SciMedCentral

Journal of Human Nutrition & Food Science

Review Article

Improving Access to Safe Drinking Water in Rural Sub-Saharan Africa with Behavioral Nudging Innovations

Chibuzo Chilaka[1], Gregory Torell[2], and Frank A. Ward[2]*

[1]Department of Water Science and Management, New Mexico State University, USA
[2]Department of Agricultural Economics and Agricultural Business, New Mexico State University, USA

***Corresponding author**
Frank A. Ward, Department of Agricultural Economics and Agricultural Business, New Mexico State University, USA

Submitted: 29 January 2023
Accepted: 27 Febraury 2023
Published: 27 Febraury 2023
ISSN: 2333-6706

Keywords
• Behavioral nudging
• Safe drinking water
• Clean water technology
• Waterborne diseases
• Culture
• Capacity to pay; Institutions; Sub Saharan Africa

Abstract

Access to safe drinking water is an important element of human nutrition and food science confronting residents and governments in rural regions of developing countries, particularly in rural Sub-Saharan African (SSA). Despite vigorous and sustained efforts by governments, donors, and local stakeholders since 2000, water for more than 650 million in rural SSA as of 2020 are unsafe for drinking, with significant attendant morbidity and mortality. Since 2000, considerable research published by western scientists has focused on development of economically workable and institutionally acceptable technologies to make water safe to drink, for which behavioral nudging could offer a potentially low-cost method to improve access to drinking water. In spite of these potential gains, little work in the published literature has investigated how behavioral nudging could see use to improve human nutrition and promote more widespread adoption of water purification technologies that is consistent with local institutions. As a result, donors and multilaterals often implement ineffective policies for taking action to promote affordable access to safe drinking water. This paper addresses that gap by investigating behavioral nudging implementations that could be made compatible with economic and institutional characteristics unique to rural SSA to promote greater adoption of water disinfecting technologies there. This contribution is implemented by formulating and investigating three distinct behavioral nudging approaches institutionally compactible with much of rural SSA: "word of mouth," "public proclamation," and "educational nudging." Findings of a model characterizing the economic capacity to pay for safe drinking water technologies have positive capacity to pay for water when aligned with well-designed implementations for each of these three information delivery institutions. While the approach and findings are illustrated for rural SSA, its method carries some adaptability and generalizability.

BACKGROUND

The relationship between water and human nutrition is well established. Despite continued efforts internationally, water and food contamination persist. Water pollution from nitrates, arsenic and nitrites is a worldwide problem, with research indicating that excessive quantities in water and food can cause a variety of ailments [1-3]. The primary sources of these contamination stems from drinking water, crops irrigated with contaminated water, and food prepared with polluted water.

Access to safe drinking water is a major challenge confronting many living in the rural regions of developing countries and presents an especially pervasive problem in rural Sub-Saharan Africa (SSA). Despite vigorous and sustained efforts by governments, donors, and local stakeholders since 2000, drinking water sources of at least 600 million in rural SSA are unsafe for drinking, resulting in significant morbidity and mortality. It has been estimated by 2050 that rural population in that region will increase to 909 million [4].

Considering this outlook with forecasts of climate extremes, floods and droughts will place drinking water source under growing stress and may cause a population diaspora due to water and nutrition-related stress and conflict. Rural dwellers and low-income earners benefit from better access to safe drinking water through improved health, averted health care costs and large amounts of time saved from traveling significant distances to haul water. Science-informed management of water resources and related food security brings more certainty and efficiency in productivity across economic sectors and contributes to human health. Taken together, successful safe drinking water interventions lead to direct and long-term economic, social, and environmental benefits that matter to lives of billions internationally.

Yet, in many places, households and communities lack the financial and technical capacity to develop water systems that supply safe drinking water affordably, leading to health and economic consequences. This problem has created considerable imbalance that led to large numbers of people lacking access to basic safe drinking water [5]. Of this number, more than 600 million live in rural SSA [6]. Prioritizing and choosing the most economical and institutionally acceptable safe drinking water measures in SSA, especially rural regions, requires a complex and well-mapped set of choices. The most suitable choice for a family or community is subject to factors, such as culture and

Cite this article: *Chilaka C, Torell G, Ward FA (2023) Improving Access to Safe Drinking Water in Rural Sub-Saharan Africa with Behavioral Nudging Innovations. J Hum Nutr Food Sci 11(1): 1158.*

religious acceptability, water quality, implementation feasibility, availability of technology, financial, and other local conditions [7].

Many policies have attempted to combat the challenges of unsafe drinking water and related poor food nutrition in rural SSA but few have seen widespread success. The large number of non-government organizations (NGOs) foundations, academia, faith-based organizations, and private organizations with a wide range of policies and plans for providing safe water to rural SSA continue to face unsolved challenges. The political economy of these diverse interests often shapes policies and interventions, which may poorly serve rural water users despite the best of intentions. Ensuring basic and adequate water was an existential priority in Mayan, Persian, Mughal, and Roman civilizations, which prompted innovations in the institutions and infrastructure. These stimulated many of the urban public piped systems that remain today [8]. Looking to rural SSA, an important question arises what can be done to help the region deal with perennial water safety and related nutrition challenges that have challenged it for so long.

Behavioral nudging as a method to adjust individual behavior to meet social needs has seen much success in the western world since 2010. Still, little knowledge seems available on how to implement behavioral nudging in rural SSA to support better access to safe drinking water and human nutrition. Behavioral nudging refers to any part of the choice architecture that alters people's behavior in a predictable manner without prohibiting or denying options or substantially altering their economic incentives [9-13]. Behavioral nudge implementations in the west have focused mostly on designing options that to alter many kinds of human activity for which the modification of the individual's choices can be made desirable for those individuals and, by extension, for the greater benefit of society.

Previous Work

The use of behavioral nudges to address water management, protection, safety, and sustainability has seen considerable scholarly attention since the late 20th century - both from policymakers and in peer-reviewed publications. Some work has shown that due to economic, institutional, and infrastructure constraints, achieving sustainable level of safe drinking water have been difficult [14-18]. Generally, water disinfecting technologies are simple and have a comparatively low cost, but the reasons behind their poor adoption are complex [19]. Adoption of new technology can influence the uptake of new behavior and dependent on individuals' ability to use the technology [20].

Behavioral nudging policies that address the challenges of safe drinking in SSA generally deals with point of use (POU) water disinfecting technologies in a universal sense. The strategy of sustainable safe drinking water management in various forms has been examined. The overarching agreement from a range of widely cited works from the past concluded there are challenges of acceptance of these technologies in rural SSA because of inconsistence in planning, differences in economic situations of the people, access to requisite skill set, and educational attainments [21].

The *Journal of Human Nutrition and Food Science* have published a number of works addressing methods to improve access to safe drinking water and human nutrition [22-25]. This journal has published many innovative institutional frameworks for handling food, water, and nutritional management challenges. While these papers did not all present detailed modeling or statistical work, they all made important scientific contributions to understanding the structure of institutional innovations to address water management problems needing attention. A few works in other journals have also investigated challenges and opportunities to achieve better access to safe drinking water in Sub Saharan Africa [16,26-32].

Gaps

Despite these achievements seen in the peer-reviewed literature, one difficult question remains unanswered that faces water and nutrition experts, rural communities, water financers, and scientists. How can affordable safe drinking water and nutrition be made available to the large region of rural SSA by designing effective behavioral nudging institutions while maintaining cultural, institutional, and financial requirements that are compatible with the community's need. To pose the unanswered question differently, we ask how can policymakers penetrate the maze of rural SSA's institutions to achieve the elusive goal of making safe drinking water available to the people of rural SSA without undermining local institutions. This work aims to address that question.

Contribution

This work contributes to addressing that unanswered question by investigating behavioral nudging implementations that can be made compatible with cultural and institutional characteristics unique to rural SSA with a potential to promote greater adoption of water disinfecting technologies in rural Sub-Saharan Africa, a region for which this challenge is immense. It attempts to establish a framework by which policies could be designed to nudge rural communities in SSA towards achieving safe and affordable drinking water.

It investigates the relationships between economic incentives, behaviors, and community awareness regarding the design of behavioral nudging methods that could promote more widespread access to and use of drinking water purification technologies in rural SSA, with a focus on potential successes that could be secured with behavioral nudging. In addition, it reviews the role of water institutions in bringing behavioral nudge messages to the people in a culturally acceptable manner.

METHODS OF ANALYSIS

We implement innovative designs of behavioral nudging that reflect the unique conditions in rural SSA. Rural SSA lacks services and infrastructure to enable traditional behavioral nudging as known and practiced in the west [33-37]. At the outset it becomes clear that it is important to find a way to design behavioral nudging plans that draw on nudging theory's well-known ease of use and non-confrontational appeal. We achieve this by investigating how "word of mouth," "public proclamation," and "demonstrated interactive education" could be used to convey nudge messages to the people of rural SSA. The methods developed will need contrast with methods used in the west, where access to information is faster, smoother, easier, and cheaper thanks to internet access, mass media, and social media. The communication methods are markedly different in rural SSA, where these fundamental amenities are rarely guaranteed. This makes word of mouth, public proclamation, and interactive education workable only if designed carefully.

The majority of the population of rural SSA is poor, weakly-educated, superstitious, illiterate, and suffers from unsafe drinking water with related impacts on food safety and nutrition. In response to these obstacles, both local and international organizations have attempted to design policies to address the problem. These strategies are often ill-suited to local requirements and, as a result, ineffective in dealing with the widespread problem of poor access to safe drinking water.

Data

Value of a Statistical Life: The value of a statistical life (VSL) is a measure of the economic value that individuals place on reducing their risk of death from bad water, poor nutrition, or other hazards [38]. It is often used by governments and organizations to evaluate the benefits of policies and programs that aim to reduce fatalities, such as traffic safety measures or environmental regulations. The VSL is typically estimated by examining how much individuals are willing to pay to reduce their risk of death, either through the choices they make or through stated preference surveys. For example, people may be willing to pay more for a car with a higher safety rating or to live in a neighborhood with a lower crime rate or secure access to safer drinking water. These choices can provide insight into how much people value reducing their risk of death.

The VSL is often expressed as a dollar amount per statistical life saved. This dollar amount represents the amount of income that individuals are willing to pay to reduce their risk of death by a marginal amount. The VSL can be used to compare the benefits of different policies or programs, as well as to estimate the costs and benefits of a given policy or program. It is important to note that the VSL is not a measure of the intrinsic value of human life. Rather, it reflects the economic value that individuals place on reducing their risk of death. The VSL can vary across different populations and contexts, and it is generally higher for individuals who are younger and in good health [39].

Table 1 shows the VSL data used in this analysis, along with the data sources. The main source of the data was obtained from a recent peer-reviewed paper by one of the VSL pioneers [41]. This work compiled global VSL data, from which the values for the four regions in Sub-Saharan Africa (SSA) were extracted. To arrive at a workable amount for this analysis, an average VSL was calculated for each of four regions in Sub-Saharan Africa (SSA): West Africa, East Africa, Central Africa, and Southern Africa. The economic fortunes of the people in these regions vary, as do the individual countries that make up each region. In addition to the VSL data, other relevant data were collected for the analysis, including GDP and headcounts data for the countries in each region. These data were obtained from publicly available sources, such as the International Monetary Fund (IMF) and the United Nations (UN) [41-43]. A complete list of the parameters and data is shown in Tables 1 and 2. The numerical value of all parameters used along with provenance where available is available by request from the authors, for those who would like to see our data and GAMS® code.

Probability of Adoption: The probability of adoption is an important consideration when evaluating the potential impact of a new policy or program. It refers to the likelihood that affected individuals will adopt a new technology not currently in use. There are several factors that can influence the probability of adoption, including the perceived benefits and costs of the policy or program, the level of uncertainty surrounding it, and the level of support or resistance from key stakeholders. To estimate the probability of adoption, it may be necessary to consider both qualitative and quantitative data. Qualitative data, such as expert opinions and stakeholder feedback, can provide insight into the perceived benefits and challenges of the policy or program. Quantitative data, such as adoption rates for similar policies or programs, can provide a more objective measure of the probability of adoption. It is important to note that the probability of adoption is not a fixed value. Rather, it may change over time as new information becomes available or as the policy or program is implemented. As such, it is important to regularly reassess the probability of adoption to accurately predict the potential impact of the policy or program [44,45].

This research opens the door to further advancement by scholars who conduct field surveys. However, for the purposes of this paper, we utilized estimates of probability that have been previously employed by other researchers who have conducted studies with some similarities to this work. As such, we employed an approximation to generate the probabilities presented in this paper. Given that there is limited published research on adoption probabilities in rural areas of Sub-Saharan Africa (SSA), we used plausible estimates to establish our probability [46-55].

Table 1 shows the range of probabilities used in this work. Different technologies, regions, and method delivery message are assigned different probabilities. For example, word of mouth and public proclamation are assigned higher probabilities for simple technologies like chlorination, pasteurization, and filtration. And by similar reasoning, education is assigned a higher probability for complex technologies like ozone, ultraviolet filtration, and Mixed Oxidation Gas Systems. The probability of adoption was used in this work to assess varying technologies by regions and message delivery methods. Despite the categorization of SSA as a unit or block, there are notable differences in capacity to pay by different regions, which equally reflected on the different regions adoption rate.

Population: Tables 1 and 2 show the population of our four SSA regions selected. Organized in descending order: East Africa has the largest population at 445 million, West Africa has 401 million, Central Africa has 179 million, and Southern Africa has

Table 1: Key Data on Drivers of Capacity to Pay for Access to Safe Drinking Water by Technology, Region, and Information Delivery Method, Rural Sub Saharan Africa, 2022

Technology	Region	Population (millions)	Value of a Statistical Life ($US millions)	Probability of Technology Adoption by Technology, Region, and Information Delivery Method		
				01_word_of_mouth	02_public_proclamation	03_education
Ozone	01_Central_SSA	179	0.85	0.20	0.20	0.25
	02_Eastern_SSA	445	1.40	0.20	0.20	0.25
	03_Southern_SSA	67	1.50	0.20	0.20	0.25
	04_Western_SSA	401	1.65	0.20	0.20	0.25
Pasteurization	01_Central_SSA	179	0.85	0.25	0.25	0.20
	02_Eastern_SSA	445	1.40	0.25	0.25	0.20
	03_Southern_SSA	67	1.50	0.25	0.25	0.20
	04_Western_SSA	401	1.65	0.25	0.25	0.20
Chlorination	01_Central_SSA	179	0.85	0.30	0.25	0.25
	02_Eastern_SSA	445	1.40	0.30	0.25	0.25
	03_Southern_SSA	67	1.50	0.30	0.25	0.25
	04_Western_SSA	401	1.65	0.30	0.25	0.25
Filtration	01_Central_SSA	179	0.85	0.25	0.20	0.20
	02_Eastern_SSA	445	1.40	0.25	0.20	0.20
	03_Southern_SSA	67	1.50	0.25	0.20	0.20
	04_Western_SSA	401	1.65	0.25	0.20	0.20
Mixed Oxidation	01_Central_SSA	179	0.85	0.20	0.25	0.30
	02_Eastern_SSA	445	1.40	0.20	0.25	0.30
	03_Southern_SSA	67	1.50	0.20	0.25	0.30
	04_Western_SSA	401	1.65	0.20	0.25	0.30
Ultraviolet Filtration	01_Central_SSA	179	0.85	0.20	0.25	0.30
	02_Eastern_SSA	445	1.40	0.20	0.25	0.30
	03_Southern_SSA	67	1.50	0.20	0.25	0.30
	04_Western_SSA	401	1.65	0.20	0.25	0.30

Table 2: Economic Capacity to Pay to Secure Safe Drinking Water by Technology, Region, and Information Delivery Method, $US Per Capita, Rural Sub Saharan Africa, 2022

Technology	Region	Population (millions)	Capacity to Pay (per capita, $US)		
			Message Delivery Method		
			01_word_of_mouth	02_public_proclamation	03_education
Ozone	01_Central_SSA	179	170,000	170,000	212,500
	02_Eastern_SSA	445	280,000	280,000	350,000
	03_Southern_SSA	67	300,000	300,000	375,000
	04_Western_SSA	401	330,000	330,000	412,500
Pasteurization	01_Central_SSA	179	212,500	212,500	170,000
	02_Eastern_SSA	445	350,000	350,000	280,000
	03_Southern_SSA	67	375,000	375,000	300,000
	04_Western_SSA	401	412,500	412,500	330,000
Chlorination	01_Central_SSA	179	255,000	212,500	212,500
	02_Eastern_SSA	445	420,000	350,000	350,000
	03_Southern_SSA	67	450,000	375,000	375,000
	04_Western_SSA	401	495,000	412,500	412,500
Filtration	01_Central_SSA	179	212,500	170,000	170,000
	02_Eastern_SSA	445	350,000	280,000	280,000
	03_Southern_SSA	67	375,000	300,000	300,000
	04_Western_SSA	401	412,500	330,000	330,000
Mixed Oxidation	01_Central_SSA	179	170,000	212,500	255,000
	02_Eastern_SSA	445	280,000	350,000	420,000
	03_Southern_SSA	67	300,000	375,000	450,000
	04_Western_SSA	401	330,000	412,500	495,000
Ultraviolet Filtration	01_Central_SSA	179	170,000	212,500	255,000
	02_Eastern_SSA	445	280,000	350,000	420,000
	03_Southern_SSA	67	300,000	375,000	450,000
	04_Western_SSA	401	330,000	412,500	495,000

the fewest, at 67 million. The population was important in the investigation since it helped determine the value of statistical life across different regions, technology, and message delivery methods. It important to clarify that this number is only for the rural parts of SSA. This is important as value of statistical life may be much different in the urban areas in relation to rural.

Information Delivery Institutions

Word of Mouth: Word of Mouth carries particular cultural significance in SSA, particularly among rural inhabitants [56,57]. It represents neighbors communicating vital information by word of mouth. People share with their neighbor's new information they have received through culturally acceptable groups such as the church, community gatherings, and marketplace. Due to the absence of most modern media in most rural areas, individuals inform neighbors about the new technology and how it has benefited their family. This method of communication is a potentially important institution for deploying behavioral nudges more quickly. When someone learns something new and useful, they pass it forward. This expedites the dissemination of knowledge throughout the community. Sharing what they know or have found costs little and requires no specialized medium.

Public Proclamation: In rural SSA, elders are respected, knowledgeable, and represent cultural protectors [58]. Public proclamation constitutes important way information is dispatched in a communal setting. Village elders send the town crier to bring all adults to the community leader's residence for public announcement. This pronouncement comes in numerous versions. Facing a public health crisis like COVID-19, community leaders inform the public of the consequences of ignoring government prohibitions but did not explicitly force compliance. When noncompliance has serious consequences for the community, the message may be delivered as a directive. All community members obey or risk serious punishment. People may make their own decisions based on the facts, so behavioral nudging stands a chance of being implemented. Public proclamation has the potential to be more successful than NGOs or governments presenting a single agenda not adapted to cultural constraints. People in the community know and have developed trust to their leaders, speak the same language, and share much in common, so nudging becomes easier than from strangers. This form of nudging is important in that leaders can measure compliance and determine if policies are accepted or not, with the results being readily apparent in the community.

Interactive Education: Demonstrative Interactive education refers to the process of educating individuals or communities on how to employ previously unused technologies. Examples include education on the use of mixed oxidation gas systems, ozone treatment, and other water purification technologies in the context of SSA. Therefore, this kind of education will impart device-use expertise [58-60]. Ordinarily in the western world, when individuals purchase simple equipment, they can read the instructions and follow, but where illiteracy is high, the situation becomes complex. Therefore, the education that may work in SSA, particularly in rural areas, is demonstrative education, in which specialists demonstrate to individuals how to use, maintain, and implement a product. Utilizing behavioral nudges in SSA is crucial, particularly for educating people on high-impact technologies that can result in more water disinfection improvement. Some members of the community with some sophistication can be trained first, and they will then show use of the technology concept to the rest of the community, a classic example of training the trainers [61-67]. Education will help both urban and rural residents, but rural residents will profit far more owing to the aforementioned factors.

Technology

Ozone: Worldwide access to improved water sources and basic sanitation remains elusive but an important long-term goal to many families in developing countries and rural SSA in particular [68]. The ozone germicidal ability for making water safer is not controversial. It has been saving lives since 1906 and remains steadfast in its effectiveness ever since then [69]. Even though it is well known, what is less well recognized is how behavioral nudges can be implemented using word of mouth. With all the benefits of ozone for making water safe, the dissemination in rural SSA has not been appreciable. This could be credited to the level of awareness of this technology, where to obtain it from, and basic information on the effectiveness of this product. While ozone can successfully disinfect water, it is not workable for majority in rural SSA due to its high cost, requirement for operational and maintenance setups**.** Thus, the question is how can this important technology be made available to the people of rural SSA and by what technique considering the region's cultural and institutional uniqueness? Behavioral nudging represents a credible, easy, and cheap alternative in providing information to people with the opportunity to make the selection or choice themselves. Because of the technical nature, cost involvement, and constant maintenance of ozone as a water treatment process, using anything other demonstrative education as medium of nudging the people will be ineffective.

Pasteurization: It is well known in the western world that the knowledge of water pasteurization presents incredible benefit in making unsafe water safe for the people [70]. This kind of water purification technique has been proven to be effective, requires no technical expertise, and can be done in variety of settings, urban and rural. Another added benefit is the fact that it does not change water tastes or color, which can be problematic in some culture. In spite the fact that it is well-known that pasteurization works, what is less apparent is how behavioral nudges can be implemented using word of mouth. Boiling water to make it safe for use is easy, requires no high tech or special equipment. Although it can be expensive due to fuel needed to boil the water. Behavioral nudging using word of mouth or public proclamation maybe the optimal approach in this regard so far as there is consideration to community's institutions and culture that will promote greater water disinfecting devices among the locals. This is because pasteurization requires no high technology or expertise.

Chlorination: One of the first reported uses of chlorine for water disinfection occurred in 1897 in Maidstone, Kent, UK [71]. This was in response to an outbreak of typhoid. Ever since, the use has steadily continued throughout the world. Chorine has been found to be one of the least expensive and effective disinfectants for neutralizing microorganisms and guarantee water safety [72]. Chlorine as water purification device ability to make water safe from domestic to industrial settings are well recognized. What is not well recognized is how behavioral nudges can be applied using the three message delivery methods to inform the people of rural SSA about the benefit of chlorination, as a water treatment device. Considering all these benefits, one would expect that the challenges of safe drinking water will have been solved, especially in SSA where they have persisted; however the problem there remains. From the policy standpoint, behavioral nudges through one of the three message delivery methods are worth considering to the extent they could shorten the time from policy implementation to safer drinking water and attendant better nutrition.

Filtration: Water filtration is one of the basic water disinfecting devices shown to work [73-76]. It has considerable flexibility in that it can be used in many settings- homes, schools, and industrial level, thus being compatible with rural SSA environment. It has other advantages such as using little raw material, energy, labor, cost and skill or expertise. These characteristics are important considering SSA income and other socio- economic conditions. Even though it is known, what is less well known is how behavioral nudges can be implemented using message delivery methods “word of mouth, public proclamation, and education”.

Mixed Oxidation: Mixed Oxidation Gases Systems (MOGGOD) as a water disinfectant procedure has been attributed to be effective in removing germs causing microorganisms that lead to human health problems of varying magnitudes [77,78]. It has however been noted to be expensive, financially challenging, requiring technical skills and education to operate and maintain.

What is less apparent is how behavioral nudging can be implemented to disseminate this vital technology to the residents of rural SSA where if adopted would create massive turnaround and gains in water and related food safety in the region.

Ultraviolet Filtration: UV drinking water disinfection has made an enormous progress in the last decade [79]. Globally ultraviolet (UV) disinfection is being increasingly known and used in drinking water treatment because of its ability to kill disease causing microorganisms [74,80,81]. Knowing UV disinfection ability to make water safer is well established, what is less well known is how behavioral nudges can be applied. Considering the characteristics and requirements of UV disinfection, word of mouth and public proclamation would be inadequate because of reasonable amount of technical expertise, maintenance, and electricity to operate UV effectively. UV treatment is reasonably competitive if access to technical infrastructure for maintenance is adequate [82].

Region

Central SSA: Central Africa is a region located in the center of the African continent and is home to a diverse range of cultures, languages, and landscapes. The region is home to several large countries, including the Democratic Republic of Congo, Angola, Cameroon, Equatorial Guinea, Sao Tome and Principe, and Chad, as well as smaller countries like the Central African Republic and Gabon. The region has a rural population of 179 million people with GPD of $216.48 billion [41,43]. Safe drinking water in the region is poor due to years of neglect, and dearth of investment in modern water treatment facilities [83].

Eastern SSA: Eastern Africa is a region situated on the eastern part of the African continent and is home to an assorted range of cultures, languages, and topographies. The region is home to several large and smaller countries, including Ethiopia, Tanzania, Kenya, Uganda, Mozambique, Madagascar, Malawi, Zambia, Zimbabwe, South Sudan, Rwanda, Burundi, Somalia, Eritrea, Mauritius, Djibouti, Reunion, Comoros, Mayotte, and Seychelles. It has the largest headcount of 445 million in the continent, with a GPD of 442.79 billion [41]. Central Africa water safety challenges ranges from drought, climate change, and general lack of investment in water infrastructure [84,85].

Southern SSA: Southern Africa is a region located in the southern part of the African continent, comprising the countries of South Africa, Namibia, Botswana, Lesotho, and Swaziland. The region is known for its diverse geography, which includes savannas, grasslands, forests, mountains, and coastlines. It is home to a wide range of wildlife, including many species that are found nowhere else in the world. Southern Africa has a rich cultural heritage, with many different indigenous groups and languages. The region has a long history of trade and colonization, and its cultures have been shaped by interactions with European, Asian, and other African societies. It has the least population of 67 million with appreciable GDP $ 452.128 billion [43]. Southern Africa has serious water issues ranging from severe drought, water financing, and general management of water infrastructure [86-88].

Western SSA: West Africa is a region located in the western part of the African continent, comprising the countries of Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo. West Africa is known for its diverse cultures, languages, and histories. The geography of West Africa is varied, with landscapes ranging from desert to rainforest. The region is home to a wide range of wildlife, including many species that are found nowhere else in the world. West Africa’s economy is diverse, with industries ranging from agriculture and mining to manufacturing and service sectors. It has the biggest GDP of $776.544 billion in SSA with a population of 401 million rural population [43,42]. The water crisis in the region is multifaceted, from drought, to flood, lack of sufficient investment in water safety, and lot of other issues in that regard [89-93].

Model: Capacity to Pay by Technology and Information Delivery Institution

The model aim is to present each region’s capacity to pay and capacity to pay per capita subject to the available knowledge of water disinfecting technologies by the people. This calculation was based on VSL, this is based on the net benefit, which is the probability of adoption by region, technologies, and message delivery method, divided by the population. Capacity to pay per capita was derived by capacity to pay divided by population.

Benefit(r,i,t) = prob(r,i,t) * VSL(r) * population(r);

Where

r = region in rural SSA

i = intervention method

t = water purification technology

Benefit per capita(t,r,i) = Benefit(t,r,i) / population_p(r);

Generally speaking, per capita capacity to pay is derived from VSL divided by the population. This calculation entails what households or individuals' willingness or capacity to pay is. Terms are

t = water purification technology

r = region in rural SSA

i = intervention method

RESULTS

Overview

Results summarizing the data we used to drive our results appear in Table 1. Shown are the data we used on value of statistical life (VSL), population, and probability of adoption by regions. The most important data sources are [40,42,38]. These data are important because, as described in Methods of Analysis, they are used to calculate per capita capacity to pay for water purification methods by technology, region, and information delivery method. Results shown in Table 2 that come from the data and model we used reveal several overarching messages. It shows that capacity to pay for access to safe drinking water by technology, region, and information delivery method, was positive for all regions in Rural Sub-Saharan Africa [94]. One core message with important policy implications is that all regions in the rural SSA are calculated to have a considerable capacity to pay for SDW, both for totals and for per capita levels. This remarkable result was found to occur despite the fact that rural SSA rarely expresses a sizeable willingness to pay for the technology when presented with an opportunity to improve their access to SDW [95]. The table also shows the capacity to pay in terms of income gained for improved water services that varies among the four regions of rural SSA, indicating that any policy intervention to be successful needs to be tailored to the characteristics of the target region's population. These results suggest an important message that when the information on safe drinking water technologies is presented to the rural villagers using the right behavioral nudging mechanisms, the outcome has the potential to promote widespread diffusion of these technologies and provide notable health improvements.

Nevertheless, an important question tempers these sanguine discoveries: if the people of the four regions presented show a positive capacity to pay as shown in Table 2, why do such low levels of access to safe drinking water persist in these regions? The answers may lie on the value that people placed on their own lives and / or their perceived capacity to influence or adjust that value through systematic choices [43,94,96-99]. As many from the west who have travelled to this part of the world have observed, rural villagers in SSA commonly believe their lives are influenced by many factors beyond their own control. Despite the fact that our results show an unexpectedly high capacity to pay for most technologies and information delivery methods in all regions of rural SSA, the typical rural villager sees poor drinking water as one of many forces outside their control, for which investments are rarely made in all or even most of those elements that reduce mortality or morbidity. Investments in safe drinking water simply are one of many stressors on daily life, and unlikely to be highest in their order of priority [100,101].

Many in rural SSA see water as a public good for which improvements are not their responsibility, for which they have little to no obligation to make the requisite investment. Perceiving water as a public good can affect an individual's willingness to pay for improved access. It has been well-established in the water economic literature that a public good is a resource of value that is non-excludable and non-rivalrous, for which it is available to all members of a society and one person's consumption of the resource does not diminish its availability to others [102], [103]. See in this light, many villagers in rural SSA believe they have no moral or legal obligation to pay for water because they believe its responsibility of supply and delivery rests with the government to provide it as a basic human right. Alternatively, an individual may reveal a willingness to pay for methods to improve access to SDW but may believe it is not their personal responsibility to do so and, for which the burden is properly shared by the larger society [101,102,104,105].

Our results show outcomes for four regions in rural SSA: Central, Eastern, Southern, and Western regions. Each of the regions has a unique value of statistical life (VSL) shown in table 1, that is reflected in the productivity of labor in contributing to gross domestic product (GDP) [38,40,41]. The VSL is a measure used in economics to quantify the value of measures that reduce the risk of death. It is often used to assess the cost-effectiveness of public policies intended to reduce the risk of death, such as investments in transportation infrastructure or health interventions. There are several reasons why the value of a statistical life may be low as well as showing variability across our four regions of rural SSA. These include differences in economic development, cultural values, and societal preferences. For example, the wealthiest region in SSA is West Africa with a GDP of Africa $US 777 (2021) [40]. In general, VSL tends to be higher in countries with higher levels of economic development and income earning capacity [106,107], as people in these countries reveal a greater capacity to pay for measures that reduce the risk of death or injury. This occurs because labor has a greater productivity to generate income, giving rise to a greater implied willingness to pay to reduce the risk of death.

Cultural values and preferences can also play a role in determining the VSL. For example, some societies may place a higher value on the lives of their citizens than others because of income elasticity's vary across rich and poor countries [106,107]. Additionally, individual preferences for risk and the level of risk tolerance within a society can affect the value of a statistical life. It is important to note that the VSL is a complex and many-layered concept, and ongoing debate remains among economists about how it should be calculated and used to inform policy debates.

Table 2's column summarizes the capacity to pay per capita to for SDW by technology, region, and information delivery method, for which the methods used for its calculations are identical for all technologies, regions, and delivery methods in SSA. Increases in GDP increases the capacity to pay, for example West Africa with the highest sub-regional GDP has the highest capacity to pay per capita for all information delivery methods and for all technologies (Table 2).

By Technology

The capacity to pay for the various point-of-uses (POU) technologies varies based on complexity of the technology. Table 1 shows that POU technologies such as ozone, mixed oxidation, and ultraviolet filtration, which are complex in applications, have a lower probability of being adopted through word of mouth or public proclamation. However, these technologies do have a more significant probability of being adopted through education. Complexity of a water purification technology in this part of the world can be a major factor in its adoption. If a technology is too complex, it may be difficult for people who are already pre-occupied, weakly-educated, superstitious, and time stressed, to understand and use it, which can make it less appealing [108-110]. This can be especially true if the technology requires a significant amount of training or has a steep learning curve. On the other hand, if a technology is easy to use and understand, it may be more likely to be adopted using word of mouth, even if it is not the most advanced or feature-rich option. Tables 1 and 2 show that for the Central region for example, ozone with probability of adoption of 25% for education has a $US 212,500 capacity to pay per capita and a $US 170,000 capacity to pay per capita for word of mouth and a $US 170,000 capacity to pay per capita for public proclamation.

The consistency of this result was further strengthened when evaluated with simpler POU technologies: pasteurization, chlorination, and filtration. Table 1 shows a higher probability for word of mouth and public proclamation, with a correspondingly lower probability for education. The reduction in the probability of education for pasteurization, chlorination, and filtration show that these technologies are simple enough that anything other than word of mouth and public proclamation add comparatively little incremental capacity to pay for this approach. The probabilities and value of statistical life (VSL) were used in this analysis were obtained from IMF, UN, and other sources described in the references [38,40,42]. A significant question challenging the capacity to pay to inform technologies adoption centers on what method of behavioral nudging approach is viable for the people of the region to accept these technologies while considering capacity to pay.

By Region

Rural populations in each of the four SSA regions differ considerably. Central Africa has a rural population of 179 million, while Eastern Africa has a rural population of 445 million, Southern Africa, 67 million, and Western Africa, 401 million. As shown in Table 1, VSL varies greatly among these regions too. While the entire regions under review have positive capacity to pay per capita for water purification measures as shown in Table 2. The Eastern and Western, the two most populous regions, also have the highest capacity to pay per capita. Total regional capacity to pay for access to safe drinking water can be calculated by multiplying per capita capacity by population. Table 1 and 2 taken together also show that regions with the lowest per capita capacity to pay tend to have lower adoption of basic water purifying technologies. Another important observation seen in Table 1 is that the four regions followed the same pattern of having higher probabilities of technology adoption with less complicated technologies such as filtration, chlorination, and pasteurization.

It is worth noting that the regions with higher capacity to pay and capacity to pay per capita equally have higher GDP seen, as shown in Table 3. Central Africa with the smallest VSL and least improved water has the lowest capacity to pay per capita among our four study regions.

By Information Delivery Method

Table 1 illustrates the effectiveness of three different behavioral nudging approaches in terms of probabilities of adoption in promoting the adoption of various point-of-use (POU) technologies for safe drinking water in rural Sub-Saharan Africa (SSA). The data in this table suggest that the use of word of mouth is the most effective method for inducing the adoption of basic POU technologies, especially filtration. This suggests that word of mouth through social influence and peer recommendations may be particularly effective in encouraging the adoption of these technologies in rural SSA. In terms of hierarchy or stratifications of probabilities of adoptions based on which medium that are being espoused, word of mouth and public proclamation indicated likelihoods of been adopted especially with basic POU and the more convoluted the technology, the more the likelihood of education been better choice, all of which are seen in Table 1.

DISCUSSION

Significance

The importance of this work comes from discovering the potential power of unlocking and implementing behavioral nudging to improve access to safe drinking water in rural Sub-Saharan Africa.

It examines methods to implement behavioral nudging strategies that align with the cultural and institutional features of rural Sub-Saharan Africa and has the potential to increase the use of water disinfection technologies in these regions. By focusing

Table 3: Sub-Saharan Africa Sub-Saharan Africa Subregional GDP 2020, 2021.					
Region	**GDP (Nominal) ($US billions) 2020**	**GDP (Nominal) ($US billions) 2021**	**GDP (Nominal) ($US billions) Net change**	**Share (%) Africa**	**Share (%) World**
04_Western_SSA	695.903	776.544	80.641	28.84	0.82
03_Southern_SSA	367.098	452.128	85.03	16.79	0.48
02_Eastern_SSA	419.041	442.79	23.749	16.44	0.47
01_Central_SSA	186.389	216.48	30.091	8.04	0.23

Source: Data adapted from IMF (Original tables contain each sub regional GDP, (41), (43)).

on local institutions and cultural barriers to adopting known technologies for providing safe drinking water at comparatively low cost, this work contributes to a better understanding of the issue and potential methods to address it.

Paradoxes Revealed

Remarkably, results of this work produced several notable and, to us, unexpected results in connection with our measured large economic capacity to pay per capita for access to safe drinking water in rural SSA. These unexpected results are tied to (1) access to information, (2) value of a statistical life, and (3) the role of safe drinking water as a contributor to GDP. Each is discussed.

Weak Access to Information: One reason that the capacity to pay per capita for access to SDW so high comes from the fact that few rural residents know of those opportunities to improve their lives at a low cost, so these high-valued opportunities to reduce morbidity mortality go unused, i.e., are scarce. Access to information remains a big problem in many parts of rural SSA [111,112]. Many in these rural areas have little to no access to the internet or other forms of modern communication, making it difficult for them to access information and stay informed about low-cost opportunities to protect or improve their health. In addition, low levels of literacy and a lack of educational attainment or resources often makes it hard for rural villagers to access and understand information even if available. As a result, many in rural SSA lack access to important information that could help improve their lives through better access to SDW. While this work presents six water disinfection technologies, information about their accessibility or affordability is typically lacking to rural villagers in SSA. In addition, even when disinfection technologies are used, it is not always possible to remove all contaminants from water, especially if the source water is heavily polluted. Furthermore, the infrastructure and resources needed to maintain and operate these technologies can be expensive and difficult to implement in some areas, particularly in underdeveloped communities. As a result, unsafe water remains still a problem in these for regions of SSA.

Low Implied Value of a Statistical Life: Another reason for the very high capacity to pay for SDW per capita in this part of the world has to do with the measured versus locally perceived value of a statistical life (VSL). The VSL is often used as a measure of the economic value of reducing mortality rates [113-116]. Despite its objectivity, the measured VSL may not accurately reflect the perceived value of safe drinking water in increasing statistical lives to those who would adapt those technologies living in rural Sub-Saharan Africa. VSL is based on estimates of how much people are willing to pay to reduce their risk of death. Yet these estimates may not accurately capture the value that people place on safe drinking water in rural areas. The rural SSA community typically spends little time thinking about impacts of small investments for better drinking water on the value of reduced mortality in light of the many competing demands on their time and in light of the limited perceived control people believe they have on the additional length, additional productivity, or additional quality of their lives these investments could secure. People make rational decisions based on the resources available to them and the value of those resources in improving their welfare. Despite the importance of economic rationality in the western scientific world, the notion of rationality is complex and can be interpreted in different ways in different cultures [117]. In most places, people try to make choices that they believe will maximize their chances of achieving their goals and meeting their needs with their available resources. However, their choices may be influenced by a variety of factors, such as their beliefs, educational and life history, and information and resources available to them. As a result, what one inhabitant of the western world considers a rational choice may not reflect rationality in a culture where there are few opportunities to define, implement, or assess rational choices that could be made.

Safe Drinking Water Connections to GDP: The role of safe drinking water as a contributor to GDP is often overlooked but is an important factor in the overall economic health of a community [118,120]. Access to safe drinking water can improve health outcomes and increase productivity, leading to economic growth and development. This can have a positive impact on the overall economic capacity of a region to pay per capita for access to safe drinking water.

Our results show a larger-than anticipated capacity per capita to pay for safer drinking water. Improving access to safe drinking water can have a positive impact on the gross domestic product (GDP), which is the total value of goods and services produced by the community in a given year. For example, providing safe drinking water can improve public health and reduce the incidence of waterborne diseases, increase school and labor participations which can lower healthcare costs and increase productivity [121]. Furthermore, the fruits of investments in water infrastructure can create income and production. Overall, improving access to safe drinking water can have many positive economic benefits for a country that are often not measured in the minds of those who would make investments in SDW.

Limitations and Future Research Needs

One limitation of this study is dearth of peer reviewed work on probabilities of adoption [122,123] as well as culture and institutions that are different from majority of places around the world and data in rural SSA. This may have limited our ability to generalize the findings to other cultures, regions, and places. This work includes data and references from a single geographic region, which may not be representative of the broader international population. These limitations may have affected the generalizability of the study's results and conclusions. In order to overcome these limitations and provide more robust findings, future research should include a larger and more diverse population from across different developing countries from multiple geographic regions. This would allow for more generalizable results and greater confidence in the conclusions drawn from the study.

To overcome these limitations and provide more robust findings, it is important for future work to include a wider range of sources, including peer-reviewed studies, and to consider a more diverse set of regions and cultural contexts. This would provide a more comprehensive and generalizable understanding of the issue and potential solutions. Additionally, involving experts from different regions and cultural backgrounds in the research process could also help to ensure that the findings are relevant and applicable to a wider range of contexts.

CONCLUSIONS

Rural communities and governments in poor nations, especially Sub-Saharan Africa (SSA), struggle to get clean water. Since 2000, governments, NGOs, and politicians have worked to make at least 600 million rural SSA residents' drinking water safe, yet morbidity and death remain high. In the last 20 years, western researchers have developed practical and economically viable solutions to make safe drinking water a reality, including behavioral nudging. Despite these successes, limited research has proven how behavioral nudging may be used in rural SSA to promote technology adoption while respecting local culture. Policymakers, NGOs, and multilaterals execute ill-informed policies. These organizations often propose water program solutions without considering local history, culture, or needs. This article investigates behavioral nudging methods that show consistency with rural SSA's cultural and institutional features to increase water disinfection technology adoption. Word of mouth, public proclamation, and education impacts on individual and community adoption of fundamental POU technologies were used to implement this contribution in rural SSA. Results show that current practices and rules may be overcome to promote safe drinking water availability. Three fundamental behaviors fit local culture and institutions. Word of mouth, public declaration, and education may help rural SSA embrace clean water technology. This work addresses rural SSA's clean drinking water crisis. While presented for rural Sub-Saharan Africa, the strategy and conclusions are adaptable and generalizable. Sociology, anthropology, psychology, and cultural studies can determine how cultural and institutional ties might be used to supply clean drinking water to rural SSA.

REFERENCES

1. Kotopoulou S, Zampelas A, Magriplis E. Dietary nitrate and nitrite and human health: a narrative review by intake source. Nutr Rev. 2022; 80: 762-73.
2. Parvizishad M, Dalvand A, Mahvi AH, Goodarzi F. A Review of Adverse Effects and Benefits of Nitrate and Nitrite in Drinking Water and Food on Human Health. Health Scope. 2017; 6: e14164.
3. Powlson DS, Addisott TM, Benjamin N, Cassman KG, de Kok TM, van Grinsven H, et al. When does nitrate become a risk for humans?. J Environ Qual. 2008; 37: 291-5.
4. UNDESA. Revision of World Urbanization Prospects. Multimedia Library - United Nations Department of Economic and Social Affairs. 2018.
5. Suthar S. Contaminated drinking water and rural health perspectives in Rajasthan, India: an overview of recent case studies. Environ Monit Assess. 2011; 173: 837-49.
6. United Nations Children's Fund, Organization WH. Progress on household drinking water, sanitation and hygiene 2000-2017 Special focus on inequalities. 2019. 138 p.
7. Centers for Disease Control and Prevention. Household Water Treatment. 2022.
8. Hope R, Thomson P, Koehler J, Foster T. Rethinking the economics of rural water in Africa. Oxf Rev Econ Policy. 2020; 36: 171-90.
9. Balmford A, Bradbury RB, Bauer JM, Broad S, Burgess G, Burgman M, et al. Making more effective use of human behavioural science in conservation interventions. Biol Conserv. 2021; 261: 109256.
10. Kwan YH, Cheng TY, Yoon S, Ho LYC, Huang CW, Chew EH, et al. A systematic review of nudge theories and strategies used to influence adult health behaviour and outcome in diabetes management. Diabetes Metab. 2020; 46: 450-60.
11. Lakerveld J, Mackenbach JD, de Boer F, Brandhorst B, Broerse JEW, de Bruijn GJ, et al. Improving cardiometabolic health through nudging dietary behaviours and physical activity in low SES adults: design of the Supreme Nudge project. Bmc Public Health. 2018; 18: 9.
12. Lamprell K, Tran Y, Arnolda G, Braithwaite J. Nudging clinicians: A systematic scoping review of the literature. Journal of Evaluation in Clinical Practice. 2021; 27: 175-92.
13. Vlaev I, King D, Dolan P, Darzi A. The Theory and Practice of "Nudging": Changing Health Behaviors. Public Administration Review. 2016; 76: 550-61.
14. Akpabio EM. Water meanings, sanitation practices and hygiene behaviours in the cultural mirror: a perspective from Nigeria. J Water Sanit Hyg Dev. 2012; 2: 168-81.
15. Akpabio EM, Takara K. Understanding and confronting cultural complexities characterizing water, sanitation and hygiene in Sub-Saharan Africa. 2014; 39: 921-32.
16. Emenike CP, Tenebe IT, Omole DO, Ngene BU, Oniemayin BI, Maxwell O, et al. Accessing safe drinking water in sub-Saharan Africa: Issues and challenges in South–West Nigeria. Sustain Cities Soc. 2017; 30: 263-72.
17. Disinfection Efficacy Studies wWith Electrochemically Generated Mixed Oxidants in the Development of CT vValues for Drinking Water Pathogens. Grantee Research Project. US EPA. 1998.
18. Grebitus C, Roscoe RD, Van Loo EJ, Kula I. Sustainable bottled water: How nudging and Internet Search affect consumers' choices. Journal of Cleaner Production. 2020; 267:121930.

19. Peal AJ, Evans BE, van der Voorden C. Hygiene and Sanitation Software: An Overview of Approaches. 2010.

20. Huber AC, Mosler HJ. Determining behavioral factors for interventions to increase safe water consumption: a cross-sectional field study in rural Ethiopia. 2013; 23: 96-107.

21. Anderson BA, Romani JH, Phillips H, Wentzel M, Tlabela K. Exploring environmental perceptions, behaviors and awareness: water and water pollution in South Africa. Popul Environ. 2007; 28: 133-61.

22. Agarwal S, Araral E, Fan M, Qin Y, Zheng H. Plumbing vs Nudging : The Lasting Effect of Efficiency Improvements on Water Conservation. 2021.

23. Mulenga E, Amukugo HJ, Shilunga AP. The experiences of mothers and caregivers on feeding practices of children under the age of five years with undernutrition in Oshikoto region, Namibia. 2018.

24. Layman J. A histomorphometric study of the effect of Afriplex GRT (TM) on the pancreas, liver and kidney of rats fed a high-fat diet. Stellenbosch University. 2018.

25. Mulenga E, Amukugo HJ, Shilunga AP. The experiences of mothers and caregivers on feeding practices of children under the age of five years with undernutrition in Oshikoto region, Namibia. 2018; 4.

26. Foster T, Brozović N, Butler AP. Analysis of the impacts of well yield and groundwater depth on irrigated agriculture. J Hydrol. 2015; 523: 86-96.

27. Massoud MA, Tarhini A, Nasr JA. Decentralized approaches to wastewater treatment and management: Applicability in developing countries. J Environ Manage. 2009; 90: 652-9.

28. The role of institutions in society. psawa. 2008.

29. Qin HP, Su Q, Khu ST, Tang N. Water Quality Changes during Rapid Urbanization in the Shenzhen River Catchment: An Integrated View of Socio-Economic and Infrastructure Development. Sustain. 2014; 6: 7433-51.

30. Schueler TR. Microbes and Urban Watersheds: Concentrations, Sources, and Pathways. Watershed Prot Tech. 1999; 3: 1-12.

31. Wang D, Hubacek K, Shan Y, Gerbens-Leenes W, Liu J. A review of water stress and water footprint accounting. Water. 2021; 13: 201.

32. Wang H, Wang T, Zhang B, Li F, Toure B, Omosa I, et al. Water and Wastewater Treatment in Africa - Current Practices and Challenges. Soil, Air, Water 2014; 42: 1029–1035.

33. Belyanin AV. Richard Thaler and behavioral economics: From the lab experiments to the practice of nudging (Nobel Memorial Prize in Economic Sciences 2017). Vopr Ekon. 2018; 5-25.

34. Burgess A. 'Nudging' Healthy Lifestyles: The UK Experiments with the Behavioural Alternative to Regulation and the Market. Eur J Risk Regul. 2012; 3: 3-16.

35. Lindenberg S, Papies EK. Two Kinds of Nudging and the Power of Cues: Shifting Salience of Alternatives and Shifting Salience of Goals. Int Rev Environ Resour Econ. 2019; 13: 229-263.

36. Soon J, Traeger AC, Elshaug AG, Cvejic E, Maher CG, Doust JA, et al. Effect of two behavioural 'nudging' interventions on management decisions for low back pain: a randomised vignette-based study in general practitioners. Bmj Qual Saf. 2019; 28: 547-55.

37. Yadav K, Meeker D, Mistry RD, Doctor JN, Fleming-Dutra KE, Fleischman RJ, et al. A Multifaceted Intervention Improves Prescribing for Acute Respiratory Infection for Adults and Children in Emergency Department and Urgent Care Settings. Acad Emerg Med. 2019; 26: 719-731.

38. Viscusi WK, Aldy JE. The value of a statistical life: A critical review of market estimates throughout the world. J Risk Uncertain. 2003; 27: 5-76.

39. Aldy JE, Viscusi WK. Age Differences in the Value of Statistical Life: Revealed Preference Evidence. Rev Environ Econ Policy. 2007; 1: 241-60.

40. Viscusi WK. Economic lessons for COVID-19 pandemic policies. Southern Econ J. 2021; 87: 1064-89.

41. Department of Economic and Social Affairs: United Nations. 2021.

42. Department of Economic and Social Affairs Population Division. United Nations. 2022.

43. World Economic Outlook Database. INTERNATIONAL MONETARY FUND. 2021.

44. de Jalon SG, Silvestri S, Barnes AP. The potential for adoption of climate smart agricultural practices in Sub-Saharan livestock systems. Reg Environ Change. 2017; 17: 399-410.

45. Zampaligre N, Fuchs LE. Determinants of Adoption of Multiple Climate-Smart Adaptation Practices in Sudano-Sahelian Pastoral and Agro-Pastoral Production Systems. Sustain. 2019; 11: 15.

46. Whittington D, Jeuland M, Barker K, Yuen Y. Setting Priorities, Targeting Subsidies among Water, Sanitation, and Preventive Health Interventions in Developing Countries. World Dev. 2012; 40: 1546-68.

47. Abdulai A, Huffman W. The Adoption and Impact of Soil and Water Conservation Technology: An Endogenous Switching Regression Application. Land Econ. 2014; 90: 26-43.

48. Abdulai A, Owusu V, Bakang JEA. Adoption of safer irrigation technologies and cropping patterns: Evidence from Southern Ghana. Ecol Econ. 2011; 70: 1415-23.

49. Anley Y, Bogale A, Haile-Gabriel A. Adoption decision and use intensity of soil and water conservation measures by smallholder subsistence farmers in Dedo District, Western Ethiopia. Land Degrad Dev. 2007; 18: 289-302.

50. Baidu-Forson J. Factors influencing adoption of land-enhancing technology in the Sahel: lessons from a case study in Niger. Agric Econ. 1999; 20: 231-239.

51. Kassie M, Jaleta M, Shiferaw B, Mmbando F, Mekuria M. Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. Technol Forecast Soc Chang. 2013; 80: 525-40.

52. McGuigan KG, Conroy RM, Mosler HJ, du Preez M, Ubomba-Jaswa E, Fernandez-Ibanez P. Solar water disinfection (SODIS): A review from bench-top to roof-top. J Hazard Mater. 2012; 235-236: 29-46.

53. Ndiritu S, Kassie M, Shiferaw B. Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. Food Policy. 2014; 49: 117-27.

54. Ngwira A, Johnsen FH, Aune JB, Mekuria M, Thierfelder C. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. J Soil Water Conserv. 2014; 69: 107-19.

55. Theis S, Lefore N, Meinzen-Dick R, Bryan E. What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. Agric Human Values. 2018; 35: 671-84.

56. Mason RB. Word of mouth as a promotional tool for turbulent markets. J Mark Commun.2008; 14: 207-224.

57. Zimu-Biyela N. Information Needs of Women Subsistence Farmers in the Dlangubo Village, South Africa. Libri. 2021;71: 361-373.

58. Mbele J. The Elder in African Society. J Intergenerational Relatsh. 2004; 2: 53-61.

59. Damgaard MT, Nielsen HS. Nudging in education. Econ Educ Rev. 2018; 64: 313-42.

60. Munamati M, Nhapi I, Misi S. Exploring the determinants of sanitation success in Sub-Saharan Africa. Water Res. 2016; 103: 435-43.

61. Corbett MC, Mathenge W, Zondervan M, Astbury N. Cascading training the trainers in ophthalmology across Eastern, Central and Southern Africa. Glob Health. 2017; 13: 46.

62. Esau N, English R, Shung-King M. An assessment of a 'training-of-trainers programme for clinic committees' in a South African district: a qualitative exploratory study. Bmc Health Serv Res. 2020; 20: 1101.

63. Harris P, Juga E, Bay N, Adams C, Nhatitima P, Mastala A, et al. Empowering Frontline Primary Healthcare Workers in a Global Health Partnership Training of Trainers Intervention to Strengthen the Prevention and Control of Cardiovascular Disease in Mozambique. Glob Heart. 2022; 17: 51.

64. Kiptot E, Karuhanga M, Franzel S, Nzigamasabo PB. Volunteer farmer-trainer motivations in East Africa: practical implications for enhancing farmer-to-farmer extension. Int J Agric Sustain. 2016; 14: 339-56.

65. Majee W, Frantz J, Rhoda A, Schopp L. Take time to listen: community health worker perceptions on self-management trainer role. J Community Pract. 2022; 30: 3-19.

66. Van der Merwe J, Sloman M. Training the trainer - lessons from the new South Africa. High Educ Ski Work-based Learn. 2014; 4: 17-30.

67. Wheaton W, Alumai F, Onyango G. Training of trainers on mental health and psychosocial support in emergencies, Africa. Intervention. 2008; 6: 298-303.

68. Thompson T, Sobsey M, Bartram J. Providing clean water, keeping water clean: an integrated approach. Int J Environ Health Res. 2003; 13: S89-S94.

69. Rice RG, Robson CM, Miller GW, Hill AG. Uses of ozone in drinking water treatment. J Am WATER Work Assoc. 1981; 73: 44-57.

70. Abraham JP, Plourde BD, Minkowycz WJ. Continuous flow solar thermal pasteurization of drinking water: Methods, devices, microbiology, and analysis. Renew Energy. 2015; 81: 795-803.

71. Evans RB. Chlorine: State of the art. Lung. 2005; 183: 151-67.

72. Mazhar MA, Khan NA, Ahmed S, Khan AH, Hussain A, Rahisuddin, et al. Chlorination disinfection by-products in municipal drinking water – A review. J Clea Prod. 2020; 273: 123159.

73. Ehdaie B, Rento CT, Son V, Turner SS, Samie A, Dillingham RA, et al. Evaluation of a silver-embedded ceramic tablet as a primary and secondary point-ofuse water purification technology in Limpopo Province, S. Africa. PLoS One. 2017; 12: e0169502.

74. Gadgil A. Drinking-water. 1998.

75. Ndebele N, Edokpayi JN, Odiyo JO, Smith JA. Field investigation and economic benefit of a novel method of silver application to ceramic water filters for point-of-use water treatment in low-income settings. Water. 2021; 13.

76. Simonis JJ, Basson AK. Manufacturing a low-cost ceramic water filter and filter system for the elimination of common pathogenic bacteria. Phys Chem Earth. 2012; 50: 269-76.

77. Block SS. Disinfection, Sterilization, and Preservation. Google Books. 2005.

78. Braun MK. Performance Evaluation of a Drinking Water Treatment Plant in Samaipata, Bolivia. 2019.

79. Sommer R, Cabaj A, Hirschmann G, Haider T. Disinfection of Drinking Water by UV Irradiation: Basic Principles - Specific Requirements - International Implementations. Ozone: Sci Eng. 2008; 30: 43-8.

80. Gora SL, Liang R, Zhou YN, Andrews SA. Photocatalysis with easily recoverable linear engineered TiO2 nanomaterials to prevent the formation of disinfection byproducts in drinking water. J Environ Chem Eng. 2018; 6: 197: 207.

81. McGuigan KG, Conroy RM, Mosler HJ, du Preez M, Ubomba-Jaswa E, Fernandez-Ibañez P. Solar water disinfection (SODIS): A review from bench-top to roof-top. J Hazard Mater.2012; 235-236: 29-46.

82. Burch JD, Thomas KE. Water disinfection for developing countries and potential for solar thermal pasteurization. Sol Energy. 1998; 64: 87-97.

83. Fonjong L, Fokum V. Water Crisis and Options for Effective Water Provision in Urban and Peri-Urban Areas in Cameroon. Soc Nat Resour. 2017; 30: 488-505.

84. Oki T, Quiocho RE. Economically challenged and water scarce: identification of global populations most vulnerable to water crises. Int J Water Resour Dev. 2020; 36: 416-428.

85. Ahmed SA, Florez MG, Karanis P. The impact of water crises and climate changes on the transmission of protozoan parasites in Africa. Pathog Glob Health. 2018;112(6):281-93.

86. Ziervogel G, New M, Liu W. Making Cities Water-Wise And Climate-Resilient - Lessons And Experience From The Cape Town Drought. Landscape Architecture Frontiers. 2019; 7: 94-9.

87. Rodina L. Water resilience lessons from Cape Town's water crisis. Wiley Interdiscip Rev Water. 2019; 6: e1376.

88. Millington N, Scheba S. Day Zero and The Infrastructures of Climate Change: Water Governance, Inequality, and Infrastructural Politics in Cape Town's Water Crisis. Int J Urban Reg Res. 2021; 45: 116-32.

89. Besada H, Werner K. An assessment of the effects of Africa's water crisis on food security and management. Int J Water Resour Dev. 2015; 31: 120-33.

90. Ahaneku IE. Conservation of soil and water resources for combating food crisis in Nigeria. Sci Res Essays. 2010; 5: 507-13.

91. Aliyu AA, Amadu L. Urbanization, Cities, and Health: The Challenges to Nigeria - A Review. Ann Afr Med. 2017; 16: 149-58.

92. Ezugwu C, Onyelowe K, Ezugwu C, Onyekweredike K, Odumade A, Omunakwe O, et al. Community Water Demand and Sustainable Water Supply Planning in Nigeria: A Review. Jurnal Kejuruteraan. 2021; 33: 517-30.

93. Shiru MS, Shahid S, Shiru S, Chung ES, Alias N, Ahmed K, et al. Challenges in water resources of Lagos mega city of Nigeria in the context of climate change. J Water Clim Chang. 2020; 11: 1067-83.

94. Raje DV, Dhobe PS, Deshpande AW. Consumer's willingness to pay more for municipal supplied water: a case study. Ecol Econ. 2002; 42: 391-400.

95. Hope R, Ballon P. Global water policy and local payment choices in rural Africa. Npj Clean Water. 2019; 2.

96. Somanathan E. Effects of Information on Environmental Quality in Developing Countries. Rev Environ Econ Policy. 2010; 4: 275-92.

97. Haddad M. Social, Religious, and Cultural Influences on the Sustainability of Water and Its Use. In: Leal Filho W, Sümer V, eds. Sustainable Water Use and Management: Examples of New Approaches and Perspectives. Springer International Publishing. 2015; 359-81.

98. Diendere A, Nguyen G, Del Corso JP, Kephaliacos C. Modeling the Relationship Between Pesticide Use and Farmers' Beliefs about Water Pollution in Burkina Faso. Ecologica Econ. 2018; 151: 114-21.

99. Alonso EB, Cockx L, Swinnen J. Culture and food security. Glob Food Sec. 2018; 17: 113-27.

100. Ahmed MA, Abimbola IO, Lukman Y, Abdulsalam BA. Superstitious Beliefs Held By the People of Ilorin, Kwara State, Nigeria. KIU J Soc Sci. 2018; 4: 127-133.

101. Oestigaard T. Holy water: the works of water in defining and understanding holiness. Wiley Interdiscip Rev Water. 2017; 4: e1205.

102. Booth D. Towards a Theory of Local Governance and Public Goods Provision. Ids Bull. 2011; 42: 11-21.

103. Morrell K. Governance and the Public Good. Public Adm. 2009; 87: 538-56.

104. Miguel E, Gugerty MK. Ethnic diversity, social sanctions, and public goods in Kenya. J Public Econ. 2005; 89: 2325-2368.

105. Van de kragt AJC, Orbell JM, Dawes RM. The Minimal Contributing Set as a Solution To Public-Goods Problems. Am Political Sci Rev. 1983; 77: 112-22.

106. Hammitt JK, Robinson LA. The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations. J Benefit-Cost Anal. 2011; 2: 28.

107. Hammitt JK. Extrapolating the Value Per Statistical Life Between Populations: Theoretical Implications. J Benefit-Cost Anal. 2017; 8: 215-225.

108. Venkatesh V, Morris MG, Davis GB, Davis FD. User acceptance of information technology: Toward a unified view. Mis Quarterly. 2003; 27: 425-78.

109. Stoneman P. The Diffusion of Innovations: Some Reflections. Int J Econ Bus. 2018; 25: 85-95.

110. Rogers EM. Diffusion of innovations. Glencoe. Ill: The Free Press of. 2003.

111. Kinyondo A, Pelizzo R, Asongu SA, Nwachukwu JC, Abel Kinyondo, Zim Kinyondo. Poor Quality of Data in Africa: What Are the Issues?. Polit Policy. 2018; 46: 851-77.

112. Pelizzo R, Kinyondo A. Public Accounts Committees in Eastern and Southern Africa: A Comparative An Polit Policy. 2014; 42: 77-102.

113. de Blaeij A, Florax R, Rietveld P, Verhoef E. The value of statistical life in road safety: a meta-analysis. Accid Anal Prev. 2003; 35: 973-86.

114. Dekker T, Brouwer R, Hofkes M, Moeltner K. The Effect of Risk Context on the Value of a Statistical Life: a Bayesian Meta-model. Environ Resource Econ. 2011; 49: 597-624.

115. Lindhjem H, Navrud S, Braathen NA, Biausque V. Valuing Mortality Risk Reductions from Environmental, Transport, and Health Policies: A Global Meta-Analysis of Stated Preference Studies. Risk Anal. 2011; 31: 1381-407.

116. Milligan C, Kopp A, Dandah S, Montufar J. Value of a statistical life in road safety: A benefit-transfer function with risk-analysis guidance based on developing country data. Accid Anal Prev. 2014;71:236-47.

117. Schwartz B, Ben-Haim Y, Dacso C. What Makes a Good Decision? Robust Satisficing as a Normative Standard of Rational Decision Making. J Theory Soc Behav. 2011; 41: 209-27.

118. Fukuda S, Noda K, Oki T. How global targets on drinking water were developed and achieved. Nat Sustain. 2019; 2: 429-34.

119. Lu Z, Bandara JS, Paramati SR. Impact of sanitation, safe drinking water and health expenditure on infant mortality rate in developing economies. Aus Econ Pap. 2020; 59: 13-33.

120. Meng XM, Tu LP, Yan C, Wu LF. Forecast of annual water consumption in 31 regions of China considering GDP and population. Sustain Prod Consum. 2021; 27: 713-36.

121. Hunter PR, MacDonald AM, Carter RC. Water Supply and Health. Plos Med. 2010; 7: e1000361.

122. Megnigbeto E. International collaboration in scientific publishing: the case of West Africa (2001-2010). Scientometrics. 2013; 96: 761-83.

123. Vieira ES. International research collaboration in Africa: a bibliometric and thematic analysis. Scientometrics. 2022; 127: 2747-72.