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IMPACTS OF SUSTAINED PUBLIC EDUCATION AND IMPROVISED SOURCE PROTECTION ON SUSTAINABLE WATER RESOURCES IN THE DEVELOPING WORLD

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ABSTRACT

To increase the United Nation's chance of achieving its Sustainable Development Goal of providing clean water and sanitation especially in the developing world, a new approach that combines sustainable water resources management with mass reorientation of rural populations must become a priority. This is important considering the increasing global water stress faced by humans and the occasional knowledge gap in demand management and conservation between developed and developing regions where the majority live in rural areas. Contemporary endeavours often focus on providing technology and introducing practices that improve or preserve water quality and quantity. But some of these efforts suffer either from a failure to correctly interface with existing local practices or an inability to adequately address the local knowledge gap. This study addressed this problem by combining location-specific public enlightenment with access to source protection, storage, and treatment technologies.

The study area consists of rural settlements in the central region of Nigeria. Datasets used include population statistics, source types (surface water, groundwater, tap water, etc.), demand and availability, water stress levels, quality and quantity enhancement technology, and access to water education (radio, local health official, etc.). Results showed that communities that received properly instituted water quality/quantity enhancement technologies with little to no orientation (or vice versa) experienced inconsistent improvements in water sufficiency across the tested populations and some stagnation afterwards. But in communities that benefitted from continuous sustainability orientation as well as a careful interfacing of water quality/quantity enhancement and protection technologies, dramatic improvements in water sufficiency resulted. In addition to socioeconomic and environmental benefits, insights gained from this study have potential applications in planning/policy-making by stakeholders in similar developing regions in Central America and Southeast Asia.

Keywords: Africa water scarcity, drinking water stress, sustainable development goals SDGs, water education, water sustainability.

1 INTRODUCTION AND BACKGROUND

Access to water and sanitation are two of the most fundamental factors on which Goal #6 of the sustainable development goals (SDGs) set by the United Nations are based and evaluated [1]–[3]. However, many people around the world do not still have access to safe drinking water and effective sanitation. In 2008, about 1 billion people globally lacked access to improved drinking water supplies [4]–[6]. About 10 years later, that number has increased to about 2 billion [3, 7]. As a result, access to proper sanitation has also worsened. This is because in many parts of the developing world, water free from biological contamination is not accessible by people who need it either because of poor source protection or poor education about safe practices and health impacts. Where populations have access to relatively improved supplies like piped connections, public taps, and pumping wells, the water is not necessarily always safe [4, 5, 8].

Limited access to safe water contributes significantly to the global burden of disease and death resulting from infectious diarrhoea and other enteric illnesses. However, while it has been established that there is an obvious connection between poor access to safe water and deplorable sanitation, the impact of the former on the latter is often difficult to predict or quantify [9].

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Despite this, an improvement on sanitation can be achieved by improving water quality and water access. Many studies have demonstrated that adequate provision of safe water and sanitation to both rural and urban populations lead to improvements in the health and well-being of the population and helps increase life expectancy over time [2, 9–11]. Developing regions of the world have struggled with improving access to water and sanitation for its citizens as evidenced both by the frequency and severity of water-borne illnesses and by the inability to meet the millennium development goals (MDGs) that relate to these areas. Associated water-borne disease outbreaks were evaluated and found in some cases to be often worse. For example, developing regions in Sub-Saharan Africa, Southeast Asia, and Central America have been found to still lag behind [2, 12–14]. Any effort towards developing a plan for the achievement of this SDG must first evaluate the problems and prospects for a given geographical area. Effective strategies for community water supply and sanitation programmes in developing countries must be based on the existing problems, the beneficial impacts achievable, and the parameters which determine sustainability of such programmes [15, 16]. One of the reasons for this is that there are limitations to the long-term effectiveness of such systems. Many also break down and are never repaired or are simply abandoned. One study [12] applied data obtained from the Rapid Assessment of Drinking Water Quality project. It looked at whether drinking water sources in five countries, one of which was Nigeria, complied with water quality guidelines set by the World Health Organization on contamination with thermotolerant coliform bacteria, arsenic, fluoride, and nitrates in 2004 and 2005. These data were used to make adjustment to estimates of the percentage of the population with access to safe drinking-water at the MDG baseline. The baseline reference years were 1990 and 2008 and were made by the Joint Monitoring Programme for Water Supply and Sanitation, which classified all improved sources as safe. Results showed substantially lower estimates of the percentage of the population with access to safe drinking water in 2008 in four of the five study countries: where the absolute reductions were found to be was 11% in Ethiopia, 16% in Nicaragua, 15% in Nigeria, and 7% in Tajikistan. This study focused on one these countries (Nigeria).

2 STUDY AREA AND METHODOLOGY

The study area consists of six rural settlements along the lower basin of one of Africa's major rivers, the Niger. These settlements are in central Nigeria (Fig. 1). Nigeria is an important choice in both a local and global context. Cohen (2006) reported that over the next 30 years, a huge amount of the world's population growth is expected to be concentrated in urban areas in developing countries. Nigeria accounts for a large percentage of this with its population of about 200 million people being first in Africa and seventh in the world [18]. It has faced some water management issues in the past 20 years [19]–[23] which have necessitated location-specific solutions. Vairavamoorthy et al. (2008) wrote that urban areas of developing countries are facing increasing water scarcity and that due to water scarcity and limitations to the development of new water resources, it is prudent to shift from the traditional 'supply based management' to a 'demand management' style. Similarly, other researchers may need to use a location-specific approach.

Therefore, this study examined the impacts of two key factors on water quality and availability in a selection of rural communities in Nigeria. These factors include: (i) sustained public education and (ii) improvised source protection and enhancement means. Data analysed include population statistics, source types (surface, ground, tap-water, etc.), demand/consumption patterns, water stress (based on scarcity and pollution levels), and access to water education (radio, local health official, etc.). The methodology used for this study was applied in the following sequence.

Figure 1: Location of Nigeria in Africa.

2.1 Identification of communities

Six contiguous rural communities were selected and analysed for this study. Data for additional adjoining communities of interest were either unavailable or incomplete. Therefore, only these six communities for which the availability and reliability of data could be ascertained and where the number of parameters could be kept to a minimum were used. The data collected spanned a two-year period starting just before the study was begun to a period at the end of the study. The geographical proximity and sociocultural similarity of the communities were also advantages in this study. The former guarantees that the communities are likely experiencing similar hydrological effects on their natural water systems like groundwater and surface water. The latter hopefully helped prevent the need to adjust for the cross-communal effect that factors like ancestral or tribal attitudes may have on water and sanitation habits, which can be otherwise significant [25], [26]. An easy nomenclature was adopted by naming the communities Community 1 (population 4,962), Community 2 (population 4,443), Community 3 (population 3,128), Community 4 (population 3,383), Community 5 (population 4,305), and Community 6 (population 2,877).

2.2 Water sources and determination of initial water stress

The types of drinking water sources evaluated in each community included tap water, sachet water (drinking water purified and sold in one-litre bags by private sellers), well water, and surface water sources (Tables 1 and 2). Tap water supplied by municipalities is usually safe in most parts of the world. But it was still included for evaluation in this study due to contamination recorded during low pressure incidents and after storage, and other unforeseen factors

Table 1: Water source classes and types in Nigeria [9].

Source class	**Type of source**
Unimproved drinking-water source	Unprotected dug well, unprotected spring, cart with small, tank or drum, surface water (e.g., river, dam, lake, pond, stream, canal or irrigation channel) and bottled water
Improved drinking-water source (piped to dwelling, plot or yard)	Piped water connection located inside the user's dwelling, plot or yard
Improved drinking-water source (other sources)	Public taps or standpipes, tube wells or boreholes, protected dug wells, protected springs and rainwater collection

Table 2: Assessment of water stress before study.

	Initial assessment of water stress											
	Community											
	1		**2**		**3**		**4**		**5**		**6**	
Source	**Quality**	**Quantity**	**Quality**	**Quantity**	**Quality**	**Quantity**	**Quality**	**Quantity**	**Quality**	**Quantity**	**Quality**	**Quantity**
Tap water	S	U	S	U	U	U	S	U	S	U	U	U
Well water	S	U	U	U	S	U	S	U	U	U	U	U
Sachet water	S	U	U	U	U	U	S	U	U	U	U	U
Surface water	U	S	U	S	U	S	U	S	U	U	U	U

that can affect treated effluent quality. Also, tap water supply is typically rationed and, in all of these communities, runs only for a few hours about one or two days each week. An initial level of water stress was determined before any measures were put in place to address the water issues in each community (Table 2). The basis for the assessment scores (satisfactory, S, or unsatisfactory, U) given in Table 2 is explained below.

2.3 Water quality metrics and evaluation of sufficiency

The water quality measures used for this study included one physical, chemical, and biological characteristic each. These were turbidity, pH, and coliform bacteria, respectively. The acceptable turbidity limit used was 5.0 NTUs (Nephelometric Turbidity Units) to match the recommendation of the World Health Organization. The acceptable range for pH adopted was 6.0–8.5. The acceptable coliform limit used was 0 CFU/100 mL or simply non-detect (ND) [27], [28]. For each parameter, a score of satisfactory (S) was assigned when the water met these limits described above or a score of unsatisfactory (U) was assigned when the water did not meet these limits. A water quality sufficiency coefficient was then calculated by dividing the number of satisfactory scores in an assessment period by the total scores assigned in that period. This water quality sufficiency coefficient C_1 was determined as shown in eqn (1) to help compare communities and periods.

$$Water\,quality\,sufficiency\,quotient\,C_1 = \frac{number\,of\,satisfactory\,scores, S}{total\,number\,of\,scores\left(U+S\right)} \tag{1}$$

2.4 Water quantity metrics and evaluation of sufficiency

The basis of assessment of water quality sufficiency included *perceived sufficiency* (eqn 2). This was defined as the ratio of water availability to water needs in each household. It was evaluated using approximate volumetric ratios by counting the number of water storage tanks filled to capacity to meet water needs (availability) and the number of empty storage containers (demand) over time. In a few instances where quantitative data could not be easily obtained, perceived sufficiency or lack thereof was reported based on self-reporting by each household. In either case, a score of satisfactory (S) was given for perceived sufficiency equal to or greater than 1.0 and unsatisfactory (U) for perceived sufficiency less than 1.0. A sufficiency coefficient C_2 for water quantity was also determined, similar to that determined for water quality above, by applying these scores to the below equation

$$Perceived\,sufficiency = \frac{Estimated\,water\,availability}{Total\,demand} \tag{2}$$

$$Water\,quantity\,sufficiency\,quotient\,C_2 = \frac{number\,of\,satisfactory\,scores, S}{total\,number\,of\,scores\left(U+S\right)} \tag{3}$$

2.5 Public education measures

Public education of the populations on sustainable water quality and quantity practices was performed through weekly oral communication by a local government official speaking in the local language. Others included monthly distribution of educational leaflets with instructional graphics and texts, instructional plaque at water source (wells and tap), and electronic media in the form of a weekly shortwave radio program. These taught things like importance and methods of water conservation, water-borne disease transmission and prevention, common water contamination pathways, siting latrines away from wells, boiling, abandonment of unsanitary and unsustainable water-related beliefs and practices, etc.

2.6 Protection and enhancement measures

One important measure provided to these populations included simple repair kits for fixing leakages and breakdowns of hand-pumped wells and storage systems without waiting for the delegated local government official especially on weekends and long public holidays. Other methods for provided for enhancing water quality were aluminium sulphate coagulants to reduce solids and turbidity levels, improvised homemade filtration systems made of sand layers, and chlorine-based tablets for disinfection. Flow meters were also installed to hopefully instil discipline against indiscriminate use.

2.7 Stages and period of study

This study was conducted over 24 months in three stages of eight months each. None of the six communities had begun to receive any water sustainability/enhancement or public education measures in stage I (February 2017—September 2017). In stage II (October 2017—May 2018, only Communities 3 and 4 received sustained public education with no quantity/quality improvement technologies. In the same period, only Communities 5 and 6 received water quality and quantity improvement technologies but with no sustained public education measures. In stage III (June 2018–January 2019) which marked the final period, only Communities 5 and 6 were upgraded to receive water quality and quantity enhancement technologies as well as frequent public education (Table 2)

All of this was due to the different paces at which government and other stakeholders moved to try to upgrade the water systems and teach improved practices in these communities, as opposed to a deliberate attempt to deprive some of the communities from beneficial technology or education to fulfil research purposes.

3 RESULTS AND DISCUSSION

The overall trends demonstrated a tendency for the smaller populations (communities A and C) to quickly show results, perhaps due to faster dissemination of information and its effect. The communities with the larger populations (communities B and D) also seemed to the slowest improvement in water quantity quotient. These communities are agrarian and tend to use water heavily so perhaps this explains relatively higher consumption of water and slower move towards sufficiency.

3.1 Initial level of water stress

The results of initial level of water stress are shown in Table 2. Tap water and well water ranked highest in water quality due to better monitoring and natural filtration, respectively. Communities 1 and 4 had the highest number of satisfactory water quality scores for tap, well, and sachet water. The reason for this is not clear but could perhaps be due to the fact that some wells in these communities are privately owned and hence better maintained and many sachet water sellers simply bag and resell well water and tap water. Communities 1–5 had satisfactory numbers for quantity assessment for surface water due to its abundance and ease of access.

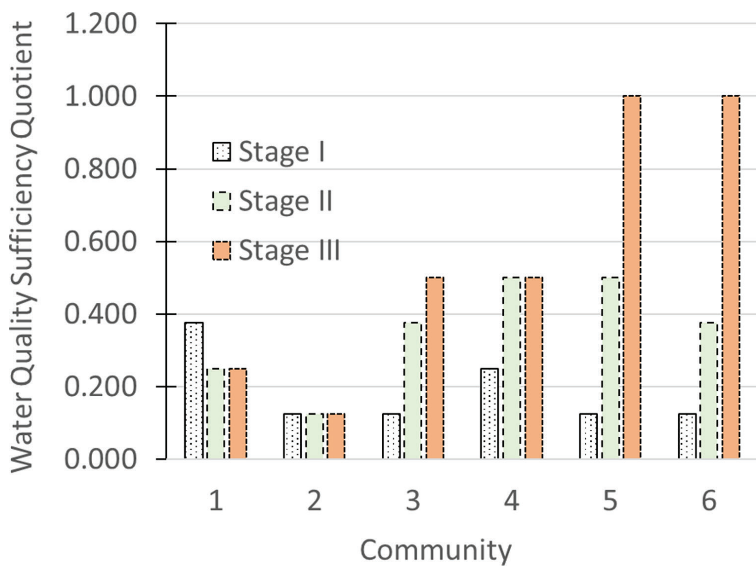
3.2 Water quality sufficiency

The result of the evaluation of water quality sufficiency in all six communities is shown in Table 3 and Fig. 2. In stage I, all six communities had quality sufficiency quotients of 0.125 except for communities 1 and 4, again depicting the trend observed before the study began (Table 2).

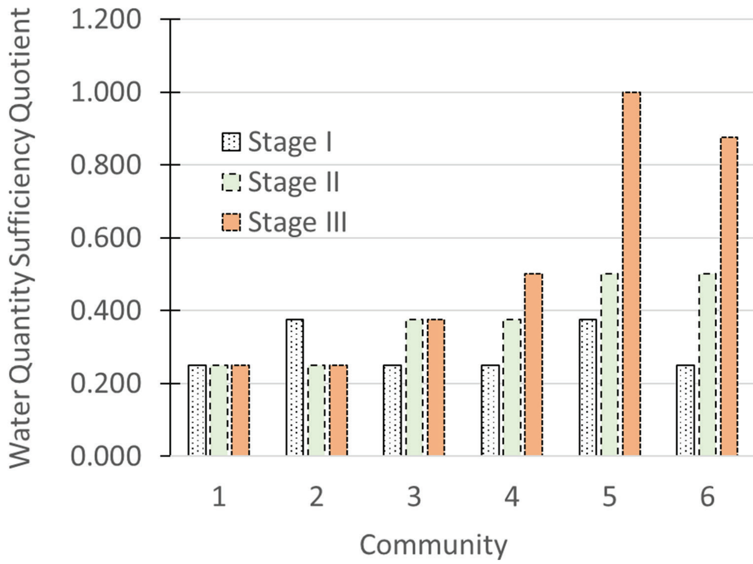
In stage II, when only Communities 3 and 4 were upgraded to receive public education and water quality/quantity enhancement technology, their sufficiency quotients improved from 0.125 to 0.375 and from 0.250 to 0.500, respectively. These increases represent a 200% and 100% increase in water quality sufficiency, respectively. Improvements in quality sufficiency observed in Communities 5 and 6 (which received only water enhancement means with no public education) were 0.125 to 0.500 and 0.125 to 0.375, respectively. With no public education or enhancement methods provided, Community 1 declined to 0.250 in stage II while

Table 3: Results of water quality sufficiency.

Water Quality Sufficiency								
Stage	Description	Period	Perceived Sufficiency in Community					
			1	2	3	4	5	6
I	Communities 1 through 6 received neither public education nor quality/quantity enhancement measures	Feb-17	S	U	U	S	U	U
		Mar-17	U	U	U	U	U	U
		Apr-17	U	U	U	U	U	U
		May-17	U	U	U	U	U	U
		Jun-17	U	U	U	U	U	U
		Jul-17	U	U	U	U	U	U
		Aug-17	S	U	U	U	U	U
		Sep-17	S	S	S	S	S	S
II	Communities 3 and 4 received only public education. Communities 5 and 6 received only water quality/quantity protection and enhancement means	Oct-17	S	S	S	S	S	S
		Nov-17	S	U	U	U	S	S
		Dec-17	U	U	U	U	U	U
		Jan-18	U	U	S	S	U	U
		Feb-18	U	U	U	S	S	S
		Mar-18	U	U	S	U	U	U
		Apr-18	U	U	U	S	S	U
		May-18	U	U	U	U	U	U
III	Only Communities 5 and 6 received both public education and water quality/quantity enhancement means	Jun-18	U	U	S	S	S	S
		Jul-18	U	U	U	U	S	S
		Aug-18	U	U	U	U	S	S
		Sep-18	S	U	S	S	S	S
		Oct-18	S	S	U	S	S	S
		Nov-18	U	U	S	U	S	S
		Dec-18	U	U	U	S	S	S
		Jan-19	U	U	S	U	S	S
	Sufficiency quotient, C_1 (Stage I)		0.375	0.125	0.125	0.250	0.125	0.125
	Sufficiency quotient, C_1 (Stage II)		0.250	0.125	0.375	0.500	0.500	0.375
	Sufficiency quotient, C_1 (Stage III)		0.250	0.125	0.500	0.500	1.000	1.000
Cumulative Percentage Improvement after stage I			-33.3	0	200	100	300	200
Cumulative Percentage Improvement after stage II			-33.3	0	233	100	400	367



(a)



(b)

Figure 2: Water sufficiency for six communities. (a) Quality; (b) Quantity.

Community 2 remained the same at 0.125 between stages I and II. In stage III, Communities 5 and 6 saw dramatic improvements over both stages I and II with cumulative percentage increases in sufficiency of 400% and 367%, respectively. By comparison, for Communities 1–4, only Community 3 saw a gain in sufficiency quotient in stage III.

3.3 Water quantity sufficiency

In Table 4 and Fig. 2, results from the evaluation of water quantity sufficiency in all six communities are presented. In stage I, all six communities had quantity sufficiency quotients that ranged from 0.250 to 0.375. The number of satisfactory scores in stages I–III is highest for the period between July and November likely because this is the typical rainy season in Nigeria which increased the availability of all source types. The drier months of December to May show higher unsatisfactory scores for the same reason. In stage II, when only Communities 3 and 4 were upgraded to receive public education and water quality/quantity enhancement technology, the water quantity sufficiency quotients both improved from 0.250 to 0.375, respectively. These represent a 50% increase in water quantity sufficiency, respectively. Water quantity sufficiency observed in Communities 5 and 6 (which received only water enhancement means with no public education) increased to 0.500. With no sustained public education or technology provided, Community 1 remained the same at 0.250 and Community 2 declined to 0.250 between stages I and II. In stage III, Communities 5 and 6 saw dramatic improvements over both stages I and II with cumulative percentage increases in sufficiency of 133.3% and 175%, respectively. By comparison, for Communities 1–4, only Community 4 saw a gain (+50%) in water quantity sufficiency quotient in stage III.

Table 4: Results of water quantity sufficiency.

Water Quantity Sufficiency								
Stage	Description	Period	Perceived Sufficiency in Community					
			1	**2**	**3**	**4**	**5**	**6**
I	Communities 1 through 6 received neither public education nor quality/quantity enhancement measures	Feb-17	U	U	U	U	U	U
		Mar-17	U	U	U	U	U	U
		Apr-17	U	U	U	U	U	U
		May-17	U	U	U	U	U	U
		Jun-17	U	U	U	U	S	U
		Jul-17	S	S	S	U	U	S
		Aug-17	S	S	U	S	S	U
		Sep-17	U	S	S	S	S	S
II	Communities 3 and 4 received only public education. Communities 5 and 6 received only water quality/quantity protection and enhancement means	Oct-17	S	S	S	S	S	S
		Nov-17	S	S	S	S	S	U
		Dec-17	U	U	S	U	S	S
		Jan-18	U	U	U	U	U	U
		Feb-18	U	U	U	U	U	U
		Mar-18	U	U	U	U	U	U
		Apr-18	U	U	U	U	S	S
		May-18	U	U	U	S	U	S
III	Only Communities 5 and 6 received both public education and water quality/quantity enhancement means	Jun-18	U	U	U	S	S	S
		Jul-18	U	U	U	U	S	S
		Aug-18	S	U	S	S	S	S
		Sep-18	S	S	S	U	S	S
		Oct-18	U	S	S	S	S	S
		Nov-18	U	U	U	U	S	S
		Dec-18	U	U	U	S	S	U
		Jan-19	U	U	U	U	S	S
	Sufficiency quotient, C_2 (Stage I)		0.250	0.375	0.250	0.250	0.375	0.250
	Sufficiency quotient, C_2 (Stage II)		0.250	0.250	0.375	0.375	0.500	0.500
	Sufficiency quotient, C_2 (Stage III)		0.250	0.250	0.375	0.500	1.000	0.875
Cumulative Percentage Improvement after stage I			0.0	-33.3	50.0	50.0	33.3	100.0
Cumulative Percentage Improvement after stage II			0.0	-33.3	50.0	83.3	133.3	175.0

4 LIMITATION AND CONCLUSION

4.1 Limitation

One limitation of this study is that although the number of months examined were the same for each stage, the actual months examined were different. This means the possible influence of seasonal characteristics of natural water systems on the reliability of water supply may not have been adequately captured. In addition, subsequent studies will need to cover more than two years of data to allow time for the effects of the changes introduced to become apparent.

4.2 Conclusion

This study examined the impacts of sustained public education and water quality/quantity enhancement on water resources sufficiency. The results showed that public education alone is not enough to improve water sustainability for some populations and neither is providing improvement technology alone. A combination of both methods must be used to bring about maximum and lasting results on water and, indirectly, sanitation. The lessons learned from this study have potential implications for planners and policy makers in similar developing and water-stressed regions in Central America and Southeast Asia.

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