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Designing a Holistic Composite Metric for Sustainable Integrated Solid Waste Management: Economic, Social, and Environmental Perspectives

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ABSTRACT: The Sustainable Development Goals (SDGs) have provided the opportunity to ensure adequate, safe, and affordable housing and basic services (including sustainable waste management) for all by 2030. A Sustainable Integrated Solid Waste Management System (SISWMS) is defined as one that fits a particular location with its inherent characteristics and peculiarities in line with the SDGs. There is no one-size-fits-all, comprehensive waste management system or metric that worked everywhere in the world indefinitely. Hence, waste management stakeholders worldwide were actively engaged in designing their own versions of the Sustainable Integrated Solid Waste Management Composite Index (SISWMCI) and frameworks that were economically, environmentally, and socially viable. This work aimed to develop a scalable, versatile, holistic, and innovative tool, in the form of a metric, to assess and benchmark solid waste management practices and systems. The proposed SISWMS framework and metric were rooted in the tripod of SDG pillars (economic, social, and environmental domains), interwoven using the Analytical Hierarchy Process (AHP) and Multi-Criteria Decision-Making (MCDM) weighting and aggregation methodologies, applied to 45 indicators across 10 sub-domains. The results indicated a red signal requiring urgent intervention, as the overall performance was 0.46, aggregated from the economic (0.49), social (0.49), and environmental (0.40) performance scores. The proposed metric was expected to serve as a robust and reliable sustainability performance benchmarking and improvement tool for waste management practices at the area, local government, state, and national levels.

KEYWORDS: Solid waste performance indices; sustainability; Sustainable Development Goals (SDGs); Ibadan-Southwest Nigeria

1. Introduction

Solid Waste Management (SWM) is a perennial challenge that increases with a locality's socio-economic development [1, 2]. Stakeholders in waste management research and practice had adopted different methods and technologies to plan and keep up with emerging trends, based on the realization that what could not be measured can not be managed or improved [3, 4]. The United Nations (UN) General Assembly presented an action plan for the 2030 Agenda for sustainable development, 17 of which centered on waste management within the tripod of economic, environmental, and social domains [5]. There is a need for composite metrics for

Sustainable Integrated Solid Waste Management Systems (SISWMS) that fit particular locations with their inherent peculiarities. The purpose of this study was to develop a composite index based on the principles and agenda of sustainable development and its goals. The statements of the SDGs were embedded in the SISWMS concept, as presented in Figure 1.

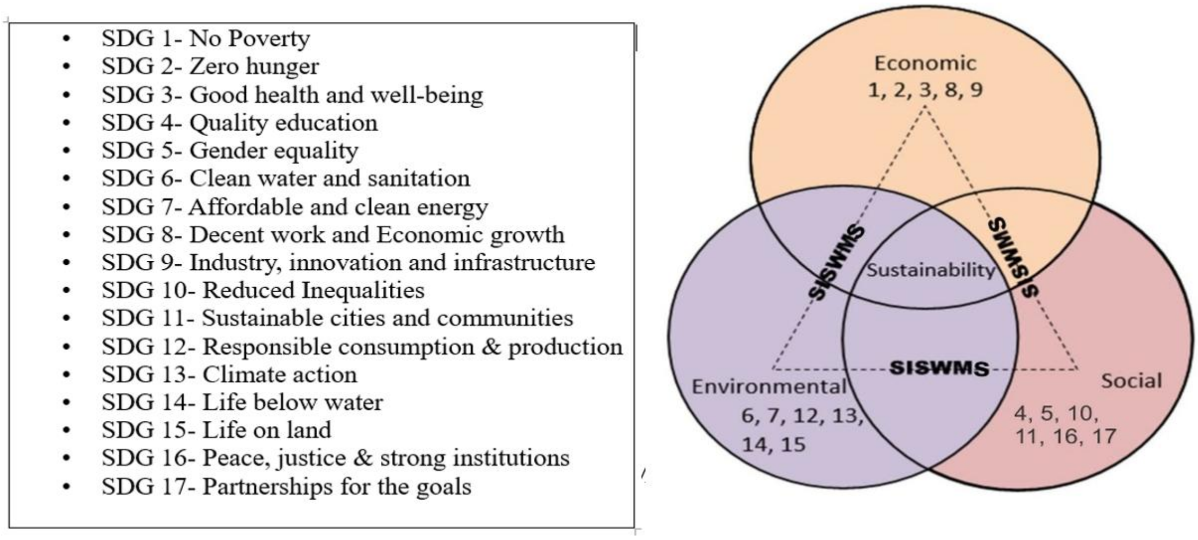

Figure 1. The SDGs are embedded in SISWMCI.

The SWM problem is a global challenge driven by exponential population growth, rapid urbanization and industrialization, inefficient utilization of natural resources, lack of public awareness regarding proper waste handling, socio-economic conditions, and other contributing factors [6]. Approximately 20–50% of the recurring municipal environmental budget was spent on solid waste management, yet only about 50% of the urban population was covered. Moreover, 80–90% of this budget was consumed by waste collection activities, while only about 30% of the waste generated was recyclable [7]. Researchers in the field of waste management have adopted different approaches and tools to develop reliable waste management performance indices [8]. The severity of the challenge was lower in middle-income nations and higher in low-income nations. In Nigeria, there were 33 different regulations on environmental and waste management, while approximately 32 million metric tons of waste were generated annually, with per capita generation rates varying between 0.4 and 0.9 kg depending on location [9,10].

In Ibadan, south-west Nigeria, with a collection rate of 40–50% and a waste generation rate ranging between 0.629 and 0.644 kg per capita per day, and given a population growth rate of 2.62, approximately 4,149 metric tons of municipal solid waste were projected to be generated monthly by 6.44 million people, compared to the current generation of about 2.1 metric tons across wards by 3.8 million people [11,12]. Globally, waste generation was approximately 0.9 kg per capita per day and was projected to increase to 1.26 kg per capita per day by 2050. Inadequate waste management constituted a serious risk to human health and the environment [13,14].

A composite index is defined as an aggregated combination of performance indicators (PIs) into variables that constituted the domains of a metric. Performance indicators were simple, easy to interpret, accessible, and reliable measures for monitoring various systems, including waste management services [15]. Performance indicators were derived from system parameters that described the level of achievement of the proposed system. In traditional performance benchmarking procedures, PIs served as the fundamental inputs used by participating localities, enabling cross-comparisons with other areas possessing similar demographic, geographic, environmental, and financial characteristics [16]. Composite indicators were useful tools in policymaking because they measured multidimensional concepts that could not be represented by a single indicator. Indices summarized complex development processes by evaluating and comparing the performance of key components using individual PIs or their normalized scores. Operations managers then developed performance action plans by focusing on how the underlying processes of essential components will be performed [17,18]. This information could be obtained from empirical local data through intra-assessment of SWM performance. In such assessments, goal levels were established, followed by component and sub-component identification, down to the determination of PIs at the lowest decision-making level. Performance measurement and benchmarking of SWM practices had not reached their full potential in many countries, particularly in emerging economies and those that are further down the development trajectory [19,20].

In benchmarking or framework development for performance evaluation, the selection of weighting and aggregation techniques is crucial, especially for sustainability assessments, due to their significant influence on outcomes. Weighting methods could be objective or subjective [21]. Objective methods included equal weighting and statistically based approaches such as Principal Component Analysis (PCA), Factor Analysis (FA), Data Envelopment Analysis (DEA), and Regression Analysis (RA). Subjective methods included the Analytic Hierarchy Process (AHP), Conjoint Analysis (CA), and Budget Allocation Process (BAP) [22,23]. The AHP integrated with Multi-Criteria Decision Making Analysis (MCDMA) was selected for this study due to its capacity to incorporate expert judgment, handle both qualitative and quantitative criteria, and capture the complex, interdependent nature of sustainability assessments. The integration of AHP and MCDMA provided a robust, flexible, and context-sensitive framework for evaluating and benchmarking solid waste management performance [20]. By combining objective data with subjective expert insights, this approach produced a composite metric that quantified sustainability performance and supported strategic decision-making toward achieving the Sustainable Development Goals at local, regional, and national levels. It enabled a comprehensive evaluation of complex systems, which could then be synthesized into a single comparable index [24–27].

To create usable indices, indicator values had to be aggregated. A composite indicator resulted from combining individual indicators that reflected distinct aspects of the concept under investigation. At the time of this study, no attempt to develop a comprehensive index or benchmarking metric was identified in Ibadan, Oyo State, neighboring states, or across Nigeria. The closest effort was a geo-spatial analysis [28] that investigated the adequacy of skip bins in Ibadan North Local Government Area, without a specific metric to determine required or available waste volumes and facilities. Another study [29] examined waste management infrastructure and facilities in Ibadan using the Adequacy Facility Index (ADFI), which was based solely on the number of skip bins. The primary objective of this research was to develop a composite index that addressed uncertainty and sustainability within SISWMS. The resulting SISWMCI could be applied simultaneously for inter-locality and intra-locality performance assessments in solid waste management. The algorithm for SISWMCI involved the processes presented in Figure 2.

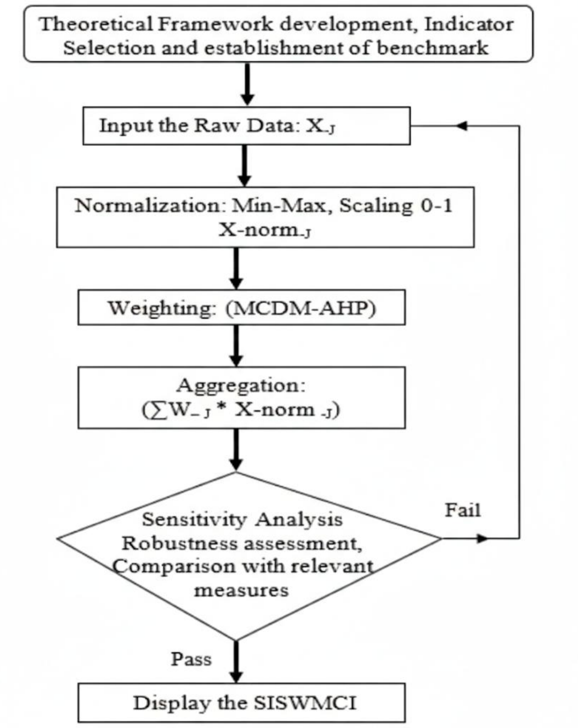

Figure 2. The processes involved in the development of SISWMCI.

2. Materials and Methods

2.1. The study area.

Ibadan was located on a hilly terrain at approximately 210 meters above sea level in south-west Nigeria. It lay between latitudes 7°05′N and 7°25′N and longitudes 3°20′E and 3°55′E, and was situated about 145 km north-east of Lagos. Ibadan comprised 11 Local Government Areas (LGAs), with Ibadan North LGA being the largest and most prominent, as it served as the seat of many major institutions as well as local and state government secretariats at the time of this study. The projected population of Ibadan North Local Government was 625,170 as of 2023, with an annual growth rate of 2.3% based on the 2006 census. The reported waste generation rate ranged between 0.5 and 1.5 kg per person per day. The city had experienced several floods and disasters in the past as a result of waterway blockages caused by improperly managed waste. These events attracted global attention and led to the establishment of the Ibadan Urban Flood Management Project (IUFMP) by the World Bank. Waste management activities in the city were supervised by the Oyo State Waste Management Authority (OYWMA) in partnership with private waste management companies [11]. The government had faced challenges in controlling the increasing volume of waste in the study area due to rapid urbanization and socio-economic growth. Since waste that could not be measured could not be improved, waste management stakeholders were developing a 20-year plan to (i) increase the proportion of treated waste to at least 40% of the total waste generated, (ii) establish a state-wide organizational framework for integrated waste management, and (iii) develop a comprehensive performance evaluation system capable of comparing current performance, identifying deficient performance domains and sub-domains, and highlighting potential future improvements in material and energy recovery.

2.2.The parameters and criteria for the SISWMCI assessment.

The SISWMCI was a hierarchical, top-down model consisting of three main components (domains), ten sub-components (sub-domains), and forty-five indicators, as itemized and presented in Supplementary Materials (SM) Tables S1. It was structured in multiple levels following a generation-based parent–child hierarchy. The four generations comprised the performance objective (parent); performance attributes for the components (domains) and sub-components (sub-domains) at Levels 1 and 2; and performance indicators, which were fed by basic inputs consisting of data variables and decision variables. The data variables were obtained annually from the study area to derive the performance indicators and support decision-making across the various system components, thereby promoting concurrent growth and development across levels and sectors. The main components (domains or sectors) were economic (ECO), environmental (ENV), and social (SOC). The environmental sub-domains included global warming potential (GWP), ozone layer depletion (OZL), and human health and eco-toxicity (HHE). The social sub-domains comprised proximity and land use for facilities (PLA), people's awareness and enlightenment (PAE), and people's participation (PPT). The economic sub-domains included design cost (DCST), set-up cost (SUCST), operating cost (OPCST), and contribution to gross domestic product (CGDP).

2.3.The key performance indicators.

The potential performance indicators for the SISWMS were identified through an extensive review of the solid waste management literature. Based on these indicators, five distinct sets of questionnaires were developed for waste management officials and relevant stakeholders. The selection of indicators was informed by the judgment of waste management researchers and academics, policymakers in the waste management sector, landfill operators and managers, and the general public. A 9-point Likert scale, ranging from 1 (not important) to 9 (extremely important), was used to collect opinions on the relative importance of each performance indicator. The relative significance index (X_i), as expressed in Equation (1), was subsequently applied to determine the relative relevance of the performance indicators.

$$X_{-J} = \sum_{i=1}^{n} \frac{W_i X_i}{A \times n} \tag{1}$$

Where A was the greatest weight (9 in this study), n was the number of respondents, and Wi and xi were the weight and frequency of the ith response, respectively. In this work, a 90% cutoff value was employed.

2.4.Methodology.

Composite index building is a complex process that entailed a series of steps, determining the quality and reliability of the index. The SISWMCI drew heavily from the concepts and principles of the Sustainable Development Goals (SDGs), using the three fundamental pillars: environmental, economic, and social domains. The conceptualization, formulation, normalization, weighting, and aggregation processes were presented in this section.

2.4.1. Conceptualization of the framework and establishment of a benchmark for the SISWMCI.

The literature on solid waste management (SWM) was replete with documented challenges related to waste handling and management across various locations worldwide. The SISWMCI sought to provide a sustainable solution by developing an SWM framework and system embedded within the SDGs framework. As presented in SM S1, the economic domain comprised four sub-domains with a total of 22 performance indicators; the social domain consisted of three sub-domains with nine performance indicators; and the environmental domain included three sub-domains with 14 performance indicators. In total, 45 performance indicators were selected through an extensive literature review and stakeholder consultations in a manner that enhanced and preserved the versatility and flexibility of the proposed approach, subject to data availability and the intrinsic characteristics of the study location.

Each performance indicator functioned as either a decision variable or a data variable, which were combined to derive the overall performance of the variable. This adaptability prevented data limitations from adversely affecting indicator performance and ensured that the framework remained robust and applicable across diverse urban contexts. The minimum and maximum values of each indicator were defined by key stakeholders, including managing directors of government agencies (OYWMA), directors of five major non-governmental organizations involved in solid waste management, landfill managers and monitors, researchers and academics in waste and environmental management, and members of the public. This approach aimed to provide a comprehensive yet flexible framework for evaluating the effectiveness of the waste management system while acknowledging the dynamic nature of urban data environments. Figure SM S1 illustrates the structure of the SISWMCI.

2.4.2. Normalization of SISWMCI input data.

Due to differences in the dimensions of the indicators, normalization of the input data was unavoidable prior to the aggregation process used to build the composite index. This step involved transforming the data to a common or standard scale so that it could be combined into a single measure, thereby eliminating discrepancies in units and magnitudes. Common normalization methods included the Z-score, min–max, distance-to-a-reference, and categorical scale approaches. The min–max method was adopted in this study, as it was the most widely used and versatile normalization technique. It was applied to transform indicator values between the minimum and maximum reference (benchmark) values, which were set to 0 and 1 in this work. Two normalization equations, Equations (2) and (3), were employed. Equation (2) was applied when an increase in an indicator led to an increase in the SISWMCI value, whereas Equation (3) was used when an increase in an indicator resulted in a decrease in the SISWMCI value.

$$X_{\_norm\_j} = \frac{(X_{raw} - X_{min})}{(X_{max} - X_{min})} \qquad (2)$$

$$X_{\_norm\_j} = 1 - \frac{X_{raw} - X_{min}}{X_{max} - X_{min}} \qquad (3)$$

where X_{norm_j} is the performance indicator's normalized value, Xraw is the performance indicator's raw value, Xmin and X_{max} are the minimum and maximum benchmarking values of the performance indicators, respectively[16].

2.4.3. SISWMCI weighting.

A hybrid of the Analytic Hierarchy Process (AHP) with additive aggregation, combined with equal weighting, was employed in this study. The AHP and MCDM methods were selected due to their ability to incorporate expert judgment, accommodate both qualitative and quantitative criteria, and capture the complex, interdependent nature of sustainability assessments. This methodological choice was further supported by the broad acceptance, frequent application, ease of use, clarity in communication, and wide applicability of these techniques.

2.4.4. Aggregation process for the SISWMCI.

The aggregation process was conducted at three levels. The first level involved lower-level aggregation, in which normalized indicators within the same sub-domain were aggregated to compute the sub-domain index. The second level was the middle-level aggregation, where sub-domain indices within the same domain were aggregated to determine the performance index of each domain, namely the environmental, social, and economic domains [21]. The final aggregation step involved combining the performance indices of all domains to calculate the overall SISWMCI value.

2.4.5. Mathematical formulation of SISWMCI from AHP and PIs' weight.

The AHP was applied in this study due to its widespread acceptance and versatility in addressing similar problems within the solid waste management literature. The hierarchical structure was established, and pairwise comparison matrices were constructed for each level following the Saaty procedure. A consistency ratio of 0.1 or less was ensured to validate the judgments. Indicator weights (Wi) and consistency indices (Ci) were calculated using AHP software. The local weight of each indicator (LKi) was derived through the aggregation of multiple indicator weights (Ki). The SISWMCI was then obtained by aggregating the sub-domain weights (Wi) with the equal weights assigned to the domains (Gi), as expressed by equation (4). The values of SISWMCI are the global weight for each performance indicator.

$$SISWMCI = \sum_{i=1}^{n} GiW_iLK_i \qquad (4)$$

3. Results and Discussions

3.1. Responses from the targeted group.

Forty-five potential PIs were identified through a literature review and consultations with stakeholders. The PIs were distributed across four distinct questionnaire sets, which were designed for the four groups of stakeholders mentioned in Section 3.4. The responses from the experts are presented in Table 1. The list of indicators, domains, and sub-domains with their respective values used in this study is provided in the supplementary materials.

Table 1. Responses from the various groups.

EXPERTS/ Stakeholders	Distributed	Returned	Response rate (%)	uncompleted	Completed	Completed (%)
Waste managers	20	18	90.00	3	15	75.0
Planning Engineer	80	63	78.75	17	46	57.5
Site Engineer	40	32	80.00	nil	32	80.0
Citizen	60	60	100.00	Nil	60	100.0
Total	**200**	**170**	**85.00**	**30**	**156**	**78.57**

3.2. Trends and policy implications in SISWMCI over time (2018 -2023).

Adopting the SISWMCI within municipal local government and NGO frameworks transformed waste management from a reactive, infrastructure-based service into a strategic, performance-oriented system. Through structured coordination, data-driven monitoring, and participatory governance, the SISWMCI became a dynamic instrument for sustainability benchmarking and continuous improvement, ensuring that waste management contributed meaningfully to environmental integrity, social inclusion, and economic efficiency in cities such as Ibadan and beyond. The overall SISWMCI results showed a gradual increase in performance, except for a surge between 2019 and 2020. The environmental domain demonstrated the best performance despite the drop observed between 2019 and 2020, followed by a steady rise between 2020 and 2023. Despite the continued depletion of the ozone layer, its impact mitigated the downward trends in human health, eco-toxicity, and the tendency toward global warming. The economic domain performed better than the social domain, as design costs decreased after the initial expenditure and subsequently stabilized around the initial cost. The higher performance of environmental indices compared to social indices reflected a structural imbalance in sustainability efforts in Ibadan. While environmental initiatives benefited from visible, infrastructure-based, and enforceable interventions, social sustainability remained underdeveloped, constrained by economic inequality, weak participation mechanisms, and limited community engagement.

To achieve a truly sustainable integrated solid waste management system, policy frameworks must evolve beyond environmental compliance to incorporate social inclusion, behavioral change, and equitable participation as integral components of urban sustainability planning. Although set-up costs decreased after the initial investment, operating costs rose in response to the economic realities of the area, maintaining a close gap to the high cost of living. Contributions to CGDP increased, with a dip between 2021 and 2022 before returning to the 2021 peak. The initial increase in public awareness led to higher participation, which dwindled over the study period. Rapid urbanization without corresponding economic and infrastructural development eroded initial gains in the social domain, as residents struggled to cope with economic downturns and rising living costs. Additionally, green areas were increasingly converted to residential zones, reducing space for waste treatment and management operations. Figure 3 presents the trend in the SISWMCI.

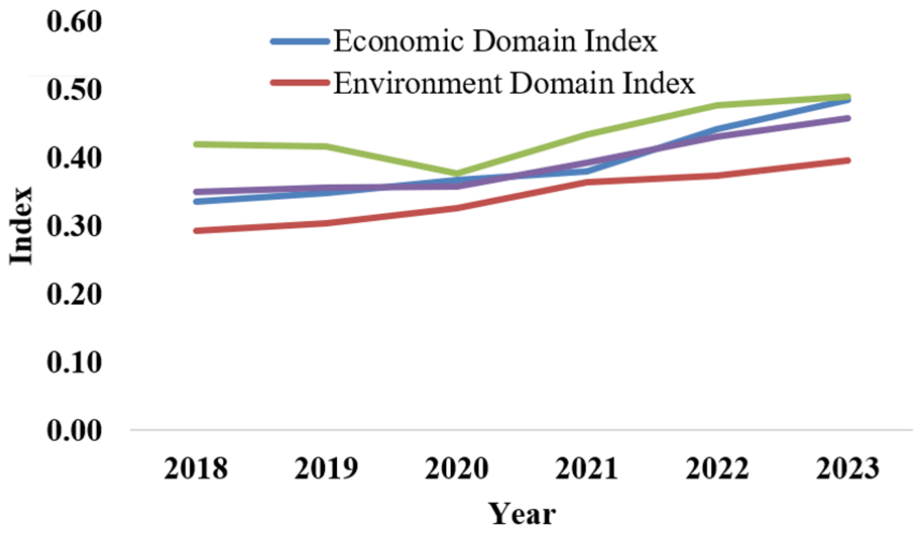

Figure 3. The SISWMCI indices and domains.

The search for a similar metric in Nigeria did not yield any results at the time of this study. The proposed SISWMCI is adaptable to any location, accommodates inherent local peculiarities, promotes data-driven decision-making and accountability in waste management, enhances transparency and community trust through measurable sustainability indicators, facilitates cross-sector collaboration and knowledge sharing, and enables performance benchmarking at local, regional, and national scales. Consequently, it supports Nigeria's commitment to the 2030 Sustainable Development Goals and circular economy transitions. These features position the SISWMCI as a practical tool for assisting other developing countries facing similar waste management challenges.

3.3.The SISWMCI correlation analysis.

It is important to examine the extent of each driving factor's contribution (domains and their respective sub-domains) to the SISWMCI. This analysis provides a deeper understanding of how each component affects overall performance. The analysis was conducted by obtaining the Pearson correlation coefficients ($|r|$) between the SISWMCI and the domains, and subsequently between the domains and their respective sub-domains. The value of $|r|$ ranges from 1 (signifying perfect correlation) to 0 (signifying no correlation). Positive (+) and negative (−) signs indicate the direction of the correlation. A $|r| \geq 0.6$ was considered desirable, representing a strong or very strong correlation; $|r|$ between 0.4 and 0.59 was considered moderate; $|r|$ between 0.2 and 0.39 was weak; and $|r| \leq 0.19$ was very weak. Design cost exhibited a very weak correlation of 0.11, indicating that SISWMCI performance between 2018 and 2023 was minimally affected by design cost. Similarly, human health and eco-toxicity showed a weak correlation, suggesting limited influence on SISWMCI during the study period. However, approximately 76.9% of the 13 relationships analyzed demonstrated strong or very strong correlations. These results corroborate findings from earlier studies [31,33]. The values of $|r|$ for the SISWMCI and the domains, as well as for the domains and their respective sub-domains, are presented in Tables 2 and 3, respectively.

Table 2. The coefficient of thePearson correlation between SISWMCI and the domains.

Benchmark values for the correlation coefficient			
Very weak |r| ≤ 0.19(7.69%)	Weak| r | = 0.2- 0.39 (7.69%)	Moderately viable |r| =0.4-0.59 (7.69%)	Strong /Very strong |r| ≥ 0.6 (76.92%)
The correlation coefficient of the domains with respect to the SISWMCI.			
	Domains		r
	Economic		0.98
	Environment		0.95
	Social		0.91

Table 3.The coefficient of the Pearson correlation between the domains and sub-domains of the SISWMCI.

Benchmark values for the correlation coefficient			
Very weak |r| ≤ 0.19 (7.69%)	Weak | r | = 0.2- 0.39 (7.69%)	Moderately viable |r| =0.4-0.59 (7.69%)	Strong /Very strong |r| ≥ 0.6 (76.92%)
The correlation coefficient of the Economic sub-domains with the Economic domain index			
Design cost			0.11
Set-up cost			0.72
Operating cost			0.79
Contribution. To GDP			0.93
The correlation coefficient of the environmental sub-domains with the Environmental domain index			
Global warming potential			0.98
Ozone layer depletion			0.88
Human Health and Eco-toxicity			0.81
The correlation coefficient of the social sub-domains with the social domain index			
Peoples'Awareness and Enlightenment			0.83
Proximity and Land alternative use			0.68
People's Participation			0.91

3.4. The SISWMCI sensitivity analysis.

To evaluate the robustness and reliability of SISWMCI, sensitivity analysis is carried out, exploring how changes to input parameters or weights affect the index as a whole. Three strategies (S1, S2, and S3) were explored. In S1, the weight of design cost was varied by 50% with respect to the economic domain; the trajectory continues to follow the trend with equal weight (EW) allocation, with a slight variation of about +0.14% (that is, going from 3.5 in 2018 to 0.49 in 2023). The S2 and S3 exhibit a more pronounced variation because they require a more substantial alteration to the structure of the SISWMI. Variation is +9%, and the S3variation is +6% between 2018 and 2023. Table 4 presents the strategies used in the sensitivity analysis.

Table 4. Sensitivity analysis strategies.

Strategy	Objective	Description
S1	▪ |r| ≥ 0.6 between design cost and economic domain	▪ Design cost weight: +50% with respect to EW[1]
S2	To assess the impact of the omission of the Strongest domains on the SISWMI	Without Contribution to GDP, people's participation, and Global warming potential, which have the highest correlation values
S3	To understand the effect of the exclusion of A specific domain on SISWMI	Examining the compensability effect of a particular domain (for instance, Economics), using additive aggregation

EW[1] Equal weight allocation

The SISWMCI has a balanced structure of indicators, which reduces the likelihood that disproportionate results from the sensitivity analysis would occur. The analysis showed that there were only limited variations in SISWMCI, even with substantial increases in weight allocation (S1) and modifications in its structure (S2 and S3). The metric effectively captures disparities without destabilizing the overall composite score, identifies top-priority improvement areas, and reinforces the reliability of its guidance for decision-making. The outcomes of the strategies over the study period are presented in Figure 4. This demonstrates the practical robustness and reliability of the SISWMCI, as it adapts to local data realities while maintaining comparability and benchmarking integrity.

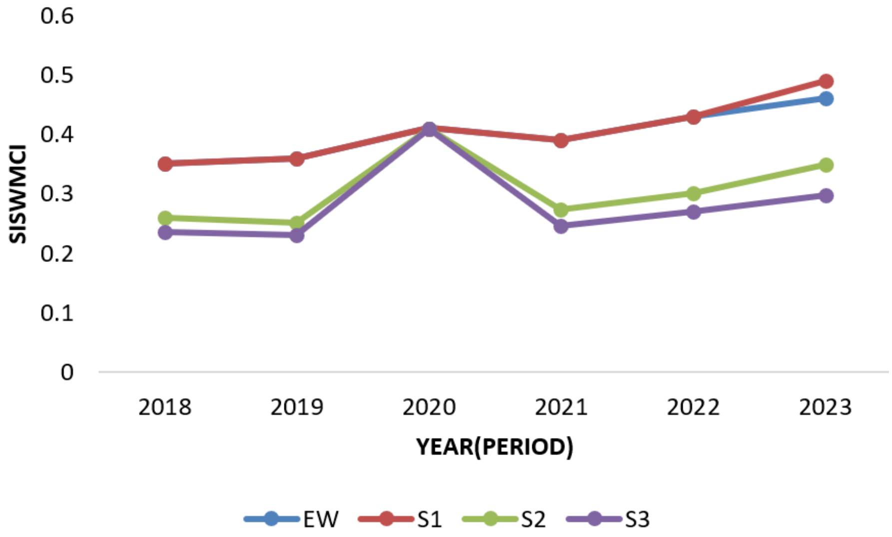

Figure 4. Sensitivity analysis results.

3.5.Comparative analysis with other studies.

Some international studies on composite metrics, highlighting their peculiarities and differences from the SISWMCI, are summarized in Table 5.

Table 5. Comparison of SISWMCI with previous local and international studies.

Study (Author & Year)	Method / Index Used	Scope / Study Area	Key Findings	How It Differs from SISWMCI
[4]	Zero Waste Index (ZWI) framework	Global cities (Australia, UK, Malaysia)	Proposed ZWI to quantify circularity and recycling efficiency; emphasizes waste diversion from landfill.	Focuses mainly on material recovery and recycling; limited integration of social and economic indicators.
[27]	Circularity & Life-Cycle metrics	European cities	Developed UWCI to assess urban waste system efficiency and material loop closure.	Strong environmental focus; does not provide holistic integration of economic or governance factors.
[4]	Multi-Criteria Decision Analysis (MCDA) for municipal waste options	Thailand	Applied MCDA to rank SWM alternatives using environmental, social, and technical criteria.	Lacks a unified composite index and benchmarking capacity; case-specific application.
[32]	Decision-Support Framework using AHP	Ireland	Identified critical criteria for evaluating waste management policies.	AHP is used only for prioritization, not for comprehensive performance measurement or sustainability scoring.
[33]	Integrated AHP–Entropy Weighting	China	Combined subjective and objective weights to assess municipal solid waste systems.	SISWMCI extends this by incorporating stakeholder-driven indicators and broader socio-economic coverage.

Study (Author & Year)	Method / Index Used	Scope / Study Area	Key Findings	How It Differs from SISWMCI
[30]	Hybrid MCDM (AHP-TOPSIS)	China (provincial comparison)	Evaluated the sustainability of provincial SWM systems; emphasized policy and infrastructure.	Less scalable; focused on regional comparison. SISWMCI emphasizes flexibility for local and municipal benchmarking.
[31]	Qualitative assessment framework for SWM in African cities	Sub-Saharan Africa	Highlighted institutional and infrastructural barriers to sustainable waste management.	Qualitative focus only; no quantitative composite metric for benchmarking.
[29]	Descriptive and Inferential Statistics	Ibadan-North, Nigeria	Insufficient number of skip bins	inadequacy of Facility Index based on the number of bins alone.
[28]	Spatial analyses, Nearest neighbours' analyses	Ibadan-North, Nigeria	Inadequate facilities for SWM	No quantitative composite metric for benchmarking.
Proposed SISWMCI (Current Study)	AHP + MCDM Composite Index	Nigeria (Local–State level)	Developed 45-indicator, 10-subdomain SISWMCI covering economic, social, and environmental dimensions; overall score = 0.46.	Unique for its holistic integration, scalability, local adaptability, and strong sensitivity-tested robustness.

4. Conclusions

The challenges and complexities of waste management practices and policy-making require the support of versatile and user-friendly tools or metrics, including indices, frameworks, techniques, and technology. Such tools help organize strategic goals and monitor how policies impact the various components of the system as a whole. This study addresses this need by proposing a comprehensive, versatile, and adaptive metric-based framework and index aligned with the SDGs. The proposed composite metric, SISWMCI, can be applied for performance evaluation and waste management benchmarking both within and across municipalities. The data collection process to access open-source urban data in Ibadan–North Local Government faced multiple constraints and bottlenecks, as there was no systematic approach for gathering and organizing information. Consequently, data for the SISWMCI were obtained from 12 different sources, including academia, dumpsite and sanitary landfill managers, private waste business managers, directors, and civil servants in OYWMA, as well as other relevant stakeholders. Structured interviews were conducted with various categories of experts, complemented by a questionnaire administered across the 12 wards of the local government area. The overall SISWMCI performance showed a clear positive trend over the study period, although it remained below average (46%) according to expert judgment. The major contributions came from the economic and social domains, both approximately at average levels (49% each), while the environmental domain scored 40%, indicating an urgent need for intervention in the study areas. Correlation analysis confirmed the appropriateness of the chosen domains and sub-domains, highlighting their critical impact on waste management practices and operations in the region. The robustness and reliability of the SISWMCI were confirmed through sensitivity analysis, which revealed only minimal variance even when weight allocation (Strategy 1) and framework structure (Strategies 2 and 3) were significantly altered. Additionally, using sample data spanning more than five years enhanced the consistency of the time-based Min-Max normalization aggregated through the equal-weighting approach employed in this study. For effective implementation and institutionalization of the SISWMCI, the Ministry of Environment should issue policy directives mandating its use for annual performance reviews. State waste management authorities (e.g., OYWMA in Oyo State) should integrate SISWMCI-based evaluations into contractor and operator audits, while local government councils should report SISWMCI outcomes in their State of the Environment Reports, aligning with SDG 11 and 12 indicators. Moving forward, it is essential to establish a consistent approach for urban data collection and to organize these data into a centralized, accessible database. This will facilitate the comparison and tracking of SISWMCI trends over time, fostering healthy competition and promoting simultaneous improvements across the domains of the solid waste management system.

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Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors Contribution:

Michael Kolawole Oluwanimifise: Conceptualization, Formal Analysis, Methodology, Investigation, Resources, Writing – Original Draft, Visualization, Investigation, Writing – Review Editing, Validation; Christopher Osita Anyaeche: Review, Validation, Supervision.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.53623/csue.v6i1.829.

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