level (SO_3)	High SO_{31}	200	12	1	0	0.89	0.05			
	Medium SO_{32}		20	2	0.5					
	Low SO_{33}		168	3	1					
Community support for septic tank system (SO_4)	High SO_{41}	200	132	3	1	0.80	0.10			
	Medium SO_{42}		54	2	0.5					
	Low SO_{43}		14	1	0					
ENVIRONMENTAL DIMENSION-*EN*										
Access to enough water supply to operate the system (EN_1)	Low EN_{11}	200	30	1	0	0.74	0.13	0.51	0.29	
	Medium EN_{12}		45	2	0.5					
	High EN_{13}		125	3	1					
Quality of septic tank effluent (EN_2)	Good EN_{21}	90	45	2	1	0.50	0.30			
	Bad EN_{22}		45	1	0					
Water quality of the stream, river, or lake in the city (EN_3)	Good EN_{31}	70	27	2	1	0.39	0.41			
	Poor EN_{32}		43	1	0					

Table 2. *Cont.*

1	2	3	4	5	6	7	8	9	10	11
Indicators	**Variables**	**N**	N_v	AS_v	VSI_v	ISI_i	w_i	DSI_d	w_d	GSI_{SS}
Compatibility of septic system with surrounding environment (EN_4)	High EN_{41} Medium EN_{42} Low EN_{43}	200	115 25 60	3 2 1	1 0.5 0	0.64	0.2			
ECONOMIC DIMENSION-*EC*										
Ability to pay for desludging charges (EC_1)	Yes EC_{11} No EC_{12}	200	143 57	2 1	1 0	0.72	0.1	0.26	0.59	
Capacity to sustain system (EC_2)	High EC_{21} Medium EC_{22} Low EC_{23}	200	56 98 46	3 2 1	1 0.5 0	0.53	0.28			
System input Level to local development (EC_3)	High EC_{31} Medium EC_{32} Low EC_{33}	200	12 20 168	3 2 1	1 0.5 0	0.11	0.96			
TECHNICAL DIMENSION-*TE*										
Durability (TE_1)	≤12 yrs. TE_{11} 12 to 20 yrs TE_{12} ≥20 yrs TE_{13}	200	32 45 123	3 2 1	1 0.5 0	0.27	0.6	0.50	0.30	
Risk of failure of system (TE_2)	High TE_{21} Medium TE_{22} Low TE_{23}	200	23 66 111	1 2 3	0 0.5 1	0.72	0.1			
Adaptability to flow fluctuation or user needs (TE_3)	High TE_{31} Medium TE_{32} Low TE_{33}	200	69 90 41	3 2 1	1 0.5 0	0.57	0.2			
Upgradability (TE_4)	High TE_{41} Medium TE_{42} Low TE_{43}	200	64 86 50	3 2 1	1 0.5 0	0.54	0.3			
Operation, and maintenance level required (TE_5)	High TE_{51} Medium TE_{52} Low TE_{53}	200	1 66 133	1 2 3	0 0.5 1	0.83	0.1			
Availability of local materials (TE_6)	High TE_{61} Medium TE_{62} Low TE_{63}	200	140 60 0	3 2 1	1 0.5 0	0.85	0.1			
The capacity of existing septic tank system (TE_7)	>5 m^3 TE_{71} 2 to 5 m^3 TE_{72} <2 m^3 TE_{73}	200	57 134 9	3 2 1	1 0.5 0	0.62	0.2			

N_v = response frequencies per specific variable; N = total number of response frequencies; AS_v = assigned scores per variable; VSI_v = variable sustainability index; ISI_i = indicator sustainability index; w_i and w_d = weights for the indicators and dimensions; DSI_d = dimension sustainability indices.

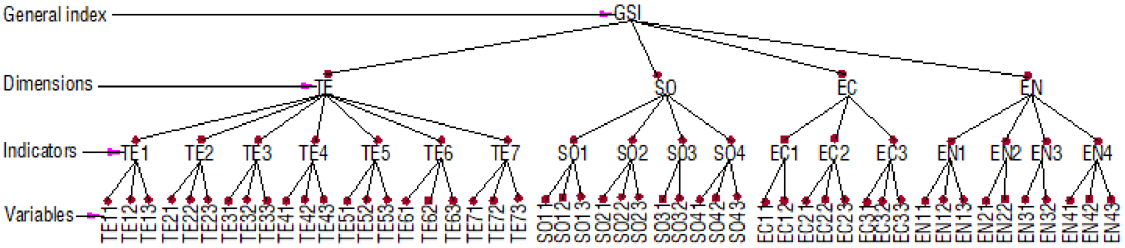


Figure 4. Systematic conceptual framework. The names of codes are given in Table 2.

3.2. *Application of FIA in Case Study Area*

A new fuzzy-based approach was applied according to the steps presented in the Section 2 for defined Sis shown in Table 2.

3.2.1. Measurements of the SIs

Table 2, in columns 3 and 4, presents the summary of all numerical values of each indicator or variable used to obtain indices regarding the case study. These values are either qualitative data from survey questionnaires and field observation or quantitative data from laboratory analysis collected by the researchers. Field observation was used to validate some information obtained from other methods. Raw data for each of the indicators concerning the variables were straightforwardly converted into the total population (N) and frequencies of variables responses (N_v). These numerical values could be modified for each situation and vary over time.

3.2.2. Normalized SIs

In this study, the variable was dichotomous or ordinal. Suppose, for the ordinal variable, the ith indicator, public awareness for septic tank management (SO_2; Table 2, column 1) has three variables—namely, high, medium, and low levels (Table 2, column 3), with assigned scores (AS_v) of 3, 2, and 1 (Table 2, column 5), respectively. These scores depend on an objective or aim of SI to the SS sustainability fulfillment.

Then, from Equation (1), $AS_{max,v} = 3,\ AS_{btn,v} = 2,\ and\ AS_{min,v} = 1$, and the normalized values VSI_v are 1, 0.5, and 0 (Table 2, column 6), respectively. This depends on the type or number of variables being analyzed. Here, SIs were represented by a unitless value ranging from 0 to 1, so the units applied and the range of changeability in measuring the SI did not impact the sustainability answers [8,43].

3.2.3. Weights of the Parameters

The weighting of the parameters (indicators and dimensions) is a key and complicated step that was calculated simply with Equations (3) and (5) for w_i and , respectively. This is a suitable approach, as the weight is provided regarding the responses' frequency of the existing situation.

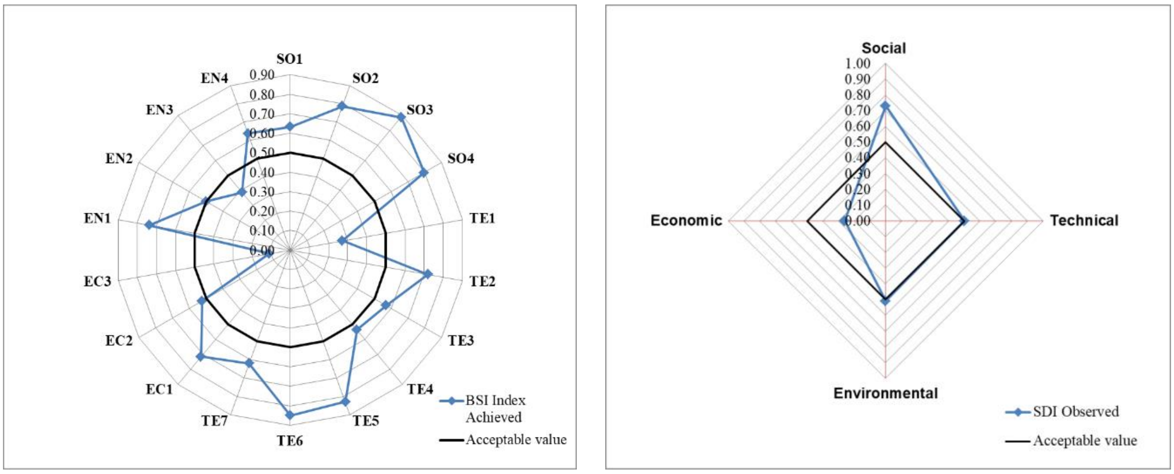
The results for weights of each SI within each dimension are presented in Table 2, column 8. The results of the four dimensions are presented in Table 2, column 10. It was found that higher weights were attributed to worst-performing factors or vice versa. It is, perhaps, not surprising that the social dimension is the least important for the understanding of the sustainable SS. Indeed, it seems that there is also a social trend in previous similar studies, which assigned little importance to social sustainability as a significant factor for selecting/planning/understanding the sustainable wastewater treatment system [6,8,29].

3.2.4. Sustainability Indices

The GSI of the SS was 0.42 (Table 2, column 11). This index falls on the verge of the "danger" category and below the acceptable starting point of 0.50 because of being the least sustainable economic dimension. Therefore, corrective actions must be suggested. A systematic analysis of the GSI offered an awareness of the theme, revealing that enhancement is furthermost compulsory.

Economically, the SS with DSI_{EC} 0.26 was the lowest among other dimensions, just beyond the unacceptable range (Table 2, column 9. The indicator EC3 obtained the smallest index value (0.11) (Table 2, column 7), which could cause the low economic sustainability. This is because almost 84% of SSs have no reuse practices of end products. Technically, the SS with DSI_{TE} 0.50 was at the acceptable threshold because six out of seven indicators were above the acceptable range (Table 2, column 7). Environmentally, the SS with DSI_{EN} 0.51 was also only just above the acceptable threshold because three of four indicators were above the acceptability range. Socially, the SS with DSI_{SO} 0.73 was the highest, superseding other dimensions, just about near the very good range (Table 2, column 9). This is because all indicators were above the acceptability threshold of 0.50 and three out of four indicators fell in the excellent range.

Figure 5a,b present sustainability indices obtained for all indicators (Table 2, column 7) and dimensions (Table 2, column 9) in a radar diagram, respectively. The diagram is essential concerning visualization to give an idea of the entire system's sustainability, identify failures to obey the standards, enable the faster transfer of outcomes to related stakeholders, and disseminate the results to a wide audience. The addition of the edge value at 0.50 (as a thick line) in Figure 5 directly explains parameters that were below the acceptable sustainability value; enhancements are, therefore, compulsory. For example, in terms of indicators, 3 out of 18 indicators (EN-3, EC-3, and TE-1) were below the acceptability threshold, as shown in Figure 5a, and therefore, adjustment actions are suggested to bring the higher overall sustainability of SS in the city. For example, natural streams can be improved and managed using advice related to pollution from SS in the study area by working on these three SIs that are weak. Similar to dimensions, the economic dimension (EC) was below the acceptable threshold (0.50), as seen in Figure 5b; corrective measures are, therefore, highly recommended. The SE of SSs in Mwanza city using FIA allowed a holistic analysis. It provided an understanding of the existing systems' weakest points and proposed measures for improvement.



(**a**) (**b**)

Figure 5. Indices for sustainability indicators (**a**) and dimensions (**b**) in radar chart diagram.

4. Conclusions

In this paper, an FIA was developed as an innovative method for evaluating the sustainability potential of SSs in 200 households, in Mwanza city, Tanzania, by investigating economic, technical, social, and environmental dimensions. Concerning DSI, the SS social and environmental aspects were within the "good" sustainability range and indicated that optimization and alteration measures are suggested, whereas technical and economic aspects were within the "danger" range and revealed that corrective measures are needed. In general, the results showed that the GSI attained for the whole SS in the study area was 0.42. This index was within the danger range, lower than an acceptable level fixed at 0.50, and reflected that immediate corrective measures are a must.

Measuring GSI for a whole city is a very effective means to express clear messages to widespread audiences and decision makers. The ease of SGI was complemented by the data confined in its 18 SIs. Each SI contained precise variables addressing an extensive range of pertinent issues. As a result, it can be claimed that FIA is an understandable and combined approach to enable an integrated SE and the monitoring of the entire SS of the city. This approach could be useful in assessing OSSs in a conceptually coherent and practically efficient manner. The information with which the GSI was calculated, in relation to pertinent SIs, makes it suitable to identify sequences of action and upgrading strategies. In general, the indices revealed weaknesses and shortfalls that point out areas where different levels and kinds of enhancements are required. Hence, the GSI proved to be valuable for those in the sanitation industry—service providers, researchers, public, and controller agencies/organizations—who are interested in evaluating the sustainability potential of SSs.

The proposed FIA reasonably discerned differences among various dimensions within the SS in the city, even when it was challenged with vague information. The index detected weaknesses and deficits that indicated areas where improvements are needed. The key steps for obtaining the indices using the FIA were suitable conceptual framework selection/development and relevant parameters (i.e., dimensions, indicators, and variables) identification or measurement. These steps are reasonably transferrable in any domain, indicating extensive relevant data collection methods.

FIA can be used with the quantitative and qualitative data that are quickly available or easily collected, causing it an appropriate approach to be suitable in developing and developed countries. It allows for the presence of relevant system owners in the whole evaluation process. Other natural and social–scientific methodologies may be required to further understand the meaning, utility, and limitations of sustainability indicators. Generally, the FIA grasps numerous possible viewpoints as an effective method for the SSs optimization, re-evaluation, and upgrading toward sustainability under uncertainty data.

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