Journal of
Water, Sanitation & Hygiene for Development

IWA PUBLISHING

 Journal of Water, Sanitation and Hygiene for Development Vol 12 No 3, 237 doi: 10.2166/washdev.2022.176

Research Paper

The complex nature of household water supply: an evidence-based assessment of urban water access in Southwest Nigeria

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ABSTRACT

Access to domestic water supply is a big challenge for many households in developing countries, as a large number of households do not have access to municipal water sources. The purpose of this study is to investigate the nature of access and characteristics of water sources and their impact on the choice and usage of water by providing empirical and statistical evidence. A survey of 1,300 households was conducted across six major cities in Southwest Nigeria, using structured questionnaires, field surveys, personal interviews, and observations. The data obtained were analysed using SPSS 27 for descriptive statistics and characterised using enhancement-based strategies. The result showed that 5% of respondents had access to pipe water, 66% used private wells and boreholes, and 29% used off-site water sources. The study discovered that 15 different water sources with unique attributes were consumed. The daily consumption ranged between 301 and 361 and 1,153 and 1,421 litres per household (L/hh/d) for those using off-site and on-site water sources, respectively. This study provides new insights with empirical evidence. As such, there is a need to re-evaluate the present water supply policy implementation, funding approach, and level of coverage. Additional policies that support and fund decentralised water projects, without compromising on water quality, should be provided, since they are more accessible to the people.

Key words: accessibility, decentralised solution, multiple water sources, Nigeria, non-tap supplies, self-help projects

HIGHLIGHTS

- A detailed description of water access in sub-Saharan Africa.
- Highlight the challenges of water access in the region.
- Application of an enhancement-based strategy for water source characterisation.
- A detailed component of the residential water supply system.
- A detailed breakdown of household water consumption in heterogeneous suburbs using multiple sources of water.

INTRODUCTION

The provision of adequate potable water for any group of people via a functional water system is a necessity because safe drinking water promotes good health and reduces avoidable deaths associated with water-related diseases. It is a cardinal objective of the sustainable development goal 6 (SDG 6), which stipulates 'safe drinking water for all'. Evidently, sub-Saharan Africa is not likely to achieve the SDGs, particularly SDG6.1, because several African populations still lack safe drinking water (Nya *et al.* 2021). This suggests the need to examine existing water access based on available data.

The nature of residential water supply in developing countries shows a clear departure from what is obtainable in the developed world, where a majority of households are typically connected to public water sources and are assured of a continuous supply of potable water. The disparity in the percentage of coverage between municipal supply (5%) and non-municipal water supply (95%) in the study area is not comparable to any city in Europe, the USA (~13% uses private water system), or the rest of the developed world (Hubbart & Gootman 2021). Many large cities in China, India, Southeast Asia, and Latin America (classified as the developing world) that are not connected to the piped water system have to rely on public wells or taps (Briand *et al.* 2009). 'The conditions of access vary significantly with a considerable heterogeneity among households

(Klassert *et al.* 2015), as all households do not have the same options of water sources to choose from' (Nauges & Whittington 2009; Huang *et al.* 2021; Nya *et al.* 2021), although 'institutional and geographical barriers deny certain people access to some water sources' (Nyong 1998). Availability of water or access to specific sources may demand certain characteristics based on the intended use. In addition, households in the developing world use different water sources for different purposes.

Sub-Saharan Africa is plagued with limited access to domestic water (WHO 2017), and when coupled with climate change, may potentially stress water supply facilities, making the region increasingly vulnerable to the impacts of water scarcity (Makwiza *et al.* 2015; Klassert *et al.* 2018). The challenges facing the region include increasing population and urbanisation, poor water network coverage, leakages, and poor cost recovery (Balogun *et al.* 2017), bad governance and infrastructural deficit (Adaku 2016), high intermittency and low supplies (Karnib 2015; Loubser *et al.* 2021), poor delivery infrastructure, increasing pressure on the demand for water (Purshouse *et al.* 2017), and poverty and the inability to pay for a connection and water service (Nganyanyuka *et al.* 2014; Bisung *et al.* 2015). As a result, there is a shift in responsibility, with several households installing private water sources fitted with water storage tanks to tide over scarcity periods (Van Koppen *et al.* 2020). Those who cannot afford private water sources have to depend on buying or collecting water from multiple alternative sources, including streams, dams, public wells and boreholes, rainwater harvesting, public standpipes, community or commercial water sources, water vendors, tankers, processed water, and bottled and sachet water (Rosenberg *et al.* 2007; Nauges & Whittington 2009; Karnib 2015; Majuru *et al.* 2016) or depend on their neighbours for free water (Baisa *et al.* 2010; Coulibaly *et al.* 2014).

Njiru *et al.* (2001) cited five levels of service differentiation in Durban, South Africa: a high-pressure system, roof tank (semi pressure), ground tank (low-pressure), communal water standpipe or kiosk, and commercial water tank or kiosk. Purshouse *et al.* (2017) classified water sources in eastern Nairobi, Kenya, into the following: water in the dwelling, water in the yard, water delivered to the dwelling, and water carried to the dwelling. Nganyanyuka *et al.* (2014) explained that water access in Tanzania is characterised by disparities between official statistics and the actual water supply situation, coupled with the problem of affordability of services and quality. Karnib (2015) further stressed that access to the water supply network in Lebanon does not imply access to a sufficient quantity of water. Moreover, the frequent intermittency usually experienced has contributed to an increased unreliability of supply. In a bid to solve the problem of water access in Bangangté, Cameroon, Nya *et al.* (2021) suggested a decentralised system.

Two earlier studies in Southwest Nigeria (Sample *et al.* 2013; Emenike *et al.* 2017) highlighted cases of multiple sources of water (Table 1). While the former focused on developing a simulation model to estimate urban water use, the latter predicted the factors influencing access to a water. Income, cost of water, proximity, hygiene, availability, and the domestic usage pattern associated with existing water sources are some of the factors influencing access to water supply in Ado-Odo Ota, Southwest Nigeria (Emenike *et al.* 2017). Sample *et al.* (2013) reported that in Lagos, Nigeria, high-income households obtained water from boreholes while others obtained their supply from wells, public and commercial boreholes, and vendors (pushcarts), although only 4% of the total water supply was obtained from a public water connection.

The nature of water access in the study area is a big challenge for researchers seeking to estimate and develop the residential water use model, especially non-tap supplies, which are used by a majority of the people. Against this background, this paper gives a deeper insight into people's water access and increases the body of literature from this part of the continent. It is, therefore, expedient to investigate the nature, characteristics, and strategies for accessing residential water based on available data, to document the details of access to domestic water, and to determine the impact of these characteristics on sustainable water access and use.

MATERIALS AND METHOD

Study area

The study was carried out across selected towns in Southwest Nigeria. The region falls within the tropical zone that ranges from the mangrove swamp in Lagos to the thick rain forest in the hinterland and the derived savanna in the northern part of the region. Rain falls from March to November in most parts of the region, while the population of the region is estimated at 55 million. The towns included in the study are Ibadan (Oyo State), Abeokuta, Mowe, Ibafo, Arepo, Ijebu ode, Sagamu, Ifo, Sango Ota, Agbado (Ogun State), Isolo, Oshodi, and Ajegunle (Lagos State), see Figure 1. The average annual rainfall is about 1,800 mm. The study locations are basically urban areas with increased economic activities, occupation of household heads including civil and public service, self-employed people, and artisans and traders of roadside shops. Houses within the area

Table 1 | Incidents of multiple sources of water use

S. No.	Sources of water	Location	References
i	Deep wells, pushcart vendors, water kiosks, community standpipes, tanker trucks, bottled water, pipe connections, shallow wells, rainwater collection, sachet water, rivers, and ponds	Dar es Salaam, Tanzania	Nganyanyuka *et al.* (2014)
ii	River water, hand-dug wells, borehole water	Ngamiland district, Botswana	Oageng & Mmopelwa (2014)
iii	Hand-dug wells, gravity piped systems, mechanised boreholes, dam water	Limpopo, South Africa	van Koppen *et al.* (2020)
iv	Small dams and rivers, community constructed hand-dug wells,	Kaduna, Nigeria	Nyong & Kanaroglou (1999)
v	Pipe water (indoors and outdoors), private and commercial boreholes, rainwater, tankers, wells, pushcarts, water retailers	Lagos, Southwest, Nigeria	Sample *et al.* (2013)
vi	Pipe water, private tankers, processed water, bottled water, private wells (rural areas)	Amman, Jordan	Klassert *et al.* (2015)
vii	Public water, tanker water, treated water, bottled water	Zarqa, Jordan	Coulibaly *et al.* (2014)
viii	Improved and unimproved water sources	Rwanda	Osei *et al.* (2015)
ix	Public water and tanker water	Western region of Saudi Arabia	Rizaiza (1991)
x	Stream/rivers, rainwater, unprotected well water, piped-public taps, private and commercial taps	Ado-Odo Ota, Southwest, Nigeria	Emenike *et al.* (2017)
xi	Lakes, standpipes, water vendors	Usoma, Kenya	Bisung & Elliot (2016)
xii	Public pipes, wells, springs, and cisterns	West Virginia, USA	Hubbart & Gootman (2021)

are both planned (estate) and unplanned (township), with clusters of households making it impossible to provide pipe connections. Piped water coverage is limited because of old and abandoned water infrastructure, and as such, access to pipe water is almost non-existent in many of the study locations (see Table 2, section on pipe connection). Most households depend on boreholes, deep wells, and in some instances shallow open wells for their daily water needs. Water supply can be characterised as heterogeneous (as households use multiple water sources), complex (as households do not have the same levels of access), and cooperative (households share from the same water sources). Most households use processed water exclusively for drinking, while the expensive tanker water is employed as a last resort by the authorities, and those who cannot afford tanker water have to walk long distances to the next available water source. Water is relatively cheap in the rainy seasons and costly in the dry seasons when most wells dry up, and households have to depend on water vendors during such periods.

Research design

Approval was given by the Stellenbosch University Research and Ethics Committee to conduct the research. This study used primary data obtained from a household survey performed in May–July 2019 using random sampling methods. Questionnaires were first tested in a pilot scheme to determine the level of understanding of the participants and the need to rephrase some ambiguous questions in order to achieve the set objectives. A total of 1,700 questionnaires were distributed during field work, while 84.5% (1,440) of the questionnaires were completed and returned, of which 1,300 were included in the analysis. The study was concentrated in Abeokuta and major cities in Southwest Nigeria (see Table 2). Selection was based on the accessibility and willingness of households to participate in the survey. Trained personnel were employed to carry out data collection through interviews, observation inspections, and fieldwork. The data collected included socio-economic and household water consumption data, the characteristics of water sources, alternative water sources, the presence of storage facilities, the ownership of water sources, and payment for water. The obtained information was used for analysis by including a description of household water sources using descriptive statistics in SPSS 27. The components of the residential water

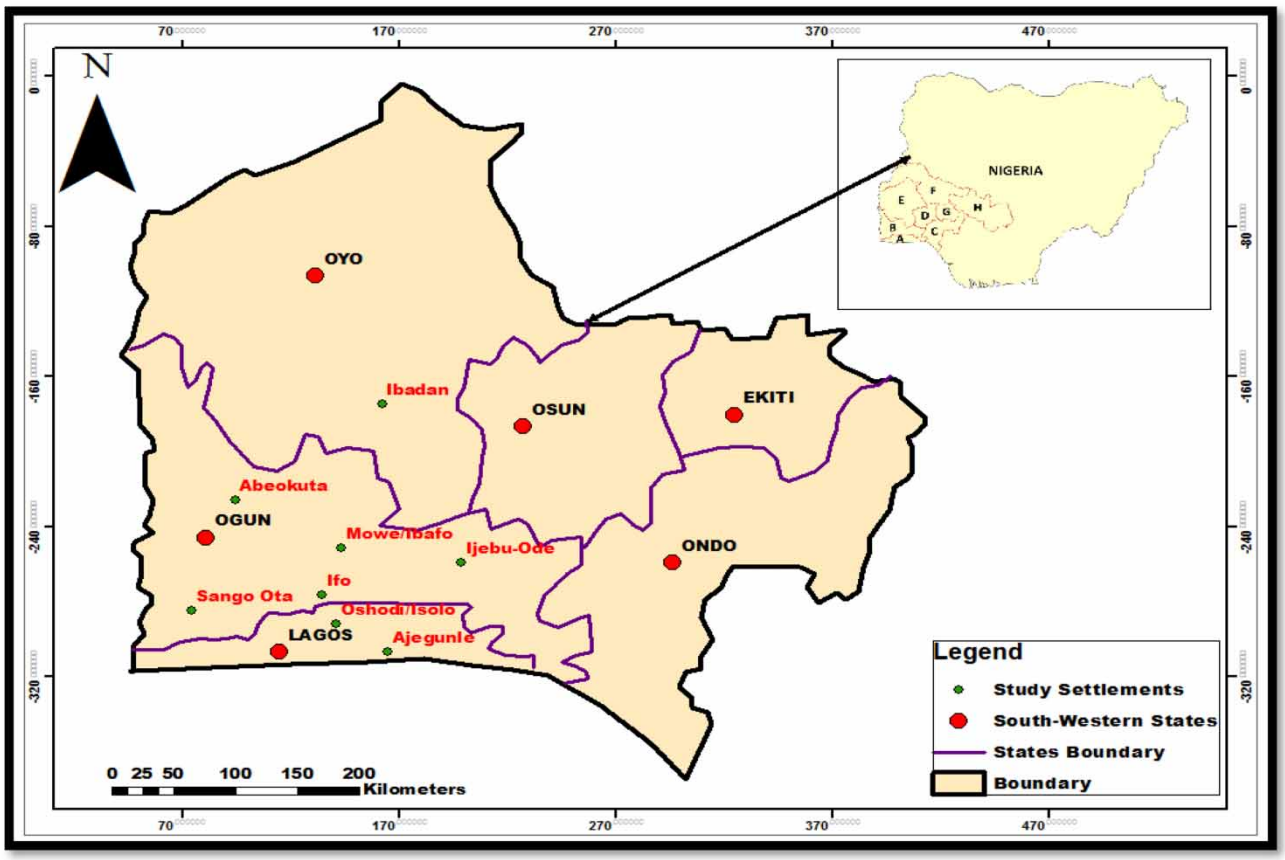

Figure 1 | Map of the study location across Southwest Nigeria.

Table 2 | Distribution of water source categories across the study area

Location	Pipe connection	Private well	Pipe borehole	Delivered water	Conveyed water	Population
Abeokuta	16	236	175	41	140	608
Ijebu/Remo	5	30	41	2	41	119
Mowe/Ibafo	10	35	34	1	17	97
Sango/Otta	15	9	10	9	45	88
Ibadan	16	35	43	8	69	171
Lagos	5	94	111	8	–	218
Total	67	439	414	69	312	1,301
% of Sample	5.15	33.74	31.82	5.30	23.98	100.00

supply system were studied through fieldwork and inspection, while the characterisation of household water sources was done through conducting interviews. Enhancement-based strategies (Nganyanyuka *et al.* 2014) were also adopted (*see* Table 3).

RESULTS AND DISCUSSION

The results of this study cut across three major investigations: a description of household water sources, components of the household water supply system, and characterisation of household water sources in Southwest Nigeria. Consumption data show that households with off-site water access use less water. Daily consumption ranges between 36 and 100 litre per

Table 3 | Parameters to characterise water sources

Parameters	Description
Source	Type of water source categories
Ownership	Personal, communal, commercial, government
Strategy	Short-term, long-term, planned, unplanned
User group	Income group
Characteristics	Nature of water sources

capita per day (lpcd) and 301 and 361 litre per households (lph) for off-site access, and between 178 and 384 lpcd and 1,153 and 1,421 lph for those with on-site water access (Oyerinde & Jacobs 2021).

Description of household water sources

Existing water sources in the study area include piped connections; decentralised and self-help solutions (private deep wells, private boreholes, community boreholes and wells, commercial boreholes and wells, public taps/standpipes, neighbourhood supplies); water vendors (push trucks, tank-mounted trucks, tankers); processed water (sachet, bottled and refilled from water shops) and rainwater. Nine of the water sources are used as major sources of water, while eight are used as additional/alternative sources of water. Processed water (refill, sachet, and bottled) is used exclusively for drinking (see Figure 2). A detailed description of household water sources and the frequency of users is found in Table 4.

Piped water

Public water supply in Nigeria is managed by the state water agency. However, most households in Nigeria do not have access to piped connections. Generally, the level of service is unsatisfactory, coupled with high intermittency and unreliable supply (Kumpel & Nelson 2016; Loubser *et al.* 2021). The percentage of access to pipe connections is about 5% and may vary significantly across cities.

Decentralised and self-help solutions

Self-supply has existed since time immemorial, and it is of three types: communal self-supply, individual self-supply, and sharing of water (van Koppen *et al.* 2020). Decentralised and self-help solutions account for 89.62% of the major sources and 22.08% of alternative water sources. Water sources are owned by individuals, the government, communities, and commercial sellers. A breakdown of these components is shown in Figure 2. Self-supply sources are more readily available to water users and are accessible and reliable, and they require little or no additional treatment.

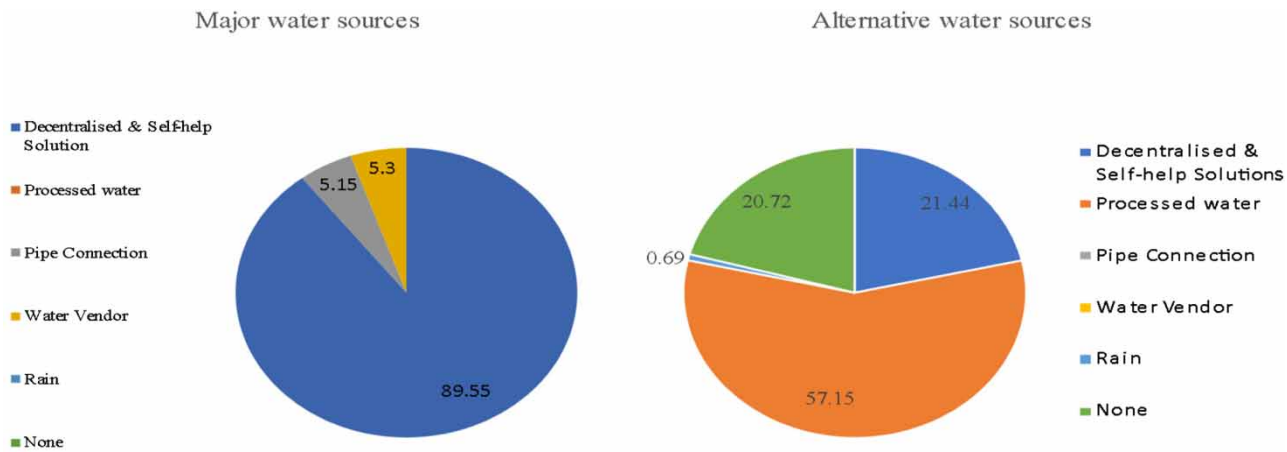

Figure 2 | Description of household water sources.

Table 4 | Distribution of water sources based on the frequency of users

	Major		Additional/alternative	
Water sources	**Frequency**	**(%)**	**Frequency**	**(%)**
Private wells	439	33.77	–	–
Private boreholes	414	31.85	–	–
Community wells and boreholes	126	9.69	27	2.08
Public taps	79	6.08	141	10.85
Commercial wells and boreholes	74	5.69	68	5.23
Piped connections	67	5.15	–	–
Tankers	48	3.69	–	–
Neighbourhood supplies	33	2.54	51	3.92
Water vendors/Kiosks	20	1.54	–	–
Bottled water	–	–	86	6.61
Sachet water	–	–	539	41.46
Processed water			118	9.08
Rainwater			9	0.69
None	–	–	261	20.08
Total	1,300		1,300	

Processed water

Processed water includes refill water bought from water shops, bottled water, and sachet water. Processed water accounts for 57.2% of water sources used by respondents mainly for drinking and ablution, with sachet water (72.5%) being the most used water source. Ownership is mainly commercial.

Water tankers and vendors

Vendors are common in urban areas that have a high level of intermittent supply and are generally more expensive than other water sources. The prices vary according to the quality of water and travel distance. Vendors use push trucks, trucks mounted with plastic tank(s) or water tankers. Water tankers are operated by the government, individuals, and corporate bodies to supply water to communities, households, and offices. They account for 5.23% of water sources.

Rainwater

Rainwater is harvested from roofs during rainfall events. Rainwater is collected into buckets, basins, drums, and tanks and is used for drinking and general purposes. However, its availability is limited to the rainy season. Rainwater cannot be stored for too long because its quality deteriorates with time. There are not enough statistics with regard to its consumption pattern since most households use rainwater as an alternative source of water.

Components of the residential water supply system

Water supply system components include motorised pumps (surface and submersible), valves, pipes, storage tanks, elevated steel stands for storage tanks, and electricity to convey water to the point of use. The components vary according to the sources of water. Multiple supply scenarios were observed in the study area: (i) A combination of pipe connections under an intermittent supply regime piped through a storage tank and augmented with additional sources from boreholes, wells, and/or tankers; (ii) water from boreholes, deep wells, and/or tankers but supplied through overhead tanks into buildings; (iii) yards or standpipes within premises supplied from external sources (municipal, tankers, etc.); (iv) standpipes or water points supplied from sources originating from within premises; (v) pipe connections to distribution mains under a continuous water supply regime. Water storage tanks made of plastic (PVC) were prominent in most households surveyed. A total of 75.8% of households had on-site storage, 66.8% had at least a single storage tank, and 33.2% had more than one tank. The average storage size of a water tank was 2.3 m^3 per household, which was similar to 2.4 m^3 reported in Vietnam

(Cheesman *et al.* 2008). The commonest size of tank available in the market was 2.5 m^3 (2,500 litres). Similarly, a motorised pump is a major component of the household water supply system. A total of 73% of households surveyed used 1.0Hp and 1.5Hp, 68% households used a single pump, and 32% used more than one water pump. Cheesman *et al.* (2008) cited that motorised pumps are used in 85% of households surveyed in Vietnam.

Characterisation of water sources

The parameters used for characterising water sources are given in Table 2. The relationship between the characteristics is complex and interwoven; these impact users in different ways, as households will demand specific attributes of water sources. The choice, acceptability, frequency of use, and volume of water extracted from water sources are all influenced by their attributes. Njiru *et al.* (2001) and Purshouse *et al.* (2017) categorised water sources based on the level of service and service differentiation, with the various service levels having different attributes, which influences unit consumption or the total water abstracted. Detailed characterisation of water sources is found in Table 5.

Accessibility, proximity, and presence of water within residential premises

Accessibility is the most important characteristic of residential water use, although there have been extensive arguments on the definition of access (Nganyanyuka *et al.* 2014; Emenike *et al.* 2017). Many households in sub-Saharan Africa do not have access to a piped water source (Kumpel & Nelson 2016), and proximity to a water source is an important variable influencing the choice of water source. The relationship between access and volume of water collected is indirectly proportional, while the quantity of water used has a significant impact on community health compared with water quality (Howard & Bartram 2003). Purshouse *et al.* (2017) concluded that service levels can be upgraded by increasing proximity to water sources, thereby enhancing accessibility.

Reliability of supply and access to alternative water sources

Reliability can be explained as the number of days that water is available and the prospect of predicting water availability in advance (Purshouse *et al.* 2017). One characteristic of municipal water supply in most developing countries is unreliability. Many households do not have such connections and those who have are not assured of continuous supply. The implication of unreliable supply is the use of multiple alternative water sources to bridge supply deficit.

Strategies

Planned or unplanned, short-term or long-term measures are all part of water supply strategies. These include the way in which an intervention is planned. The majority of short-term improvements are unexpected, designed to address emergency water supply crises, and involve less capital expense. Construction of community wells or boreholes, provision of water tankers, provision of standpipes, and rainwater collecting storage tanks are all examples of such improvements. Long-term interventions, on the other hand, are planned and will require a significant amount of resources and funding. Construction of water treatment facilities, pipe network extension, large storage facilities, and pump booster stations are examples of such interventions.

Ownership, cost, and water quality

In contrast to developed countries, where water sources are typically owned by the government, water sources in the research area are primarily privately owned (67%). Individual, communal, commercial, or government ownership of water sources is common in many parts of Africa (Njiru *et al.* 2001; Nganyanyuka *et al.* 2014; Emenike *et al.* 2017). High-income households are more likely to own water sources, whereas low-income households must purchase water from expensive commercial sources. The initial cost of building and installation of infrastructure, as well as the costs of operation and maintenance, connection fees, and water prices, vary depending on the type of water source.

CONCLUSION

Multiplicity of access and the challenge of water availability

Many households in developing countries have access to several water sources (Nauges & Whittington 2009; Nganyanyuka *et al.* 2014; Emenike *et al.* 2017), but the water supply situation has not seen any considerable improvement over the last decade, as evidenced by the failure to meet the Millennium Development Goals (MDGs). The nature, characteristics, and components of water sources influence the total volume of water abstracted, number of users, level of access, and ease of

Table 5 | Source, users' group, categories, and characteristics of access

		Users' group						Categories of strategies						Characteristics of water source								
		Poor		Medium		Rich																
	Sources	Planned	Unplanned	Planned	Unplanned	Planned	Unplanned	Short term	Long term	Enhancement	Individual	Communal	Water Quality	Quantity	Accessibility	Affordable rate	Convenience	Availability	Reliability	Initial cost	O & M cost	Connection fee
1	Private deep wells			o	o	o			o	o	o		o	o	o	o	o	o	o	o		
2	Private boreholes			o		o	o		o	o	o		o	o	o	o	o	o	o	o		
3	Community boreholes	o	o	o	o			o	o	o		o	o			o				o	o	
4	Community wells	o	o	o	o			o	o	o		o				o				o	o	
5	Public taps	o	o	o	o			o	o	o		o	o			o						
6	Commercial boreholes	o	o	o	o			o		o		o										
7	Piped connections	o		o		o			o	o	o		o		o	o	o	o				o
8	Commercial wells	o	o	o	o			o		o		o						o				
9	Neighborhood supplies		o		o			o		o	o	o						o				
10	Water vendors/ kiosks		o		o			o		o	o											
11	Tankers	o	o		o		o	o		o	o			o						o		
12	Bottled water		o		o	o	o	o			o		o									
13	Sachet water	o	o		o		o	o			o					o						
14	Refill	o	o	o		o		o			o		o			o		o				
15	Rainwater	o	o					o			o		o							o		

access. The characteristics of water sources include distance to these sources and collection time, reliability, and associated cost and affordability (Howard & Bartram 2003). Nganyanyuka *et al.* (2014) stated that being connected to a piped water system does not guarantee a reliable water supply, nor does it provide water of drinking quality. In South Africa (CSIR 2000), the recognised in-house connections are public standpipes/yard taps, tankers, and private boreholes, while greywater, stormwater, reclaimed water, and rainwater are used mainly for outdoor purposes. In Tanzania, the sources of water include pipe connections, deep/open wells, rivers/ponds, rainwater, and bottled water. More often, citizens need to install water pumps and storage tanks or tap into informal networks of their neighbours, water vendors, and other intermediaries to access water (Nganyanyuka *et al.* 2014). In Nigeria, water sources are numerous (see Table 3). However, irrespective of multiple available sources, access to potable water of good quality and quantity is still a major challenge in the country. Informal and small-scale private service providers fill this gap at least as far as quantity is concerned.

Water policy and the challenge of water access

In order to ensure sustainable access to potable water, easily accessible water sources could be developed, while subsidies or tax incentives could be given for the development of community water sources. A larger percentage of communities have access to informal water sources (self-supply sources), which account for about 90% of consumption. Therefore, it is imperative that community water development should be aligned with such informal sources. With rising urbanisation, the water demand–supply gap will keep increasing, and, therefore, the investments required to meet SDGs might be grossly inadequate. The failure of the government to provide water (in line with the existing water supply policy) of good quality and quantity have made many households seek alternative sources (that have questionable quality), with more people depending on self-supply. Much of the reported access to water supply does not provide details of what constitutes access and who is funding this access. A large percentage of people in sub-Saharan Africa are reported to be gaining access to safe or improved water sources (WHO/UNICEF/JMP 2017); however, most of these accesses are self-help projects financed by individuals or communities (Van Koppen *et al.* 2020). The amount of financial investment in self-help supply is huge and has ensured more access to people compared with the higher investment by the government that has not translated into reasonable access to public water supply.

The development of water supply should be properly coordinated to pave the way for monitoring, assessment, and further improvements and to redirect investment into the development of water sources that will increase accessibility to water of improved quality. This should be done on the basis that there is a connection between the government and the people in terms of water supply access and extension of water services. According to Nganyanyuka *et al.* (2014), much of what is reported in statistics is farther than the truth because people who are supposed to have water connections are not served well and many households are not within the reach of existing connections. While this study focused on characterising water access (quantity), water quality was not considered. However, there is a relationship between accessibility and water quality, as many households use alternative sources for drinking given the fact that quality issues plague water from main sources.

Role of government in public water provision

There is a complete absence of municipal water connections in many community areas, and where they are present, they are either located far away or have no regular or proper supply. Given such a situation, many households would rather patronise private water sources, since they are readily available and accessible. In water-stressed conditions, households will give preference to quantity (availability) rather than quality, even though good health is predicated on having access to good quality water. However, water quality is a basic characteristic that influences the consumption of water from specific sources, especially for drinking purposes. All these only point to the need for the government to be proactive in its responsibility towards the provision of water for all.

ACKNOWLEDGEMENT

I am grateful to the Tertiary Education Fund (TETFUND), Nigeria, for funding my PhD and to my office Moshood Abiola Polytechnic, Abeokuta, for supporting my study.

DECLARATION OF INTEREST

There is no known conflict of interest.

DATA AVAILABILITY STATEMENT

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

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First received 9 September 2021; accepted in revised form 10 February 2022. Available online 3 March 2022