Sustainability indices and risk analysis of drinking water systems in Southwest Nigeria

Enovwo Odjegba, Grace Oluwasanya, Olufemi Idowu, Olufunke Shittu and Gail Brion

ABSTRACT

This study focused on designing a drinking water systems sustainability index for Integrated Water Resources Management in low-income countries. Water Supply Systems Sustainability Index (WSSI), a field assessment tool, was designed for rapid appraisal of drinking water systems in selected urban, peri-urban and rural Nigerian communities. The systems were classified into Highly Sustainable, Sustainable, Averagely Sustainable, and Unsustainable WSSI categories. Sanitary Risk Score (SRS) was assigned, classifying drinking water systems into Very High, High, Intermediate (Medium) and Low-Risk categories. WSSI results revealed that for urban systems, 90 are Highly Sustainable, 27 are Sustainable and 12 are Averagely Sustainable. For peri-urban systems, 13 are Highly Sustainable, 7 Sustainable and 1 Averagely Sustainable. Only urban hand-dug wells are in the Very High-Risk category. Public water supplies occurred only in the Low-Risk (17) and Intermediate-Risk (6) categories. Urban and rural boreholes had better quality than peri-urban boreholes. WSSI and SRS correlation result indicated strong positive correlation for urban hand-dug wells' ($R^2 = 0.5688$, at $p < 0.05$) and weak positive correlation between peri-urban hand-dug wells' ($R^2 = 0.1847$, at $p < 0.05$) and urban boreholes' WSSI and SRS ($R^2 = 0.2032$, at $p < 0.05$). Findings showed that drinking water systems are, generally, sustainable and WSSI could be incorporated into community-level water supply assessment.

Key words | drinking water, Nigeria, risk analysis, sustainability, sustainability indices, water supply systems

Enovwo Odjegba (corresponding author)
Grace Oluwasanya
Olufemi Idowu
Olufunke Shittu
Federal University of Agriculture,
Abeokuta, Ogun State,
Southwest Nigeria
E-mail: *odjegbaee@funaab.edu.ng*

Gail Brion
Department of Civil Engineering,
University of Kentucky,
Lexington, KY 40506,
USA

HIGHLIGHTS

- The study designed a water supply systems sustainability index for assessing water sources.
- The index is believed to be useful as a pre-assessment tool in a comprehensive water monitoring programme in integrated water resources management.
- The index is easy to administer and results comprehensible for relevant stakeholders, especially policymakers.
- The index is not intended to replace comprehensive water monitoring programmes but can be included in such programmes to assist in decision-making processes in water resources planning.

INTRODUCTION

Access to an adequate drinking water supply is a basic human right. However, global efforts at ensuring the availability of safe drinking water, such as the Millennium Development Goals, failed to reflect the safety and sustainability dimensions of its targets (Kayser *et al.* 2013), resulting in Sustainable Development Goals (SDGs) in

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2015. Goal 6, Target 2 of the SDGs seeks to ensure the availability and sustainable management of water and sanitation for all by the year 2030, emphasizing on quality and sustainability of water resources (United Nations 2016).

Nigeria's poor public water supply coverage has increased reliance on alternative water sources, especially, privately owned self-supply hand-dug wells and boreholes. However, water from the alternative sources are mostly consumed untreated and the quality of water is threatened by the proximity of the sources to pollution sites such as burial places and toilet facilities, among others. Consumers are exposed to significant health risks, which Mohammed & Abdulrazzaq (2018) suggested could be minimized through source contamination identification and strategic management practices. Water sources are equally vulnerable to risks as water source construction regulations are either not implemented (if any) or regulations do not exist at all. Water sources risks are associated with construction flaws such as construction in proximity to sources of contamination and poor maintenance of broken parts, for instance, well covers. The effects of poor maintenance on the overall efficiency of water systems are emphasized by Shahzad *et al.* (2019). Other challenges faced by consumers include the inability to own water sources, which increases the time spent searching for water and the strain of conveying water to the point of use. Owners of water sources sometimes sell their water thereby increasing the financial burden on consumers. In dry months, distances walked are longer and water sources could be unreliable as source owners lock their water sources to restrict access.

The issues highlighted above bring the sustainability of water sources to question. Sustainability as regards water supply is the utilization of a water supply system while ensuring that the ability of future generations to use the same resource is not hampered (Carter 2010). Sustainability assessment involves system performance measurement regarding the ability of a system to satisfy the objectives of sustainable development (Motevallian *et al.* 2011). Consumer health risks, the vulnerability of water sources to risks and source unreliability are issues militating against the sustainability of water sources. Inadequate access to water could significantly reduce daily per capita water use, limit water uses to only water sources where water can be accessed, thereby restricting choice regarding quality and increasing the risk of water-related ailments. Sustainability is complex, and in assessing the sustainability of a water supply system, the complex and dynamic nature of the system must be taken into consideration. Sustainability can be evaluated using the sustainability index approach. Several sustainability indices have been developed to address various environmental-related issues. Juwana *et al.* (2011) report that successfully implemented sustainability indices in water resources management can only be adapted for use in the regions for which they were designed. Some existing indices for water sustainability include Water Poverty Index (Sullivan *et al.* 2003), Canadian Water Sustainability Index (Policy Research Initiative 2007), Watershed Sustainability Index (Chaves & Alipaz 2007) and West Java Water Sustainability Index (Juwana *et al.* 2011).

The existing sustainability indices focus on water, within the context of poverty, water/wastewater infrastructure and water resource management. Studies emphasize that water sustainability indices should be a useful tool in identifying factors contributing to the improvement of water resources, assist decision-makers to prioritize issues or programmes relating to water resource improvement and easily communicate the current status of existing water resources (Sullivan *et al.* 2003; Chaves & Alipaz 2007; Policy Research Initiative 2007; Juwana *et al.* 2011).

In this study, WSSI was designed for drinking water supply systems. The objective was to design WSSI as a field assessment tool for field researchers/professionals, simple to communicate to supply system owners and water supply planning stakeholders for effective Integrated Water Resources Management (IWRM), especially in low-income countries. In this paper, the methods are discussed including a brief on the study area, followed by the Results and discussion. In addition, a reflective discussion to highlight further implications of the major findings is presented. The paper concludes with relevant recommendations and suggestions for further research.

DESCRIPTION OF THE STUDY AREA

Ogun State, Southwest Nigeria, lies between latitudes 2°45′E and 4°45′E and longitudes 6°15′N and 7°60′N (Figure 1). The state covers a land area of 16,409.26 km^2.

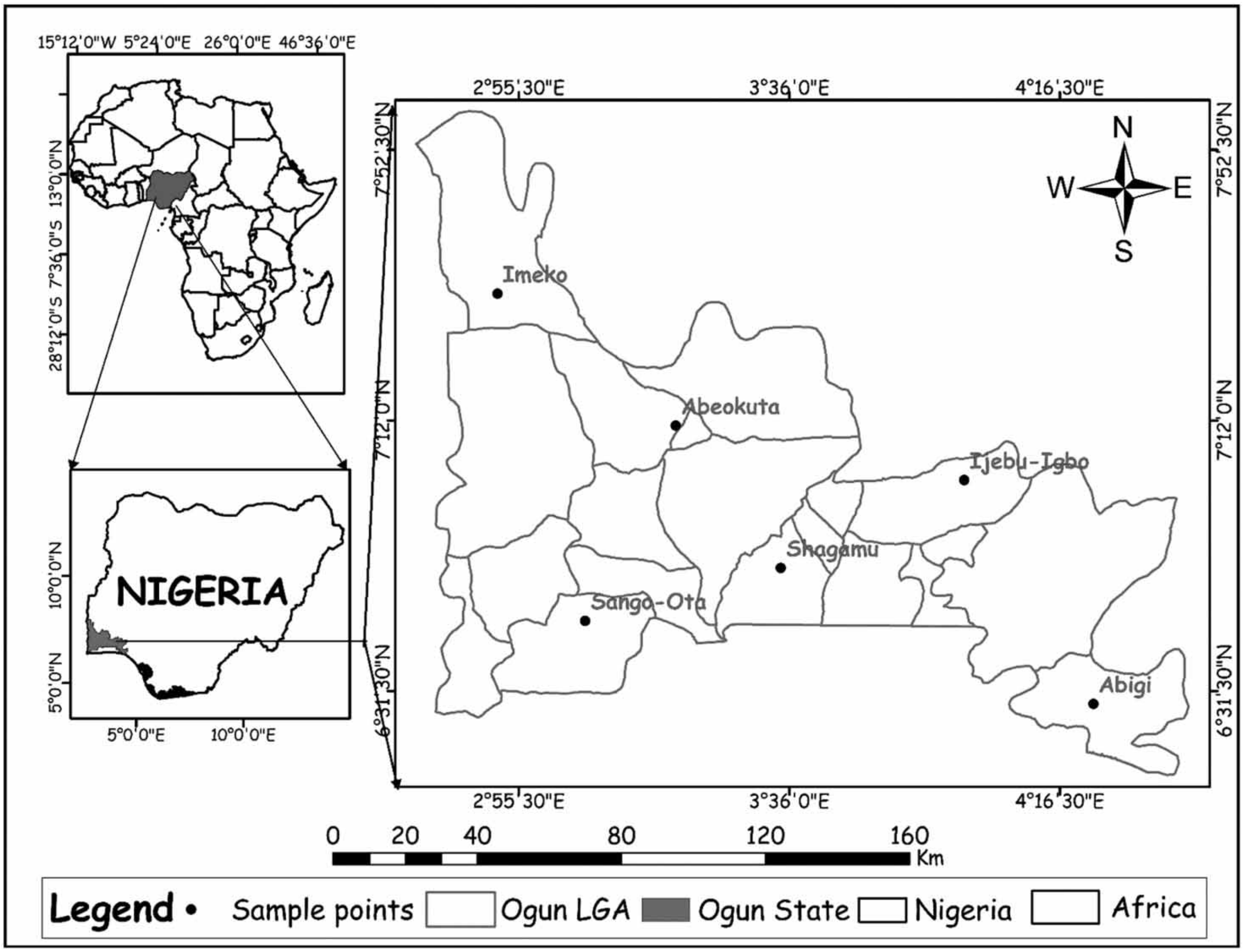

Figure 1 | Map of Ogun State, Nigeria showing the study locations (Map produced using Arc Map version 10.2).

At 2.6% annual growth rate (World Bank, 2017), the population of Ogun State is currently estimated as 5,340,113; 50.3% (2,686,077) of which are men and 49.7% (2,654,036) are women (National Population Commission 2009). The population density is about 325 persons per km^2. The climate is humid tropical with two distinct seasons: the rainy season, which lasts from March/April to October/November, and the dry season from October/November till March/April. Mean annual temperatures range between 24 and 30 °C. There are three types of water supply systems in Ogun State: public water supply (state-owned public utility), communal water supply and self-supply systems. Public water supply systems across the state are faced with challenges such as water scarcity caused by break down of infrastructure or power outages, poor coverage area or total absence of water supply in areas previously having water supply. Hence, consumers are forced to rely on communal and self-supply alternatives such as hand-dug wells and boreholes as a coping strategy.

MATERIALS AND METHODS

The study was carried out in six selected locations (3 urban, 1 peri-urban and 2 rural) in Ogun State, Nigeria, using the purposive sampling method with population density and geographic spread as criteria (Figure 1). The urban areas (Abeokuta, Shagamu and Sango-Ota) are more populated than peri-urban (Ijebu-Igbo) and rural areas (Imeko and Abigi). The flowchart for this study is presented in Figure 2.

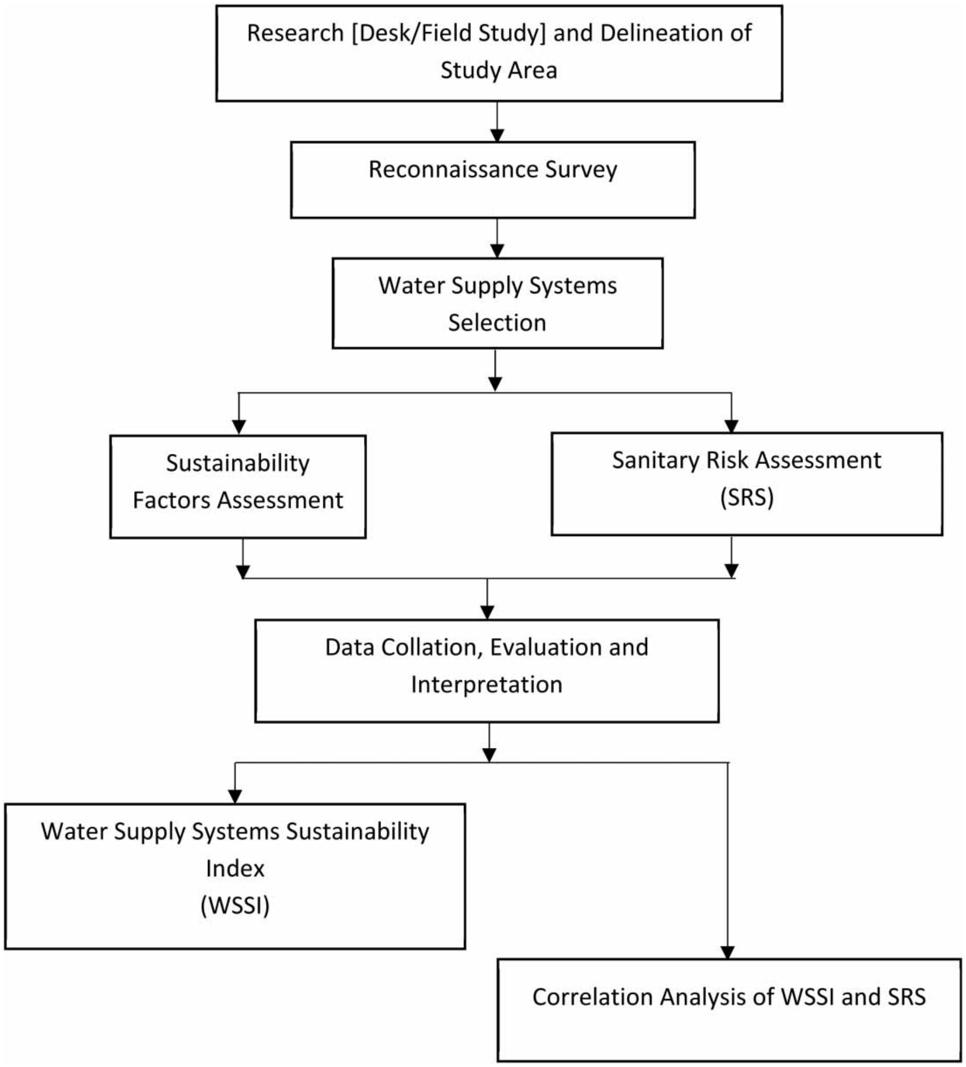

Figure 2 | Research flowchart.

The WSSI evaluated the sustainability of drinking water supply systems using Carter's (2006) five sustainability factors: access, reliability, quality, cost and management with respective scoring criteria presented in Table 1. Each factor was scored based on a set of components and corresponding description for each component. Components and description were used to define the factors for ease of scoring. As shown in Table 1, all five factors had three sets of components and three descriptions, each determined on a scale of 0–2, with a maximum sum of 10. The components and description used in this study were modified from Carter (2006). The components and description defined access in relation to distance or proximity to point of use, the influence of distance on litres per capita per day and method of collection (direct abstraction from source or pipe connection into the house). The number of litres consumed by users was estimated using a 30-litre jerry can (Figure 3). The jerry can, mostly yellow in colour, is traditionally used to collect, convey and store water.

The number of litres per capita is then estimated by the number of jerry cans used per day and the number of individuals (number of water consumers using each jerry can). Access was defined in relation to the proximity of water sources to point of use *viz-a-viz* the influence of the proximity of quantity of water accessible for use. Water sources far away from point of use (distances exceeding 1,000 m), which limited water

Table 1 | WSSI scoring criteria (adapted after Carter (2006))

Sustainability factors	Components	Description	Scores obtainable	Scores obtained
Access	Far distance to water source	Distance (exceeding 1,000 m) limits consumption to less than 8 litres per capita per day	0	
	Closer proximity	Water source is close, say between 500 and 1,000 m	1	
	Water source is easily accessible	Water source is within the compound or linked to the house through pipe networks or water source is located outside the compound less 500 m away	2	
Quality	Water source is polluted	Objectionable taste or odour, close to toilets or septic tanks, among other sources of pollution	0	
	Source is protected close to possible sources of contamination and untreated	Source is covered but close to source of contamination	1	
	Source is protected and treated	Source is covered, water is treated and treatment is high standard	2	
Reliability	Variability in quantity with respect to yield or season	Water source is affected by season or can dry up when used heavily or yield is low, or source is unavailable and so results in conflicts (quarrels)	0	
	Low quantity consumption, largely, due to access	Though consumption is low due to access, but water needs of users can still be met	1	
	Water source is available on demand	Supply is more than 20 litres per capita per day	2	
Cost	High cost	i. Sources requires high human cost of time/money/energy/health	0	
	Consumers contribute 10–15% of construction cost	i. Fees cover maintenance cost only or ii. Consumers contribute to construction cost or maintenance (NGO constructed boreholes)	1	
	Low consumer costs (time/energy/health)	Construction cost is borne by consumers, maintenance/operation fees are minimal (e.g. self-supply system)	2	
Management	Consumer contribution to management is ONLY financial	i. Operation/maintenance is borne by government/NGO ii. Operation/maintenance is borne by an individual owner	0	
	Consumer contribution is beyond financial, additional support required for the system to function	Continuous support is required to enable consumer management procedure to function	1	
	Management is solely done by the water supply system owner (self-supply system)	Water source is constructed/managed and maintained by consumers only	2	
Maximum score obtainable (MS_{obt})			**10**	
Score obtained (S_{obt})				
Percentage score (WSSI)		**WSSI** $= S_{obt}/MS_{obt} \times \mathbf{100}$		

consumption to less than 8 litres per day were assigned a score of zero, while sources within 500–1,000 m were given a score of 1. Sources within the compound, with or without building connection, were assigned a score of 2.

Quality was defined with respect to water source pollution indicators, protection and treatment. The pollution indicators used in determining the quality included objectionable taste and proximity to toilets or septic tanks.

Figure 3 | Yellow jerry cans, generally, used in water collection.

Water sources that were protected (properly covered), not treated and still prone to contamination were allotted a score of 1, while protected and treated water supply systems were scored 2. Reliability was described based on seasonal influence on yield, consumption levels and adequacy. Seasonal influence on yield refers to water sources having low yield, or drying up totally, due to low or complete absence of rainfall, especially, during the dry season. Water sources whose yields were affected by seasonal influence and heavy abstraction did not get any score.

Where low yield of water supply systems reduced the quantity of water consumed and time-wasting caused by long queues, a score of 1 was allotted. However, water supply systems where water demand of more than 20 litres per capita per day was met were scored 2. The 20 litres per capita per day benchmark was adopted from Carter (2006) and is limited to domestic water use. Although Gleick (1996) recommends a benchmark of 50 litres per capita per day as a basic water requirement, which covers drinking, sanitation, bathing and cooking, a 20 litres per capita per day benchmark was considered a sufficient measure of reliability for a water supply system. Carter (2006) simply recommends at least 20 litres per capita per day to cover basic domestic water needs, setting 20 litres as the lowest possible lower limit. Although Gleick (1996) recommends a lower limit of 2 litres per capita per day for drinking, 5 litres for bathing and 10 litres for cooking and kitchen, which brings the total to 17 litres per capita per day (with the assumption that in water-short regions, the sanitation systems used require no water). Technically, an additional 3 litres when added to create an allowance of sanitation requiring limited water use brings the lowest possible lower limit to 20 litres per capita day; this would occur in possibly extreme water scarcity.

Cost was described in terms of time, energy and health implications resulting from long hours of water sourcing, water source construction and maintenance cost, and monthly or annual water bill payments, or water purchase per container fetched. Water sources that required time and energy on the part of water user to collect water, constructed and financed by government or non-governmental organizations (NGOs), or that required water users to pay per container fetched, or monthly or annual water bills were not allotted any score. Technically, such water sources required high construction and maintenance costs. Water sources that require consumers to contribute money for maintenance only (as is the case with some communal water supply systems) were given a score of 1, while water sources that were owned by water users, such as self-supply systems, were allotted a score of 2.

Management is described based on water source operations and maintenance. Water sources that are constructed, operated and managed by the government (public water supply systems and communal water supply systems) did not get any score. Public water supply systems are, usually, poorly managed in this part of the world (Akpor & Muchie 2011). Communal water supply systems that were government or NGO constructed and required continuous post-construction management and maintenance from water users were scored 1. While self-supply systems constructed and managed by their owners were allotted a score of 2.

The WSSI of each water supply system was then determined using the following equation:

$$\mathrm{WSSI} = \frac{\mathrm{S_{obt}}}{\mathrm{MS_{obt}}} \times 100 \quad (1)$$

where WSSI is the Water Supply Systems Sustainability Index, S_{obt} is score obtained and MS_{obt} is the maximum score obtainable.

WSSI scores were used to assess the sustainability of 194 water sources in the study area. The water supply sources selected using the cluster sampling method adapted from Oluwasanya *et al.* (2011a). The water sources were ranked based on their WSSI score using the WSSI rating (Table 2) as either, Unsustainable, Averagely Sustainable, Highly Sustainable or Very Highly Sustainable.

Also determined in this study was a sanitary risk assessment score (SRS) for the selected water supply systems. The SRS scores were obtained using the sanitary risk forms. The sanitary inspection form (SIF) contained questions that were used to visually assess the water supply systems to evaluate the level of risk each system is exposed to. Two types of SIF were used, the 'Yes' or 'No' sanitary scoring approach type (Howard 2002) and the '1–5 scoring' approach type (Oluwasanya *et al.* 2011b). The 'Yes' or 'No' sanitary scoring approach type was used for public water systems and the '1–5 scoring' approach type for hand-dug wells and boreholes. An SRS value was generated at the end of each assessment that was used to classify the level of risk (Table 3) of water sources into Very High, High, Intermediate (Medium) and Low-Risk rankings (Bartram *et al.* 2009).

The study compared the result of the WSSI assessment with the SRS to determine the presence of any correlation. The goal of establishing WSSI and SRS correlations was considered necessary, as the tools are expected to be used as complimentary water supply system field assessment tools for rapid assessment studies.

Rapid assessment of water quality is a method that provides baseline information in water safety studies and is designed primarily to assess the quality and sanitary condition of a water supply to create a representative dataset (Howard *et al.* 2012). This study used Pearson correlation to test the strength of the relationship between WSSI and SRS.

Table 2 | Water supply systems sustainability index rating

Score	Indication	Remarks
0–25	Unsustainable	Water supply system is not reliable irrespective of seasonal influences, difficult accessibility (water supply system far from point of use), difficulty in management, high construction and maintenance cost or purchase of water required, poor quality
26–50	Averagely Sustainable	Water supply system is only reliable during the rainy season, less difficult accessibility (water supply system is close but not within the building), difficulty in management, minimal construction and maintenance cost or purchase of water required, poor quality
51–75	Sustainable	Water supply system is reliable, ease of access (water supply system is within the house but not connected to the building plumbing system), ease of management, cost beyond construction is only maintenance-based, good quality
76–100	Highly Sustainable	Water supply system is reliable, ease of access (water supply system connected to the building), ease of management, cost beyond construction is only maintenance-based, good quality

RESULTS AND DISCUSSION

Water supply system distribution

The distribution of the water supply systems (public water supply systems, hand-dug wells and boreholes) and distribution by area (urban, peri-urban and rural) are presented in Figure 4. Ninety-five of the selected water supply systems are boreholes, 76 are hand-dug wells and 23 are public water supply systems. The highest number (129) of water supply systems is in the urban areas, 21 in the peri-urban area and 44 in the rural areas.

WSSI rating

Figure 5 shows the result of the WSSI ratings. The result indicated that 90 water sources in the urban areas are Highly Sustainable, 27 are Sustainable and 12 are Averagely Sustainable. In the peri-urban area, 13 water supply systems are Highly Sustainable, 7 are Sustainable and 1 is Averagely Sustainable. Thirty-two (32) water supply systems in the rural areas are Highly Sustainable, 9 are Sustainable and 3 are Averagely Sustainable. There is no public water supply source in the Averagely Sustainable category and no water

Table 3 | Sanitary risk score rating criteria

	Consequences				
Likelihood	**Insignificant (1)**	**Minor (2)**	**Moderate (3)**	**Major (4)**	**Catastrophic (5)**
Almost certain (5)	5	10	15	20	25
Likely (4)	4	8	12	16	20
Moderate (3)	3	6	9	12	15
Unlikely (2)	2	4	6	8	10
Rare (1)	1	2	3	4	5
Risk score	<6	6–9	10–15	>15	
Risk rating	Low	Medium	High	Very High	

Source: Bartram *et al.* (2009).

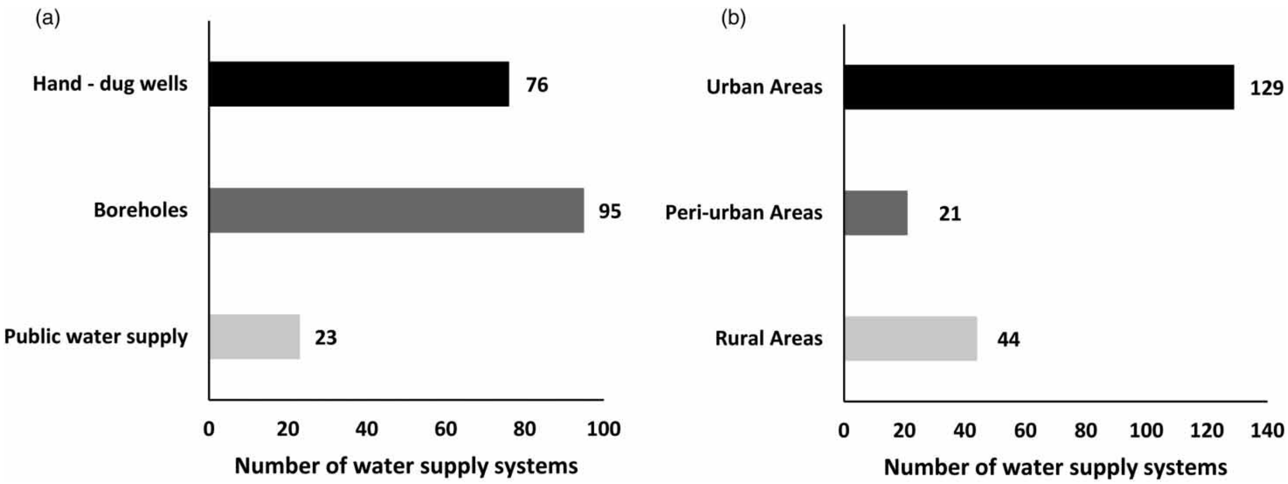

Figure 4 | Distribution of the selected water sources. (a) Distribution by water supply system. (b) Distribution by type of area.

supply source in the Unsustainable category. Most (92%) of the water supply systems are classified in the Highly Sustainable and Sustainable categories.

The findings imply that water sources that are Highly Sustainable are reliable and easily accessible (water supply sources connected to the building). The water supply systems' operation is easily managed, especially, for privately owned hand-dug wells and boreholes that are located within the confines of users' buildings. Cost after construction is only maintenance-based and quality of the water could be described as good; a conclusion that is reached based on visual assessment of the water supply systems, as in the case of sanitary inspection. Water supply systems in the Sustainable category are reliable, located within the house but not connected to the building plumbing system and easily managed. Cost after construction is also maintenance-based and the quality of the water could be described as good.

More hand-dug wells are in the Averagely Sustainable category than boreholes. Averagely Sustainable water supply sources are influenced by seasons; that is only reliable during the rainy season but less difficult to access (water supply system is close but not within the building). However, the sources' operations are difficult to manage because they are not located within the confines of users' buildings. The water supply sources are either poorly

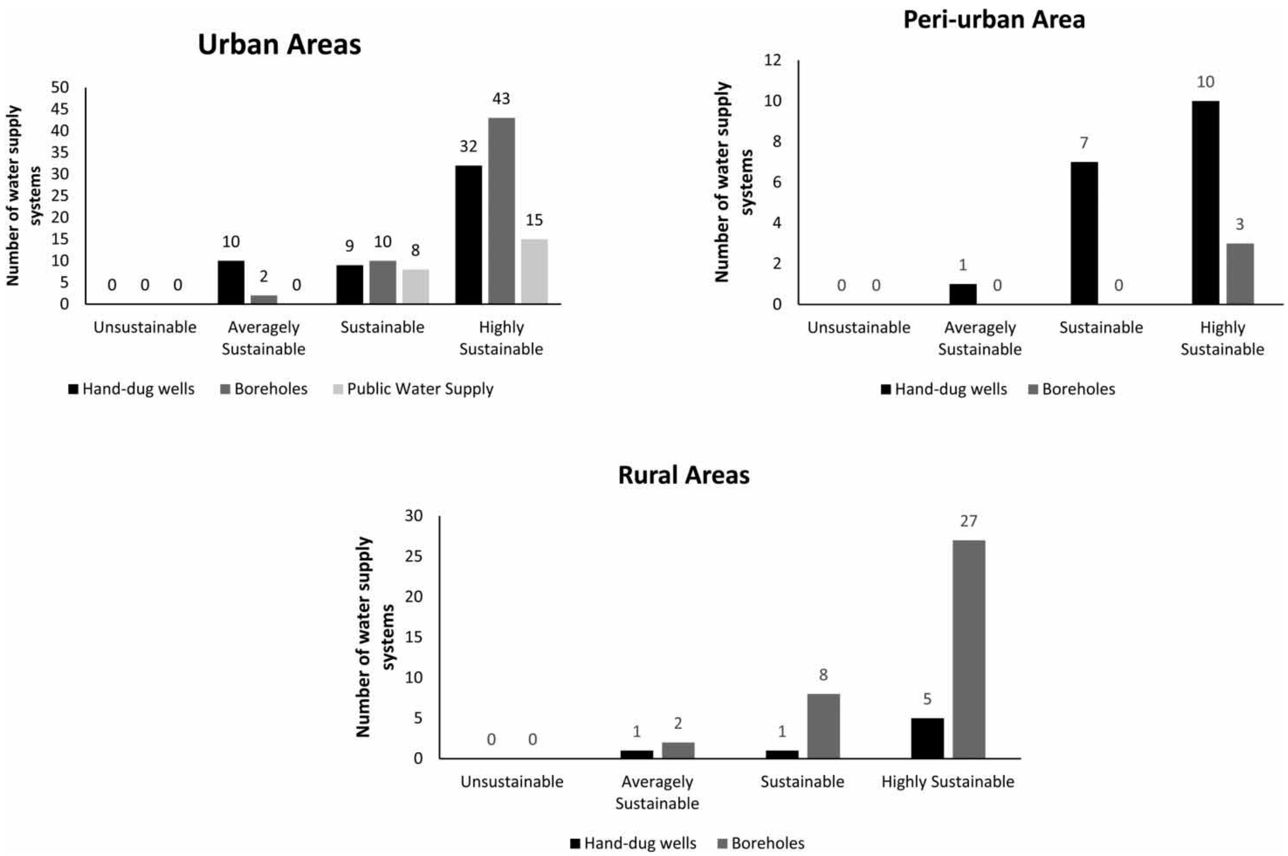

Figure 5 | WSSI of water supply systems in Ogun State, Nigeria.

constructed or maintained, or water users are often required to pay for collection of water (peculiar to boreholes) and water quality is, generally, poor.

Sanitary risk scores

Figure 6 shows a summary of the SRS for the study area. Urban hand-dug wells are the only water supply systems in the Very High-Risk category. Hand-dug wells in Nigeria are more susceptible to contamination, partly because of recharge from shallow aquifers and surface water (Oluwasanya 2013). In urban areas, public water supply scored only in the Low-Risk and Intermediate-Risk categories. Public water supply has undergone water treatment and is expected to be of better quality than hand-dug wells and boreholes (Obeta & Mamah 2017). Poor quality water from public water supply systems has been reported in the literature (Sari *et al.* 2018). Boreholes in urban and rural areas in this study are of better quality than peri-urban boreholes. Lutterodt *et al.* (2018), for instance, reported boreholes with 'high risk' SRS, highlighting factors such as worn-out borehole seals and the presence of improper on-site sanitation facilities to be responsible. Similarly, high-risk contamination in urban water supply systems due to land use practices has equally been reported (Obeta & Mamah 2017). For instance, poor sanitary risk scores of urban hand-dug wells have been attributed to proximity to burial sites, toilet facilities and poor construction, among others (Oluwasanya 2013).

Statistical analysis

Pearson correlation was used to analyse the WSSI and SRS values to determine the strength of the relationship between the results (Figure 7). A positive correlation is observed between urban hand-dug wells' WSSI and urban hand-dug wells' SRS ($R^2 = 0.5688$, at $p < 0.05$), while a weak positive correlation is observed between urban boreholes' WSSI and urban boreholes' SRS ($R^2 = 0.2032$, at $p < 0.05$). The finding

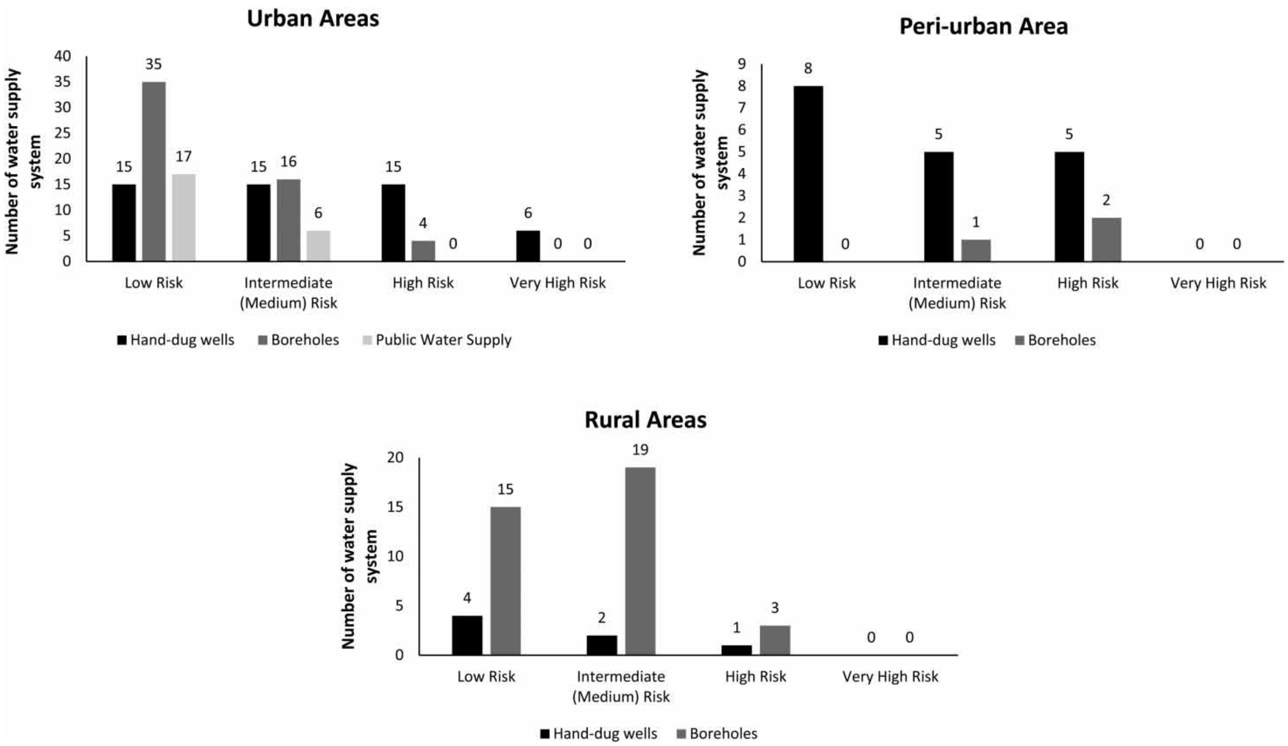

Figure 6 | SRS of water supply systems in Ogun State, Nigeria.

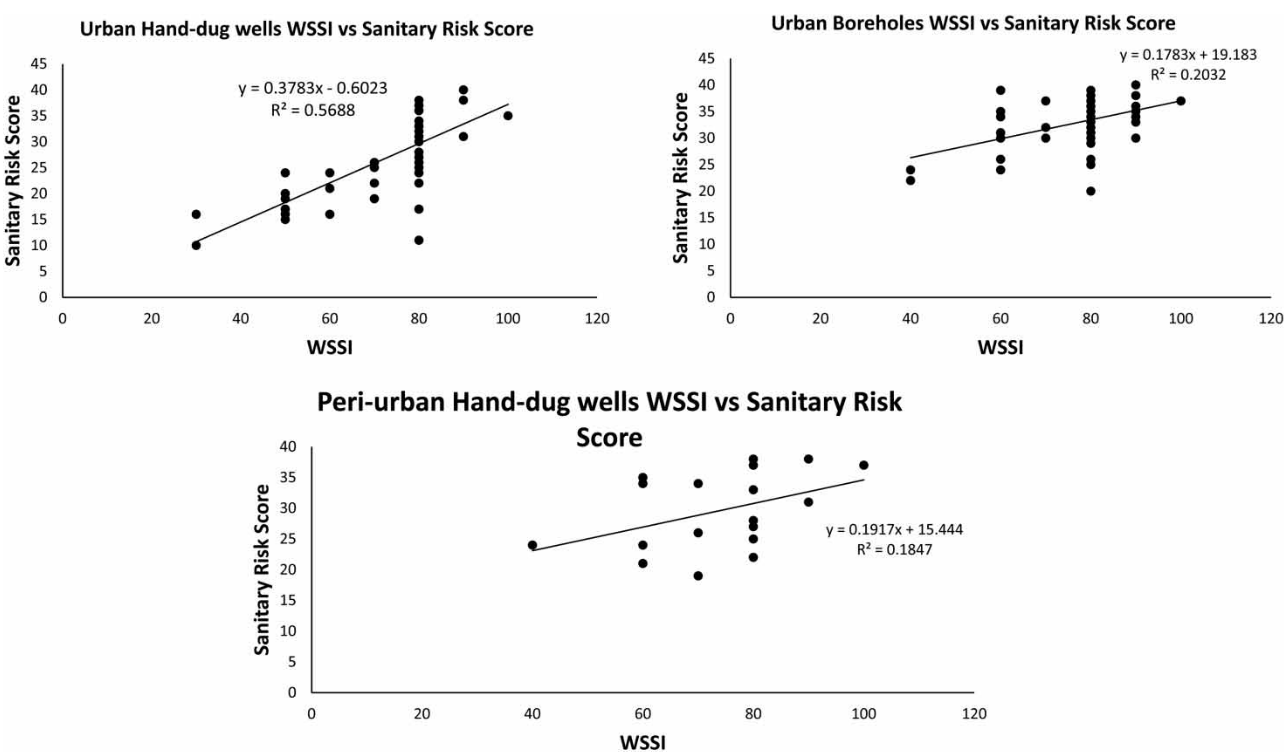

Figure 7 | Scatter plot of WSSI and SRS for water supply systems.

shows that for urban hand-dug wells and boreholes, WSSI increased as SRS increased, or decreased as SRS decreased. There was, however, no relationship between urban public water supply WSSI and urban public water supply SRS. A weak positive correlation is also observed between peri-urban hand-dug wells' WSSI and peri-urban hand-dug wells' SRS ($R^2 = 0.1847$, at $p < 0.05$), implying too that WSSI increased as SRS increased, or decreased as SRS decreased. No relationship is found between peri-urban boreholes' WSSI and SRS, and rural water supply sources WSSI and SRS. There is a need for further research on the relationships between WSSI and SRS, if any. There may be the possibility of a further relationship between urban public water supply WSSI and SRS, peri-urban boreholes' WSSI and SRS, and rural water supply sources WSSI and SRS if the sample size is increased.

WSSI, existing sustainability indices and the future of water resources management

The study found comparing WSSI to existing sustainability indices challenging as the indices are all comprehensive indices and they do not include privately owned water supply systems. Also, the indices are not designed for developing countries and are centred on access to potable water supply or community-owned and managed water sources. The CWSI component, for instance, that captures finance (cost) focuses on the capacity of a community to manage the water source and obviously excludes construction costs, which forms an integral part of private water supply systems.

Noticeably, the indices involve complex mathematical components and would require large amounts of data to compute. Similarly, they are composed of complicated, time-consuming indicators, computable only by professionals, such that water user participation in data generation is restricted majorly to interviews. The WSSI, however, is applicable to individual water sources such that sustainability index can be calculated and computed for each of the water source under evaluation and the WSSI rating system is devoid of complex mathematical procedures and extremely easy to apply. For sustainability indices and its components to be considered useful, Chaves & Alipaz (2007) highlights five criteria that must be met. The components must be available, understandable, credible, relevant and integrative. The five factors of WSSI fit the five highlighted criteria.

The WSSI could be incorporated as a component of training in trainer's manuals and taught to water supply system owners or water users who are literate, especially, at community level. To achieve sustainable development within the context of water supply management, this study supports the advocacy (Kabogo *et al.* 2017) for the need for water user-participatory approaches in water resources management through the adoption and application of simple tools such as the WSSI in conjunction with more familiar sanitary surveys. Although the WSSI is developed with low- and middle-income countries as the key target, minor alterations (if any) could occur where water sources used are different from hand-dug wells, boreholes and public water sources. The types of water sources in Uganda highlighted in Carter's study were scoop holes, unlined reservoirs, shallow wells and boreholes. The method of assessing the sustainability of water sources was modified to suit water sources in the Nigerian context. For WSSI to be applicable to other regions/countries, modifications may be with respect to water sources peculiar to the regions. However, this study believes that the concept of sustainability factors is applicable globally, developed countries inclusive. For instance, the use of 'on premises' hand-dug wells is reported in the United States (Ornelas Van Horne *et al.* 2019).

This study was carried out in southwest Nigeria where the annual rainfall of about 1,200 mm has been reported (Akinbobola *et al.* 2018). Differences in outcome are possible if the study is replicated in Northern Nigeria where annual rainfall can be as low as 500 mm or lower (Akinbobola *et al.* 2018). The limitation due to differences in annual rainfall notwithstanding, WSSI has an edge over existing sustainability indices as it captures privately owned self-supply water sources and it is expected that modifications may be necessary to suit types of water sources, climate and abstraction methods, among others.

CONCLUSIONS

WSSI for water supply systems is developed in this study. Unlike existing sustainability indices that are complex, broad spectrum and requiring tedious mathematical computations, WSSI is simple and focuses on water sources and water users, especially, owners of private water sources. The findings show that drinking water supply sources in the study area are, generally, sustainable. However, hand-dug wells are the most risk-prone water supply system. This study proposed the inclusion of WSSI, as a rapid assessment technique, not as a replacement for water quality assessment technique or sanitary risk assessment but as a complimentary water source field appraisal tool. The study, however, identified climate as a possible limitation to the global applicability of WSSI. If this study is to be replicated, attention must be paid to the reliability factor of the index. The study further highlighted the significant impact that climate has on water source reliability and reliable climatic data may be a key requirement for replicating this study.

It is believed that the WSSI would be easy to utilize by field researchers/professionals, simple to communicate to drinking water supply system owners and water supply planning stakeholders for effective IWRM in, particularly, low-income countries, and help to achieve the relevant SDG.

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RESEARCH DATA IN THIS ARTICLE

The selected water sources in this study were majorly privately owned and are used with the consent of the respective owners based on the assurance that the raw data would remain confidential and would not be shared.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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