6-2-2016

Increasing Access to Potable Water: A Question of Economics and Governance in Bo District, Sierra Leone

Alissa M. Heiring
Lawrence University

Increasing Access to Potable Water: A Question of Economics and Governance in Bo District, Sierra Leone

ALISSA M. HEIRING

LAWRENCE UNIVERSITY, 2016

ACKNOWLEDGEMENTS

I would like to thank my advisor, Professor Finkler, for being an invaluable resource throughout this project, and for investing his time and energy into my work. I would also like to thank Professor Skran for sharing her personal knowledge of Sierra Leone with me, and for providing a unique perspective to this material. I would like to acknowledge Katherine Ling, who inspired me to pursue this project and has been a resource throughout the writing process.

I would not have been able to complete this project without the close eye and careful editing of Paul Heiring. I would also like to thank Alex Kurki for his assistance as a writing tutor.

Increasing Access to Potable Water: A Question of Governance and Economics in Bo District, Sierra Leone

Alissa Heiring

Advisor: Merton Finkler

May 2016

ABSTRACT

This paper analyzes existing supply gaps that are impeding rural water access in Bo District, Sierra Leone. On a national and district level, Sierra Leone has failed to meet the target of 70% access to potable water inspired by the United Nation's Millennium Development Goals. This paper focuses on Bo District due to its near total inclusion in the Sewa River basin and split urban and rural population. Given the existing political and economic constraints, this paper identifies the most feasible way to sustainably increase access to potable water in Bo. To develop the recommendations, current supply gaps in rural Bo District were quantified at the village level, and the economic viability of potential delivery systems were evaluated. A series of policy recommendations were evaluated that each balanced predicted cost with greatest need in different ways. Pricing structures are viewed as a vehicle to ensure system sustainability, making certain that progress made on MDG 7 is not undone when systems need to be replaced at the end of their lifetime.

Table of Contents

List of Tables

List of Figures

I. Overview

This paper addresses ways to improve access to potable water in the rural areas of Bo District, Sierra Leone. Sierra Leone is a country in West Africa, bordering Guinea and Liberia. There are four main sections of the country: The Western, Northern, Eastern, and Southern Areas.

Figure 1. *Map of Sierra Leone*[1]

In Sierra Leone, a district is equivalent to a state in the United States. There are thirteen districts in the country; the most densely populated is the Western Area which contains the capital of Freetown. Bo District is located in the Southern Area, near the center of Sierra Leone,

[1] "Sierra Leone Map," *MapsOpenSource*, accessed May 2, 2016, http://www.mapsopensource.com/sierra-leone-map.html.; Nick Redmayne, "Sierra Leone," *The Independent*, accessed May 2, 2016, http://www.independent.co.uk/travel/africa/how-tourism-can-help-sierra-leones-recovery-from-ebola-a6733131.html.

with a mountainous northern half and a marshy, lowland southern half. It is almost completely contained in the watershed drained by the Sewa River.

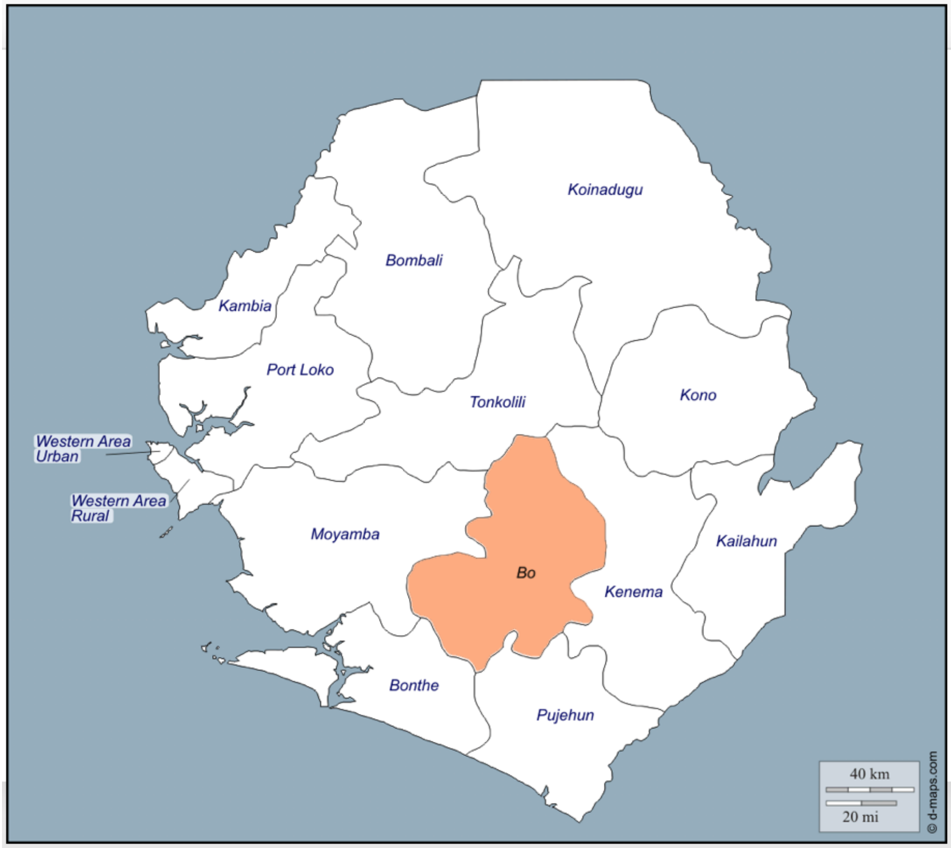


Figure 2. *District map of Sierra Leone highlighting Bo District.*[2]

Before addressing the details of water development in Bo District, it is important to briefly address the key role that potable water plays in a country's development, the ways in which water can be governed, and the different ways in which water can be valued. The historical background of Sierra Leone and its economy have a significant impact on both the current water problems identified in Bo District and the potential recommendations outlined in this paper.

[2] "Sierra Leone: Outline, districts, names," *D-Maps.com,* accessed May 3, 2016, http://d-maps.com/m/africa/sierra/sierra35.gif.

II. Potable Water and Development:

The international community has deemed potable water one of the critical components of successful development. International agreements such as the UN Millennium Development Goals (2000-2015) and the newly adopted UN Sustainable Development Goals (2015-2030) emphasize the need to prioritize increasing access to potable water in developing countries. The target set by the 7th MDG, which addressed access to potable water, was to reduce the access gap by 50 percent, and the 6th SDG has defined a target of 100 percent access to potable water.

Increasing access to potable water is one of the most effective ways to improve quality of life. It helps to prevent diseases spread by contamination, fatalities caused by dehydration and diarrhea, and infections from lack of sanitation. In the water initiative of the Sustainable Development Goals, the UN states that, "every year millions of people, most of them children, die from diseases associated with inadequate water supply, sanitation and hygiene."[3] While many countries have made substantial progress on these goals, the poorest countries have had difficulty progressing because they have pressing needs in almost all sectors of society, and fewer resources to utilize.

According to the UN, a country experiences "water scarcity" when the annual supply of potable water is less than 1,000 cubic meters per person.[4] Water scarcity is a widespread issue, present on every continent and in countries at every stage of development. Ten countries have almost completely depleted their renewable freshwater resources.[5] Currently, water scarcity

---

[3] "UN Sustainable Development Goal 6: Ensure Access to Water and Sanitation for all," *Department of Public Information, United Nations*, accessed November 17, 2015, http://www.un.org/sustainabledevelopment/water-and-sanitation/.://www.un.org/sustainabledevelopment/water-and-sanitation/.

[4] "Water Scarcity," *United Nations Department of Economic and Social Affairs*, last modified November 24, 2014, accessed November 17, 2015, http://www.un.org/waterforlifedecade/scarcity.shtml.

[5] "SDG 6: Clean Water and Sanitation," *United Nations Development Programme: Sustainable Development Goals*, accessed November 17, 2015, http://www.undp.org/content/undp/en/home/mdgoverview/post-2015-development-agenda/goal-6.html.

impacts 40 percent of the world's population.[6] This surprisingly high figure is expected to increase as global temperatures continue to rise, which is why alleviating water scarcity has risen to the top of many development agendas. "Water stress" is slightly less concerning, and occurs when annual water supply drops below 1,700 cubic meters per person. The UNDP reports that in 2011, 41 countries experienced water stress, and if these water supplies continue to be threatened there may soon be serious health problems and slowed economic development as a result.

Currently, Sierra Leone suffers from "economic" water scarcity (along with much of the rest of West and Central Africa). This means that the obstacles to increasing water supply are not environmental or reservoir-related, but are instead issues of governance and economics. Sierra Leone is an interesting case because of the technical surplus of freshwater resources within its borders. Due to its tropical climate, Sierra Leone receives an abundance of annual rainfall that meets the water needs of the population in technical terms. However, a significant portion of its population still lives without potable water because the water in many surface reservoirs and unprotected water systems is unfit to drink. Potable water in Sierra Leone is a case of technical surplus in theory, but widespread shortage in practice.

Improving access to clean water would raise the quality of life for Sierra Leone, as over half of its population is currently underserved.[6] As potable water is more readily available to the population, improvements in sanitation levels, healthcare quality, and environmental conservation will be more easily realized. These factors are all interrelated, where the success or failure of any factor can significantly impact the others. For example, if access to basic sanitation is poor, human waste will enter the groundwater system, carrying diseases with it, and degrade

[6] Alexandra Barton, "Water in Crisis - Sierra Leone," *The Water Project*, accessed November 18, 2015, http://thewaterproject.org/water-in-crisis-sierra-leone.

the surrounding environment. Access to potable water is a critical aspect of sustainable development in Sierra Leone.

In *Living with Water Scarcity*, David Zetland argues that access to water is not an issue of human rights, but rather an issue of honest governance.[7] As a relatively new democracy emerging from a brutal, decade-long civil war, Sierra Leone has not yet experienced honest governance for a significant period of time, and as a result has been unable to resolve many water related issues.

III. Common Pool Resource Approaches to Water Management

The relationship between water and its beneficiaries takes many forms. In some cases, water is perceived as a human right; in others, it is a commodity, a communal resource, a recreational activity, an aesthetic pleasure, or a habitat. The economic benefits of water are its commodity benefits: consumption, waste assimilation, aesthetic pleasure, recreational value, and fish and wildlife habitats. Other benefits of water, such as biodiversity, ecosystem preservation and social and cultural values, must be separately addressed.[8] When supplies are scarce, the economic perspective tends to frame water as a rival good, where one person's use directly impacts another person's use, and it has high exclusion costs.

The focus of this paper is on the consumptive uses of water, such as water for individual consumption and sanitation, for industrial uses, and for agriculture. Water in these settings can be viewed in three ways: as a human right that should be freely provided to all, as a commodity

[7] David Zetland, *Living with Water Scarcity* (Lexington, KY: Aguanomics Press, 2014), 67, http://livingwithwaterscarcity.com.
[8] Robert A. Young, *Determining the Economic Value of Water,* 2nd ed. (Washington DC: Resources for the Future, 2005), 6-9.

to be bought and sold, or as an existing resource that must be shared evenly with all those who have a justified claim to it.

The human rights approach of granting free access to water for all is often not feasible and can encourage waste of an increasingly precious resource. The human rights approach also fails to understand water management on a broad scale, because the majority of water consumption is not at the individual consumptive level, but rather in agriculture and industry. For example, if everyone in the USA was granted a sufficient amount of potable water for drinking and household use as a human right, this would only account for 1 percent of current fresh water consumption in the USA. Focusing on the governance of industrial and agricultural usage would address the remaining 99 percent of water usage.[9] Giving away water for free, even in relatively small quantities, requires good governance to ensure that subsidized water projects are constructed and extended to the whole population. If water is not subsidized by the government, provision of a free supply is often not feasible due to infrastructure requirements for water sourcing, treatment, storage, and distribution which create a high entry cost to this market. Consequently, competition among distributors cannot be relied upon to ensure an optimal result for consumers, and existing distributors have considerable market power. With these factors in mind, the provision of free water under the human rights approach is entirely dependent upon good governance. For the analysis conducted in this paper, the human rights approach is less practical than the remaining two options, the commodity and communal resource approaches, when the current state of governance in Sierra Leone is taken into consideration. However, good

[9] Chris Farrell, "Time for a Serious Policy on Water Pricing," *Bloomberg Business*, last modified October 15, 2014, accessed November 17, 2015, http://www.bloomberg.com/bw/articles/2014-10-15/time-for-a-serious-policy-on-water-pricing.

governance undoubtedly plays an important role in successful water management in the long-term.

The commodity approach to water management reflects scarcity through water prices, with higher prices incentivizing conservation. Rather than relying on subsidies, public information campaigns, or other methods to encourage environmentally-conscious activity, a pricing mechanism will make water conservation in times of scarcity a logical outcome because it will be in the user's best interest to conserve water and save money. Accurately-priced water can generate revenue for infrastructure to supply new areas and maintain existing pipes. These costs could be more readily absorbed by the consumer to a point, and the system would not rely so heavily on government subsidies or NGO funds because it could be run by a private or public company. A pervasive problem in pricing water is convincing a populace that is accustomed to receiving free or nearly free water to pay a more reflective price for this good. Most water can be bought at a trivially low price that does not encourage the same behavior as a scarcity-reflective pricing structure would, and there is significant political resistance to changing this price because of industry interest in maintaining low prices. A key component of the commodity approach is determining the true value of water, which is often not reflected by existing markets.

The communal resource approach focuses on issuing permits that can be freely traded in a market exchange system, which allows low-volume water users to profit from being conservative and high-volume water users to purchase extra permits to access the water they need. Successful water management relies on clearly-defined water rights and good governance of water resource distribution. The goal of the permit trading market is to incentivize water conservation by allowing permit sellers to profit from the sale of their unneeded allocation permits. They are able to profit because permits increase in value as water becomes increasingly scarce, and therefore in higher demand by high-volume users—namely the water-intensive industries operating in the area. In Sierra Leone, these industries have large amounts of political leverage because they tend to be foreign companies with close relationships with decision makers, and they are involved in resource extraction that generates significant portions of the state's GDP. These industrial interests could corrupt the permit system, and without a strong government to ensure equitable distribution, pricing, and access to water, the system has a higher potential to fail. The permit system is beneficial when reallocating a scarce resource, but it does not necessarily generate revenue for the extension of water to areas currently without access, unless auctions or other revenue generating events are held. Extending supply to rural, impoverished areas is the most significant water issue in Sierra Leone.

Water management challenges are present around the world, in countries at every stage of development. In a developing country such as Sierra Leone, water management challenges are equally difficult to overcome, but must be met with fewer resources and additional obstacles that have impeded development thus far. Corrupt institutions, industrial influence on political decisions, and low population densities make these objectives difficult to achieve.

IV. The Valuation of Water

In order to increase access to water, the value of water in the community must be understood so that delivery systems and demand elasticities can be evaluated. The literature regarding water valuation, pricing, and the applicability of economic frameworks to water management problems is summarized below.

The valuation of water and its responsible usage is a complex problem with fundamental components of governance, pricing, and environmental protection that draw upon the literature from several disciplines. Water is essential to life and incredibly useful, but it typically fails to command a market price that reflects its value. Adam Smith identified the paradox of value in the *Wealth of Nations*, distinguishing between "value-in-use" to represent the utility of the good, and "value-in-exchange" to represent its purchasing power. "Nothing is more useful than water; but . . . scarce anything can be had in exchange for it. A diamond, on the contrary, has scarce any value in use; but a very great quantity of other goods may frequently be had in exchange for it."[10] This paradox has been resolved by introducing scarcity as a component of value, with more abundant goods commanding lower prices than goods with very limited availability. The fact that water is often underpriced or not priced at all, even when scarce, makes it difficult to determine the true value of water.

The value of water can be better understood through economic valuation, because prices that reflect the relative scarcity of water encourage consumers to change their behavior. Franklin Fisher and Annette Huber-Lee argue in *Liquid Assets,* that water scarcity is a matter of costs and value, not merely of quantity, and that both the value of water and its scarcity are location-specific.[11] They also point out that water is not technically scarce because with desalination technology, potable water could be supplied around the world to fully meet demand. Therefore, the cost of desalination places an upper bound on the value of water in various scenarios and water-based conflict negotiations. When accurate prices for water are not available from competitive markets, a shadow price for water can be estimated and used in analysis. Scarcity directly impacts this shadow value in the form of a scarcity rent; scarce resources still have

[10] Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations*, (London: W. Strahan and T. Cadell, 1776), 46-47.

[11] Franklin M. Fisher and Annette Huber-Lee, *Liquid Assets: An Economic Approach for Water Management and Conflict Resolution in the Middle East and Beyond*, (Washington DC: Resources for the Future, 2005), 4.

positive values and positive prices even if their direct production cost is zero.[12] The shadow value of water reflects the marginal cost of production plus the scarcity rent, and water will be produced only when the shadow value of water at a specific location is greater than the marginal cost of production.[13]

Robert Young adds to the discussion of shadow prices in *The Economic Value of Water*, using them to determine true value where markets do not exist or do not accurately reflect value. The economic feasibility of treating, storing and distributing water from a new supply can be determined by evaluating the present value of net benefits, which requires that shadow pricing include the incremental benefit or willingness to pay, the incremental dis-benefit or external costs, and capital and operating costs.[14] The shadow price being sought is willingness to pay, or willingness to accept compensation. The price can be determined through observation of market activity, with adjustments made to reflect more accurate values if there are criteria on which to base these adjustments; otherwise, it must be estimated as a shadow price when markets do not exist. Allocation options can be evaluated in a CBA framework to determine their impact on economic efficiency, where, if the beneficiaries of a service change could compensate the losers and still be better off, the change would be judged as an improvement.

Young makes a case for using economic frameworks because water management problems involve choices as to how water should be allocated to obtain the greatest public return from scarce resources. When these management issues are approached as resource allocation problems, economic frameworks are most applicable.[15] Economic frameworks such as CBA are useful when evaluating potential impacts of proposed water management projects or policies

[12] Fisher and Huber-Lee, 16.
[13] Ibid.
[14] Young, 12.
[15] Young, 15.

because free market allocation of water does not always best serve society due to the presence of externalities, public goods, decreasing costs in supply, and high transaction costs; all of which can be incorporated into a CBA.[16] CBA is an economic framework that allows the predicted benefits of a project to be weighed against the expected expenses of implementation and the opportunity cost of directing the investment elsewhere. The result determines whether the potential benefits of the project or policy would outweigh the associated costs. When water is treated as a commodity, used for waste assimilation, or for public or private aesthetic pleasure, recreational area, or wildlife habitat, it should be considered under this economic framework because these benefits are characterized by increasing scarcity and problems of allocation among competing users.

In *Living with Water Scarcity*, David Zetland identifies valuation techniques and pricing mechanisms to accurately reflect scarcity, and the implications of increasing the price of water for consumers. While industries, agriculture, and middle-to-high income citizens should be able to readily adapt their preferences and water usage to a new pricing structure, that may not be possible for the poor. Forgoing water is not an option: it is essential to life, and there is no true substitute for it. A common initial approach is to treat access to a certain amount of water as a human right, allowing all citizens free access to that amount. However, Zetland argues that good water service does not depend on human rights, but on governance. An honest government will help poor citizens get water, while wealthy citizens will get water whether or not the government is honest.[17] Good governance is difficult to achieve, especially in developing countries where corruption often runs rampant. The poorest constituents in corrupt developing countries typically lack water service and do not benefit from subsidized prices or income supports designed to help

[16] Young, 22.
[17] Zetland, 67.

them because the same factors preventing service — corruption and incompetence — also impede delivery of those benefits.[18] While water prices would increase if better valuation techniques and market allocations were adopted, that could still help even the poorest citizens of developing countries because they would be receiving clean, potable water, rather than being excluded from the supply systems due to lack of profitability. When clean water is not delivered to poor citizens, many end up paying 10 – 20 times as much for water due to the "social tariff" incurred when they can only get water from tanker trucks or pre-packaged sources. They would potentially be saving money if allowed to pay full price for piped water.[19] Viewing water as a choice between a human right and a commodity is a false dichotomy. The goal is to deliver clean water to the entire population, which costs money. Therefore, it makes sense to employ microeconomic frameworks to optimize the allocation of this increasingly precious resource.

These authors each reinforce the importance of bringing an economic perspective to the efficient allocation of water, challenging the current failure to price water according to its value or relative scarcity of supply. Arguments that are compelling at first glance, such as the human right to water or the adverse impact of pricing on poor citizens, do not hold up when current water access is analyzed. Non-market valuation methods such as CBA can be used to estimate a shadow price for water, which can then be used to determine if the potential benefits of a proposed water management project outweigh the direct expenses and opportunity costs of implementing it. These principles have been incorporated into the methodology for simulating demand for water in Bo and developing evaluation criteria for potential water delivery systems.

V. Sierra Leone

[18] Zetland, 68.
[19] Zetland, 69.

Since gaining independence from Britain in 1961, Sierra Leone has experienced political instability and a decreased standard of living. There were five military coups between 1961 and 1991, followed by a ten-year civil war that lasted until 2002.[20] This instability has created serious challenges for development, with little national identity or accountability in the government to use resources wisely. The civil war destroyed most of the existing water infrastructure in Sierra Leone, which has handicapped its ability to increase water supply over a period of time, as shown in Figure 1 below. As of 2010, water supply in urban areas exceeds the national development goal of 70%, but rural water supply coverage remains far below the target. The government estimates of water supply have also differed considerably from the WHO/UNICEF Joint Monitoring Programme (JMP) estimates, which may call into question the reporting mechanisms in use.

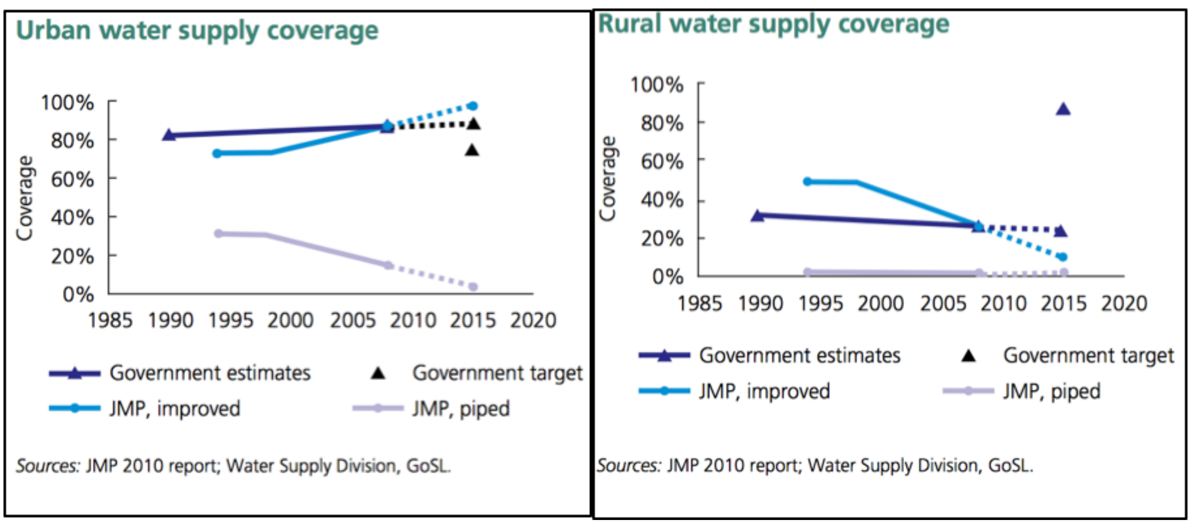


Figure 3. *Percentage of urban and rural water supply coverage in Sierra Leone from 1990-2009.* [21]

[20] Asamoah Larbi, "Country Pasture/Forage Resource Profiles: Sierra Leone," *Food and Agriculture Organization of the United Nations, International Institute of Tropical Agriculture*, last modified August, 2012, accessed November 17, 2015, http://www.fao.org/ag/agp/agpc/doc/counprof/Sierraleone/Sierraleone.htm.

[21] "Rural water supply coverage" and "Urban water supply coverage," in *Water Supply and Sanitation in Sierra Leone: Turning Finance into Services for 2015 and Beyond*, World Bank Group Water and Sanitation Program, 20-22, accessed November 17, 2015, https://wsp.org/sites/wsp.org/files/publications/CSO-sierra-leone.pdf.

The focus of current development efforts has been on the Guma Valley Water Company, which provides water to the capital city of Freetown. In 2013, the Minister of Water, Momodu Maligi, shared that over the past few months "revenues are up by 125%, billings have increased by nearly 40%, hundreds of previously unregistered connections have now been captured into our system, and we have reduced non-revenue water from 61% to 41%. . . . We have also financed the extension of the mains by 4.8 [kilometers] making the service available to more areas, especially in less privileged communities."[22] This progress shows that the government takes the MDG initiative seriously, and has made improvements to urban water management even though resources are limited. However, rural areas are often neglected in these conversations, and attention must also be given to the pressing needs present in these smaller communities. As of 2008, only 26 percent of rural communities had water supply coverage, compared to 86 percent of urban communities.[23] Extending water supply coverage to these rural areas is not an easy task, and is not one that can be solved by merely increasing funding. Measurable progress is often slower due to the geographic expanse of the rural areas, and the infrastructure costs are much higher because many small systems are required instead of a single, large-scale system in an urban area. It is also necessary to understand the watersheds, water quality issues, community governance structures, and cultural values associated with water in Sierra Leone.

[22] "Water and Sanitation in Sierra Leone with the Minister of Water Resources,"*Awoko Newspaper*, May 21, 2013, http://awoko.org/2013/05/21/water-and-sanitation-in-sierra-leone-with-the-minister-of-water-resources/.
[23] "Water Supply and Sanitation in Sierra Leone," *World Bank Group Water and Sanitation Program, AMCOW*, accessed November 17, 2015, https://wsp.org/sites/wsp.org/files/publications/CSO-sierra-leone.pdf.

Watersheds

The surface area of Sierra Leone is 71,740 km^2 and contains 17 separate river basins. “Just as a bathtub catches all of the water that falls within its sides, a river basin sends all of the water falling within it to a central river” that eventually reaches an estuary or the ocean.[24] In Figure 4, the river basins highlighted in color are entirely contained within the borders of Sierra Leone. The excluded basins to the north, which are not colored on the map, comprise the Sierra Leonean portion of the Scarcies watershed, and the excluded basins to the southeast make up the Moa watershed. The Scarcies and Moa watersheds cross international borders, with many of the upstream users residing in neighboring Guinea or Liberia.[25] Therefore, the initial focus for watershed management is on the river basins that are entirely contained within Sierra Leone and can be managed consistently with a combination of federal and local policies.

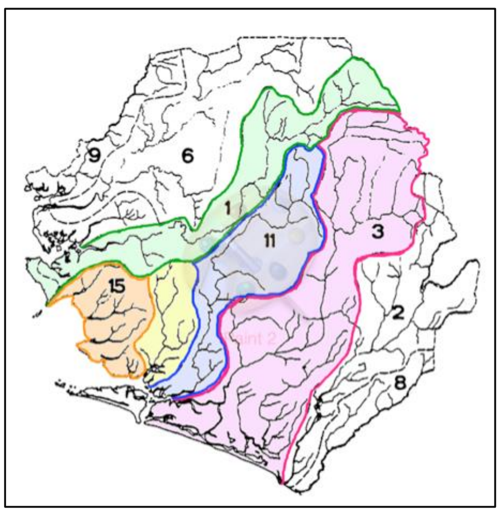


Figure 4. *Drainage areas and major river basins of Sierra Leone.* [26] *(Color edits completed manually.)*

---

[24] "Workbook Page Two - what is a River Basin?" *NC Stormwater*, accessed November 4, 2015, http://www.ncstormwater.org/pages/workbook_riverbasin.html.

[25] "Source Book for the Inland Fishery Resources of Africa Vol. 2 Country Files: Sierra Leone," *FAO Corporate Document Repository, Fisheries and Aquaculture Department*, accessed November 4, 2015, http://www.fao.org/docrep/005/t0360e/t0360e10.htm.

[26] “Drainage and Major River Basins of Sierra Leone,” in *Source Book for the Inland Fishery Resources of Africa Vol. 2 Country Files: Sierra Leone*, FAO Corporate Document Repository, Fisheries and Aquaculture Department, accessed November 4, 2015, http://www.fao.org/docrep/005/t0360e/t0360e10.htm.

The three largest river basins fully contained in Sierra Leone are the Rokel, Sewa, and Jong river basins (numbered 1, 3, and 11, respectively). The drainage areas of these three basins cover approximately 45% of the total surface area of Sierra Leone, making proper resource management a top priority on the country's development agenda (Table 1). The Sewa river basin is the largest basin to be fully contained in Sierra Leone, and is the third largest in the country overall. River basins are defined by topography and geology. Rivers are a natural erosive force that shape terrain and create some of the watershed divisions shown on the map, and they carve out a path of least resistance based on rock types in the area. Topography plays a central role in these divisions as well. At points of elevation such as ridges, hills, and mountains, rainwater flowing down either side feeds into different watersheds and creates a division. In northeastern Sierra Leone there is significantly greater elevation and relief in comparison with the low, flat remainder of the country (Figure 5). These mountainous areas cause the division between the Rokel, Sewa, and Jong rivers basins, as well as impact the mineral deposits and soil potential for agriculture. If one puts the river basin and topographical maps on top of one another, it is apparent that the boundaries of each river basin are determined by topographic features.

Table 1. Geographic information on rivers of interest. [27]

1. ROKEL RIVER	
Source:	northern Sierra Leone
Total length:	280 km
Drainage area:	10 600 km²
3. SEWA RIVER	
Source:	eastern Sierra Leone
Altitude:	490 m
Total length:	385 km
Drainage area:	14 200 km²
Major tributaries:	Bagbe, Bafi Tabe
Discharges to:	Atlantic Ocean
Special features:	Floodplain with several lakes on lower course
11. JONG RIVER	
Source:	a small lake near Kodembaya, Sierra Leone - 9° 15'N;11° 3
Total length:	249 km
Drainage area:	7 500 km²
Countries traversed:	Sierra Leone
Major tributaries:	Pampana
Discharges to:	Atlantic Ocean
15. RIBI RIVER	
There is less available geographic information on the Ribi river, but as one of the smaller river basins within the Sewa river system, it is not critical to our initial analysis.	

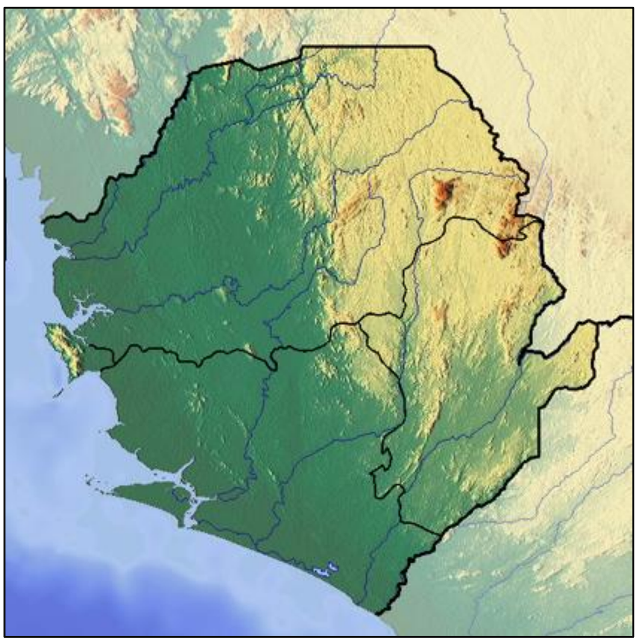


Figure 5. *Topographic map of Sierra Leone.* [28]

[27] Excerpts from "Water Bodies Directory," in *Source Book for the Inland Fishery Resources of Africa Vol. 2 Country Files: Sierra Leone*, FAO Corporate Document Repository, Fisheries and Aquaculture Department, accessed November 4, 2015, http://www.fao.org/docrep/005/t0360e/t0360e10.htm.
[28] "Sierra Leone Location Map Topographic," *Wikimedia Commons*, June 23, 2012, accessed November 10, 2015, https://commons.wikimedia.org/wiki/File:Sierra_Leone_location_map_Topographic.png.

While management at the watershed level would be the most logical when it comes to maintaining sufficient environmental flows and cleanliness of water, that is complicated by the fact that the interior political boundaries of Sierra Leone have developed independent of the watersheds. No single district, town, or chiefdom has control over the entire watershed, making cooperation between upstream and downstream water management policies essential.

Chiefdom Governance in Rural Communities

Most of the population of Sierra Leone lives in or around Freetown, which is in the Western Area District on the Atlantic coast. There are vast expanses of rural Sierra Leone that do not exceed a density of 100 people per square kilometer, as shown in Figure 6. The rural communities currently have two governance systems: a long-standing chiefdom structure, and more recently instituted provincial government councils created out of a World Bank development initiative in 2004.[29] The chiefdom governance structures are likely to be more effective at collective resource management than the current provincial governments. Paramount chiefdoms were established in 1896 by British colonial rule as the sole authority of local government, with all chiefs originating from designated "ruling families" and serving life terms in their roles.[30] Each district of each province has several chiefdoms that each have their headquarters in a separate city or town. For example, in the Southern Province, in the four districts combined, there are 52 distinct chiefdoms operating. In a comprehensive historical survey of Sierra Leonean chiefdoms, 149 chiefdoms were documented, each with a unique

[29] Tristan Reed and James Robinson, "Chiefdoms of Sierra Leone," *Michigan State University*, last modified October 20, 2012, accessed November 4, 2015, 6-8, https://www.msu.edu/~bernsten/PCSLReunion67/Documents%20(WP-Adobe)/Chiefdoms%20of%20SL(1).pdf.
[30] Reed and Robinson, "Chiefdoms of Sierra Leone," 6.

history and lineage.[31] The chiefdoms do not follow the river basin divisions neatly, but they provide a local governance structure that would likely be used to improve water access in the small, widely dispersed communities under their jurisdiction.

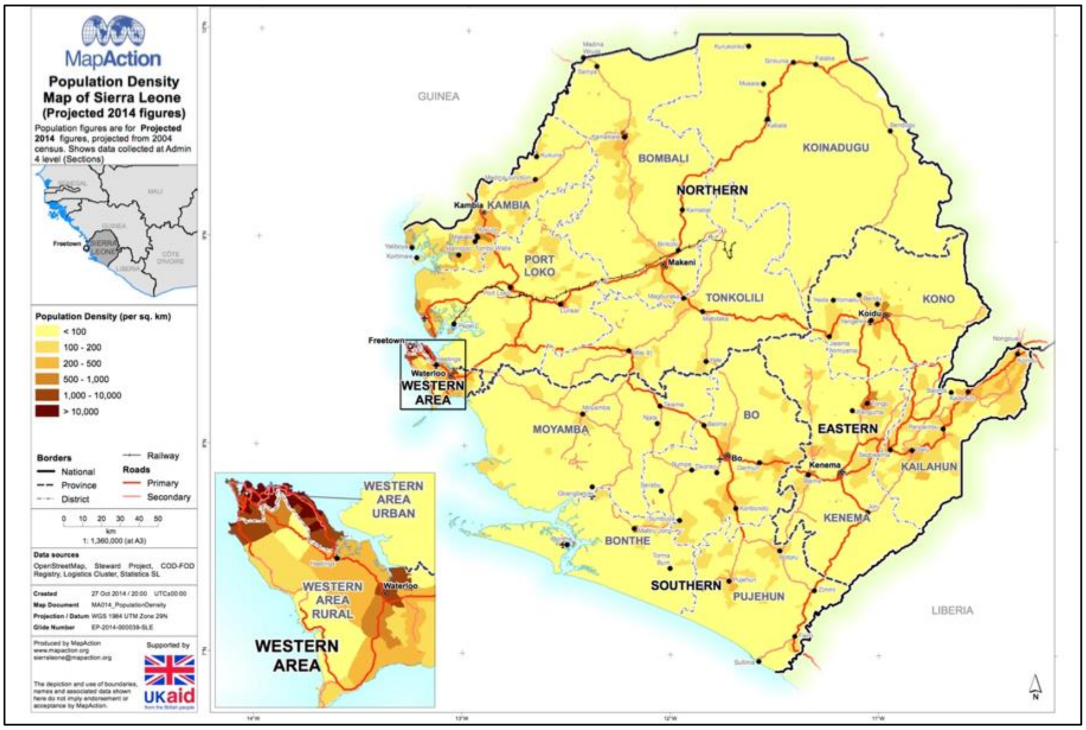


Figure 6. *Population density map of Sierra Leone.* [32]

Threats to Water Quality

Sierra Leone receives upwards of 3,000 mm of rain each year, and has extensive river systems flowing throughout the country that could support many communities' needs year-round. The major obstacle for the provision of safe, clean water to the rural populations of Sierra Leone is water quality, not a technical lack of supply. Water quality can be threatened by many factors, but the main concerns when evaluating water at a national level are the geologic

[31] Reed and Robinson, "Chiefdoms of Sierra Leone," 2.
[32] "Population Density Map of Sierra Leone (Projected 2014 Figures)," *Reliefweb: MapAction,* October 27, 2014, accessed November 15, 2015, http://reliefweb.int/map/sierra-leone/population-density-map-sierra-leone-projected-2014-figures-27-october-2014.

relationship between surface water and groundwater, the industrial and agricultural operations in an area, and the level of sanitation in communities. Sanitation levels are very low throughout rural Sierra Leone, a problem that must be addressed before sustainable changes in water quality and reductions in waterborne disease levels can be realized, but evaluating these systems is beyond the scope of this paper. Flooding in the rainy season causes serious water contamination problems, and many small communities are forced to rely on polluted water sources.

The geology of Sierra Leone plays an important role in water contamination. A hard, granitic basement rock is the base of the aquifer system. The aquifers are relatively shallow, which creates a close relationship between surface water and groundwater.[33] This means that direct and indirect pollution can easily contaminate both surface and groundwater. Groundwater is better protected from contamination due to natural filtration processes in the aquifer, but detailed information is needed regarding the capacity, recharge rate, and other characteristics of the aquifer to prevent this resource from being quickly depleted.

Figure 7 shows the potential for different areas of Sierra Leone to tap into their groundwater, with some areas having better groundwater access than others based on the geology of the area. Areas near the coast have the highest potential to utilize groundwater, excluding Freetown itself, followed by the lowland areas in the interior. The northern and eastern districts of Sierra Leone have low to moderate feasibility for manual drilling, and some areas are entirely unsuitable, because they are underlain by hard bedrock rather than softer, sedimentary material. There is a large area stretching from northwest to southeast outside of Port Loko District that has low suitability for groundwater access. Harder bedrock is more difficult to erode, and therefore

[33] Fendi Akiwumi, "The Need for More Widespread use of Geological Criteria in Water Quality Assessment in Africa," *The International Association of Hydrological Sciences*, 360-361, accessed November 11, 2015, http://hydrologie.org/redbooks/a243/iahs_243_0359.pdf.

higher elevation areas such as the northern and eastern districts often contain harder rock types that are less suitable for manual drilling. The Ministry of Water Resources has taken steps to provide official guidelines and information on borehole drilling and hand-dug wells to encourage the populace to tap into this resource in a sustainable way.[34]

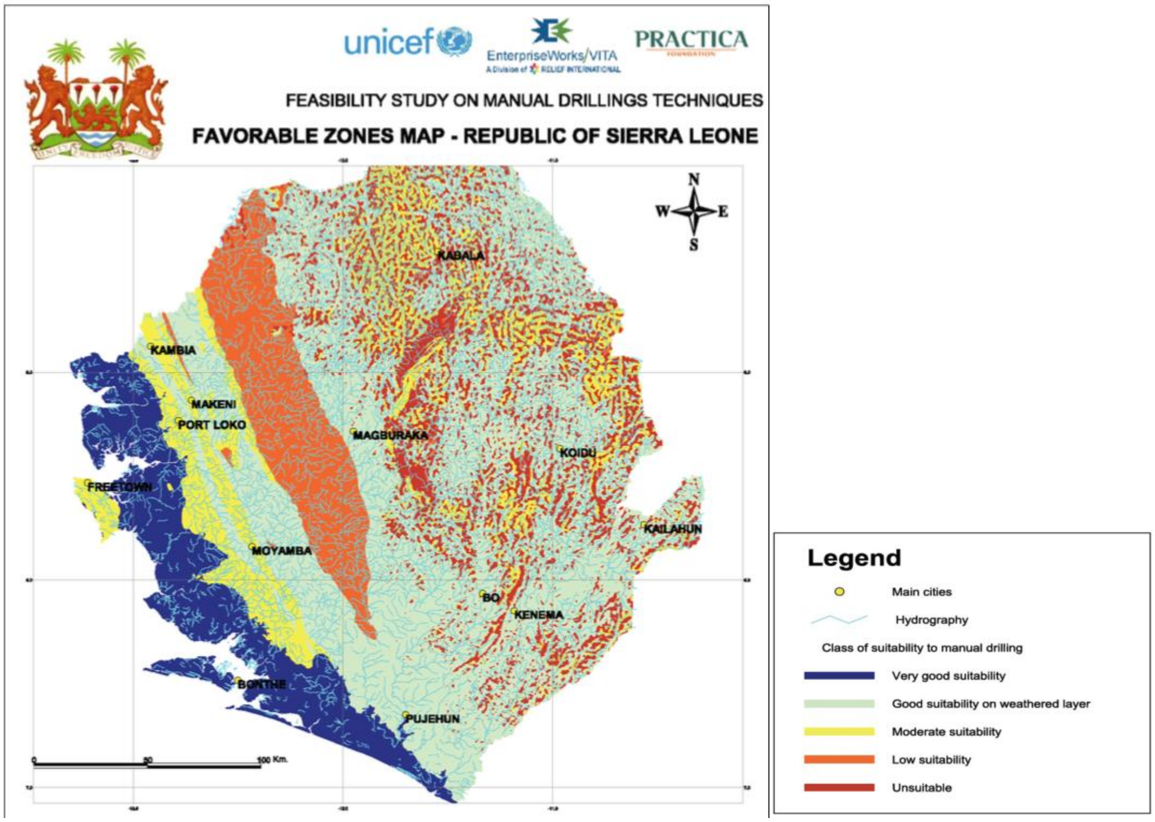


Figure 7. *Suitability of manual drilling in Sierra Leone.*[35]

Sierra Leone is part of the ancient Archean (ca. 3 billion year old) core of the African continent, and like other Archean provinces around the world has a distinctive type of geologic

[34] "Principles for Borehole Construction and Rehabilitation in Sierra Leone," *Rural Water Supply Network Resources, Ministry of Water Resources of Sierra Leone*, accessed November 11, 2015, http://www.rural-water-supply.net/en/resources/details/624.

[35] "Map of Suitability to Manual Drilling," in *Feasibility Study for Manual Drilling, Mapping of Favourable Zones*, Unicef, Ministry of Energy and Water Resources, accessed November 15, 2015, http://www.unicef.org/wash/files/Sierra_Leone_final_report_favorable_zones_(FINAL).pdf.

formation called greenstone belts, which often have high concentrations of valuable minerals.[36] As a result, Sierra Leone has a well-developed mining industry for gold and rutile. Another unusual rock type, kimberlite – the principal diamond source rock – also occurs in Sierra Leone. The bauxite mining industry relies on deeply weathered surface bedrock found in several places in Sierra Leone.

While formal mining operations are required to submit reclamation plans and adhere to regulated mining practices, many informal or artisanal mines operate in the mineral-rich areas and are destructive to the environment, adversely affecting the groundwater in the area. However, even formal operations have an indisputable impact on the environment because mineral extraction generates large amounts of waste rock. Diamond mines are dug miles deep, below existing aquifers, so excess water must be pumped out of the mine shaft regularly and may carry contaminants with it. Bauxite mines cover much more territory horizontally as they strip away all natural growth in search of the shallow mineral deposits. This dramatically changes the vegetation and topography of the area, and the way that rainfall drains into the river systems and groundwater. Changes in topography can alter aquifer recharge rates, and the quality of water in the aquifer as contaminants from mining waste are introduced to the natural water supply. The presence of greenstone belts exacerbates water quality problems because much of the waste rock may have exceptionally high levels of toxic heavy metals that can then enter the water system once they are mined and exposed to surface processes.[37] With heavy mining and agricultural land use, the contamination can increase rapidly. Sierra Leone has an active mining industry with significant political leverage and artisanal operations that are unregulated, which allows many mining operations to remain exempt from rules pertaining to pollution, reclamation, and other

[36] Akiwumi, 361.
[37] Akiwumi, 364.

environmental impacts of mining.[38] This jeopardizes the quality of water flowing into many rural areas of Sierra Leone, so treatment is needed to ensure the health of the rural population.

In the northeastern portion of Sierra Leone, where the Sewa river begins, there is extensive panning for diamonds from fluvial sediments ('placer' deposits).[39] Cassava and swamp rice cultivation occur in the more southern reaches of the Sewa river, where elevation flattens out and is conducive for these water-intensive crops. These activities also have economic and environmental implications for the communities nearby. While Sierra Leone's rainy season allows water-intensive crops to be grown without formal irrigation systems, flooding allows fertilizers and other contaminants into the groundwater system. There is a pressing need for rural communities to develop filtration capabilities in hopes of improving overall health of the population. Accounting for the impact of agricultural practices and mining operations in the Sewa river basin will allow for mitigation of contamination issues and other environmental impacts that should be reviewed before new water delivery systems are implemented.

VI. Why Focus On the Bo District?

Lack of access to potable water is a problem present in every district of Sierra Leone. The analysis presented in this paper focuses on Bo District, an inland district in the Southern Province. Bo District was selected because of its hydrology and the availability of data on current access in the district. Other districts certainly merit attention, and some districts have far lower access levels than Bo. The Western Area districts, which include Freetown, were not selected because access to water is much higher, and there is ample attention from NGOs and the

[38] "Liberia: Geology," *Aureus Mining Operations*, accessed November 17, 2015, http://aureus-mining.com/projects/liberia-2.
[39] "Sewa River | River, Sierra Leone," *Encyclopedia Britannica Online*, accessed November 4, 2015, http://www.britannica.com/place/Sewa-River.

government. The districts with greater need tended to have less information regarding current access, and Bo was one of the few districts whose upstream and downstream users were all within Sierra Leone. Out of the twelve rural districts, Bo was the best choice due to its hydrology.

Figure 8 shows Bo is located almost entirely within the Sewa River basin, with two small sections that lie within the Rokel River basin. The Sewa River basin does not have transnational boundaries, reducing the political complications of instituting water treatment and distribution systems. The location of Bo makes it an ideal choice for this analysis because the most densely populated areas of Bo remain in the Sewa basin, allowing for the assumption that all of the needed systems are drawing from water sources contained in Sierra Leone. This is important for managing scarcity of the resource, as well as predicting potential contamination from agricultural and industrial operations, because all actors are within Sierra Leone. Bo District is also the closest of any district to being fully contained in one river basin. Therefore, water quality will be impacted by all users within a single river basin, rather than having to identify or account for users of multiple basins that span a much greater area.

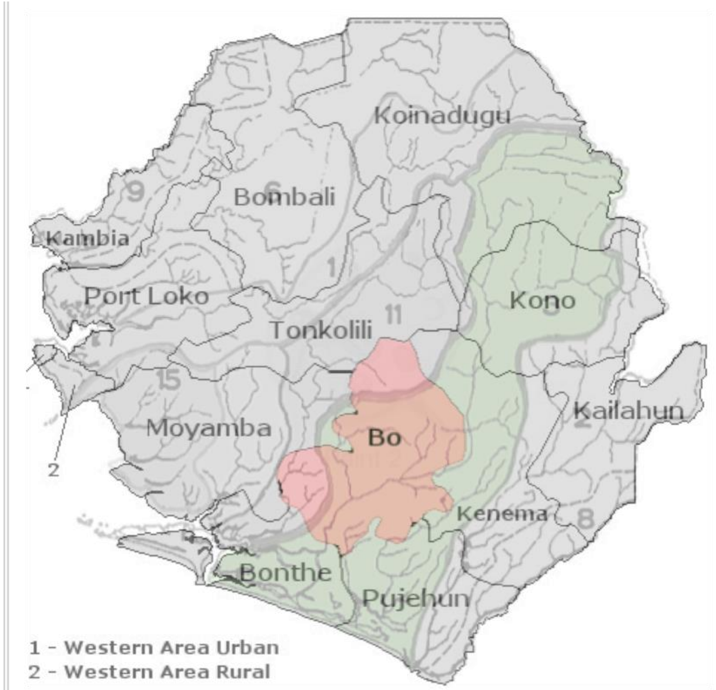


Figure 8. *The Sewa River basin is shown in light green, stretching southwest to northeast across the eastern part of Sierra Leone. The Bo District is show in light pink, and the thick border of the river basin shows the two sections of Bo that lie within the Rokel River basin.*[40]

Bo District has other advantages that make it a better choice than other districts for this analysis. The district capital, Bo Town, is the second-largest urban area in Sierra Leone. This prompts the discussion of economies of scale when identifying optimal delivery systems, because systems that are too expensive for small communities to implement may be quite feasible in larger urban areas as the infrastructure costs are shared by more users. It also happens that Bo District has been the subject of several recent water studies and surveys conducted by NGOs; therefore, the data provided about water access in Bo are more recent and more accurate than are available for many other districts. These data are fundamental to the analyses conducted in this paper.

[40] "Drainage and Major River Basins of Sierra Leone," in *Source Book for the Inland Fishery Resources.*

Not only is Bo District the best fit for this analysis, but it also provides an interesting case through which to explore the case of economic water scarcity in Sierra Leone. In 2010, Joseph Musa surveyed 390 households across four chiefdoms in Bo. There were no reports of improved water sources beyond hand-dug wells, and most of these wells were only functional during the rainy season. 78 percent of the respondents did not have access to improved water supply, and 97 percent of the respondents did not treat their water in any way.[41] In essence, Bo is a clean slate upon which all strategies can be evenly evaluated. Bo Town adds the dimension of scalability to the recommendations, potentially changing the proposed solutions in areas with higher population densities.

VII. Methodology

Water is a challenging resource to distribute amongst competing users without incurring a "tragedy of the commons" when supply is scarce. There are several types of water users that have a stake in its distribution, ranging from households to agricultural operations and industrial manufacturing. It is not uncommon for the biggest consumers to leverage their financial importance and political influence to keep water prices artificially low—encouraging and enabling wasteful behavior. The interests of each user, and his or her respective demand for water, must be balanced against the available supply of water. The environment is a stakeholder as well, because a certain amount of water is required to support ecosystems and environmental health. These challenges are addressed in Bo District by identifying current access and demand for water of each user type, quantifying the supply gap, evaluating delivery systems that could

[41] Joseph Alex Musa, "Water Sanitation and Hygiene in Sections of Bo District: Problems, Challenges, and Recommended Solutions," *Weave SL Research in Sierra Leone Studies,* no. 2.1 (2014): 9-12, accessed January 12, 2016, http://weavesl.org/ojs/index.php?journal=Weave&page=article&op=view&path%5B%5D=46.

close these gaps, and recommending a pricing structure to maintain these systems. Underpinning this analysis is the research question: given the economic and political constraints, what is the most feasible way to bring access to potable water up to 70% in Bo District?

The first step in this analysis is determining the demand for water of each user type. Water consumption is not metered or reported for Bo District; therefore, the demand of each user type will be simulated based on their known activities in the district. To simulate demand for water in a community, a representative village will be created whose demographics, water demand, water supply, and income are close to the average for a village in Bo. These key indicators are based on population and demographic information provided in survey data, as well as hypothetical user types with their respective demands for water based on relevant literature. Sensitivity analysis is used to show how influential the deviations of key indicator predictions from reality are on the result. The simulation will identify which user types have unmet demand for water and would be relying on delivery systems, allowing for more accurate predictions of required system capacity and optimal system types. Potential delivery systems costs can be weighed against the hypothetical village's ability to pay, based on relevant literature and income estimates. This will show which system types, if any, could be implemented alone by a community and which system types would require external funding sources.

The next step in the analysis is determining what gaps in the supply of clean, potable water currently exist. Several important surveys on water in Bo were conducted in 2010-2011 and provide the bulk of the data used in this study. The Sierra Leone Waterpoint Survey, conducted by the Ministry of Energy and Water Resources, reported on the functionality, financing, and GPS coordinates of every existing public improved waterpoint in Sierra Leone. The ProVictimis Foundation conducted a similar survey in 2010 focused on Bo and two other districts, providing information on public water access in every village, in addition to the respective village populations. The population data provided are critical to assessing supply gaps at the village level, but the lack of corresponding GPS coordinates limits the scope of the analysis. From these survey data, the existing supply gaps in Bo and the scope of affected populations will be defined. The number of systems that must be constructed, repaired, or completed in order to close each gap will be calculated as well. This will create a clear picture of the access problem in Bo District. It will also provide the information to determine the population with full access to potable water at the village level.

Once these gaps are quantified, a set of potential policy strategies to bring Bo District up to its target level of 70% access to potable water will be evaluated. Different delivery systems will be considered for each strategy, determining which are most plausible based on village population, projected cost, and affordability under each policy. The viability of different systems takes into account capital costs, maintenance, system lifetime and access to spare parts. It is likely that different delivery systems will be recommended to close different types of supply gaps.

The final stage of analysis focuses on pricing, and how a pricing system is the primary way to ensure the sustainability of the recommended system(s) by providing revenue for maintenance and system replacement. A fundamental component to access is affordability, and proper attention will be given to the 50.7% of Bo residents who are living below the poverty line.[42]

---

[42] Kristen Himelein, "A Poverty Profile for Sierra Leone," *The World Bank Poverty Reduction & Economic Management Unit,* 9, last modified June, 2013, accessed January 31, 2016, http://www.sierraexpressmedia.com/wp-content/uploads/2013/07/Poverty-Profile-Sierra-Leone.pdf.

Many indicators must be estimated from existent literature and small-scale surveys, and serve as a starting point from which users, supply gaps, and potential solutions can be discussed. The ProVictimis survey was conducted by the French NGO in 2010-2011, using teams of trained local interviewers to canvass the entire district, visiting every village that was known to have a waterpoint and cross-checking information on those that did not.[43] Joseph Musa's household survey provides insight into water access and filtration, sanitation, and hygiene in these rural communities, and was conducted by trained teams of local residents.[44] The Sierra Leone Waterpoint Survey was a mapping exercise led by the Ministry of Energy and Water Resources, during which every public improved waterpoint in the country was surveyed, with reports on functionality, financing, and technical specifications available.[45] These reports form the basis of the simulation, while other indicators are estimated from reports on Sierra Leone by development banks, NGOs, academics, the Ministry of Water Resources in Sierra Leone, and others.

The limitations of this approach are that simulation is not fully based on locally specific empirical data; as a result, there are limited conclusions that can be drawn from the analysis. The recommendations based on simulations are contingent on further data collection and reanalysis before they can be confidently pursued. Considering that the hypothetical village is constructed from survey data and water allocation literature, it is likely there are elements excluded from the model that may have a large impact in practice, such as family structure and cultural associations with water that impact its use. The simulation can provide valuable insight into the feasibility of different delivery systems for different income levels and populations. However, the unit costs

---

[43] Francois Bourgois and Pietro De Cao, "Existing Water Access Points in the Districts of Bo, Koinadugu, and Tonkolili in Sierra Leone," *Fondation ProVictimas Geneve,* 3, last modified February, 2013, accessed February 2, 2016, http://provictimis.org/download/provictimis_water_access_survey.pdf?lang=en.
[44] Musa, 6.
[45] "Sierra Leone Waterpoint Report," *WASH Learnings SL* (2012): 1, last modified June 26, 2012, accessed March 14, 2016, http://www.washlearningsl.org/sierra-leone-waterpoint-report-review-version-2012/.

employed do not have population parameters—most importantly, a minimum population at which these costs hold true—making it nearly impossible to map out where certain systems would have advantages over others based on density, and where opportunities for shared systems would be possible at the district level. The lack of location-specific data regarding water supply, consumption, population density, and income makes empirical analysis nearly impossible, and highly inaccurate if accomplished. Therefore, simulation of the representative water demand and distribution options provides the clearest picture of water management in Bo.

VIII. Water Demand in Bo

The three main user types in water allocation scenarios are household, industrial, and agricultural users who each have different impacts on water quality and demands for water at different times of the year. Information regarding these three users in Bo is provided below, in addition to their respective impacts on demand for water in Bo.

Household Users

Bo District has a population of 544,745 as of 2011. Bo Town is the second-largest urban area in Sierra Leone, with a population of 215,474. There are fifteen chiefdoms within the district. Population is concentrated in the center of the district, with smaller communities in the peripheral chiefdoms. 55% of the population is rural or rural periurban, and 45% is urban, with the urban population entirely located in Bo Town. 50.7% of Bo residents live below the poverty line.[46]

[46] Himelein, 9-18.

The Sierra Leone National Water & Sanitation Policy defines community sizes and their respective service levels as such:

- **Rural** means communities of 150-5,000 people and the planned service level is to provide 20 liters/capita/day (l/c/d) of water within 250m of users, with 250-500 users per waterpoint.
- **Peri-urban** water supply includes small towns and communities of 5,000 to 20,000 people. The planned service level is 60 l/c/d and the system would include some house connections as well as standposts.
- **Urban** means communities of more than 20,000.[47] The planned service level has not been outlined in the policy, but is estimated to be 60 l/c/d and would include a full range of systems.

The average village population in Bo is approximately 250 residents, so the first level of analysis will focus on rural water systems. Improve International, an American NGO dedicated to evaluation of water and sanitation programs in developing countries, conducted a study of water use per person per day in a variety of regions around the world and compared them with WHO recommendations. The study found that rural African communities had a minimum usage of 5 l/c/d, and an average usage of 31 l/c/d. The WHO recommends a standard of 50 l/c/d for a community, with an absolute minimum of 20 l/c/d in emergency situations.[48] With this

[47] "Rural Water Supply and Small Towns Strategy Document," *WASH Learnings SL*, Ministry of Water Resources, last modified 2013, accessed March 10, 2016, http://www.washlearningsl.org/wp-content/uploads/2015/03/Rural-Water-Supply-and-small-towns-strategy-document-2013.pdf.

[48] "How Much Water Is Enough? Determining Realistic Water Use in Developing Countries," *Improve International*, last modified April 27, 2014, accessed March 14, 2016, https://improveinternational.wordpress.com/2014/04/27/how-much-water-is-enough-determining-realistic-water-use-in-developing-countries/.

information in mind, the representative village will have 250 residents that each require 50 liters of water per day. A fundamental assumption of this model is that as potable water is more readily accessed, usage will increase, and therefore the recommended system should have the capacity to meet increased demand.

Table 2. *Aggregate individual demand to show simulated household use of water monthly in the representative village.*

Demand Simulation: Household User Demand

	Days in Month	Individual Demand (L)	Avg Demand per Day (L)	Individual Demand (m3)
January	31	387,500	12,500	388
February	28	350,000	12,500	350
March	31	387,500	12,500	388
April	30	375,000	12,500	375
May	31	387,500	12,500	388
June	30	375,000	12,500	375
July	31	387,500	12,500	388
August	31	387,500	12,500	388
September	30	375,000	12,500	375
October	31	387,500	12,500	388
November	30	375,000	12,500	375
December	31	387,500	12,500	388
Total		**4,562,500**		**4,563**

In the representative village monthly demand per person is under 400m^3 and annual water demand is 4,563m^3. Under the guidelines of the National Water & Sanitation Policy, this village's needs would be met by a single rural water supply system. A majority of the villages in the study have less than 500 residents, so many of the access gaps in these villages will be met with a single system. The main exception to this model is Bo Town, a much denser area with greater benefits reaped by economies of scale. A discussion of supply gaps in Bo Town is included in section VIII.

Agricultural Users

Almost half of all Bo residents cited their primary household occupation as agriculture in 2011, 75% of whom cultivate rice.[49] Rice is a staple crop for Sierra Leone, with annual consumption of 76 kg of rice per person, giving the country one of the highest rice consumption per capita levels in Sub-Saharan Africa.[50] The rural farmers have rice farms that range from 0.5-2.0 hectares in size, and produce 0.96 metric tons of rice per hectare on average.[51] The majority of the rice is consumed by the farmer's family unit, as subsistence farming is the norm in rural areas and markets for rice sales are often unavailable or underdeveloped. Rice is a water-intensive crop, requiring nearly 3,000 L of water to produce 1 kg of rice.[52] For each Sierra Leonean to consume 76 kg of rice, 228,000 liters of water per person are required for cultivation.

The 25% of farmers who are not cultivating rice are involved in a variety of other cash crops. Cassava is the second most important crop in Bo, because the tubers and leaves can be eaten by themselves, and cassava products like gari, flour, and chips are popular household items.[53] Cassava cultivation is less water-intensive than rice cultivation, and is entirely rainfed. The main tree crop is palm oil, which requires manual watering when planting seedlings, but is entirely rainfed once it has been established. Other crops that are planted are maize, groundnut, cocoa, coffee, banana, plantain, and yams.[54]

---

[49] Himelein, 23-24.
[50] Larbi.
[51] Larbi.; "National Rice Development Strategy (NRDS) Sierra Leone," *Japan International Cooperation Agency*, *Coalition for African Rice Development*, last modified 2009, accessed March 1, 2016, https://www.yumpu.com/en/document/view/25761731/sierra-leone-national-rice-development-strategy-jica.
[52] "Water Usage in Rice," *Knowledge Bank*, *International Rice Research Institute*, last modified 2007, accessed March 14, 2016, http://www.knowledgebank.irri.org/ericeproduction/III.1_Water_usage_in_rice.htm.
[53] Larbi.
[54] Saffa Moriba, "Sierra Leone News: Sierra Leone Traders Union Meet Members of Agricultural Business Centers in Bo," *Awoko News*, last modified July 30, 2014, accessed March 14, 2016, http://awoko.org/2014/07/30/sierra-leone-news-sierra-leone-traders-union-meet-members-of-agricultural-business-centers-in-bo/.

For purposes of the hypothetical village, it is assumed that roughly half of the residents cultivate rice. This would require 485,000 liters of water per hectare each month. Using average rainfall data from the Climatic Research Unit of the University of East Anglia, Table 3 shows that the rainfall during the rainy season would be more than sufficient to meet this demand, with a considerable surplus of rainwater after rice-growing demands are met. Therefore, as long as rice continues to be planted only in the rainy season, the hypothetical village allows for the assumption that rice cultivation will remain entirely rainfed in Bo District.

Table 3. *Agricultural Demand for Water in the Rainy Season*

Demand Simulation: Agricultural Demand

	Season	Rainfall (mm)	Rainfall on 1 hectare (L)	Agricultural Production (kg)	Agricultural Water Demand (L)	Net Agriculture Demand less
May	Rainy	197	1,972,484	162	485,000	-1,487,484
June	Rainy	304	3,037,683	162	485,000	-2,552,683
July	Rainy	469	4,688,293	162	485,000	-4,203,293
August	Rainy	537	5,373,153	162	485,000	-4,888,153
September	Rainy	420	4,204,737	162	485,000	-3,719,737
October	Rainy	285	2,852,786	162	485,000	-2,367,786
Total		**2,213**	**22,129,135**	**970**	**2,910,000**	**-19,219,135**

The other crops cultivated in Bo are primarily rainfed as well, so there is little reason to believe that there will be significant agricultural demand for water. There is little information that indicates any crops are grown during the dry season, when irrigation would be critical to cultivation of any sort. This is likely because formal irrigation techniques are not used on such small scale operations in Bo. The demand for water will be relatively unaffected by agricultural operations unless large-scale farming begins and extends crop cultivation into the dry season.

Industrial Users

Most of the industrial users that impact water quality are involved in the mining, refining, and use of raw materials in manufacturing. In Sierra Leone, extractive industries are the most prevalent, tapping into the rich mineral deposits throughout the country. Bo District is one of the top three districts for diamond production. Most of the diamonds in Bo are found within the Sewa drainage area. These alluvial diamond were eroded from the source kimberlites to the northeast and transported over time by running water. They are found in river channel gravel, flood-plain gravel, terrace gravel, and gravel residue in soils and swamps.[55] Gold deposits have been discovered in Bo as well, and the rivers and streams that drain the gold-rich areas often contain gold. Figure 9 shows all active mining licenses in Sierra Leone, and while the areas near Bo Town do not reflect any mining activity, there are many active mining licenses within the Sewa river basin. Figure 10 shows a series of licenses issued along a section of the Sewa River and its drainage area.

[55] "Key Minerals," *Ministry of Mines and Mineral Resources*, last modified May 14, 2014, accessed March 14, 2016, https://slminerals.org/key-minerals/.

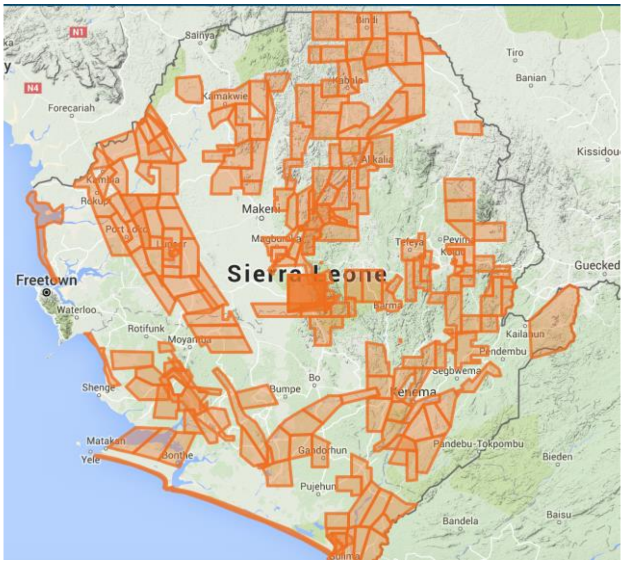
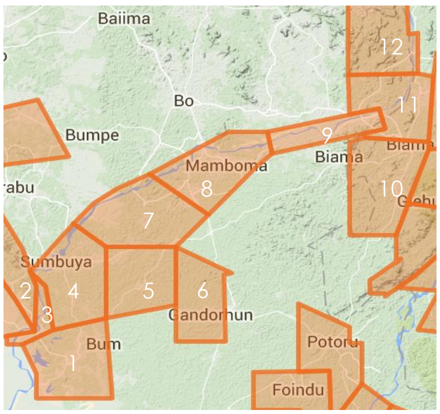


Figure 9. All active mining licenses in Sierra Leone. Each license area is marked by thick orange borders, and different companies often own neighboring license areas.[56]



1-ALLOTROPES Diamond Company Limited
2-Sierra Mineral Holdings No.1 Limited
3-Irugal Resources Limited
4-ALLOTROPES Diamond Company Limited
5-ATLANTIC Investment and Trade Company Limited
6-Rui Xiang Mining (SL) Limited
7-ALLOTROPES Diamond Company Limited
8-ALLOTROPES Diamond Company Limited
9-ALLOTROPES Diamond Company Limited
10-Universal Gold Mining and Exploration (SL) Limited
11-Minatura SL Limited
12-Golden Saint Resources (Africa) Ltd

Figure 10. Detailed section of Figure 9 showing mining licenses in southeastern Bo District along the Sewa River and its drainage area. Labeled areas and the company owning the license are listed.

It is important to note that these licenses do not account for the informal or artisanal operations active throughout Sierra Leone. The Ministry of Mines and Mineral Resources currently estimates that there are approximately 1,700 artisanal mining operations across the Bo,

[56] "GoSL Online Repository," *Ministry of Mines and Natural Resources*, accessed March 14, 2016, http://sierraleone.revenuesystems.org/login/auth.

Kono, Kenema, and Pujehun districts.[57] These small-scale informal mining operations are often undertaken by small groups using simple equipment, such as sieves and pans, to search for diamonds in alluvial deposits. These operations are taking place on land that is not licensed or regulated for mining activities, and there is little regard for environmental impact or the related effects on biodiversity and potential agricultural land use.[58]

The diamond and gold mining operations in Bo are directly affecting the water quality of the Sewa River. In both formal and informal operations, river sediments are disturbed and may be removed from the river entirely once panned through, and other contaminants often enter the river during the mining process. Formal operations often have more serious environmental impacts as they are removing river sediments in much larger quantities and returning it back to the river rapidly. The presence of mining operations within the river basin will increase filtration requirements and treatment needs for potable water in nearby communities. However, mining operations of this nature do not require water for processing and will not alter the demand simulation.

The main three users in a watershed are households, agriculture, and industrial operations. While typically all three user types are stakeholders in water allocation problems, Bo is a simplified case because only the household users have an unmet demand for water. Therefore, when identifying gaps in water supply only individual and household consumption will need to be addressed. The agricultural and industrial operations are important only insofar as

[57] "Key Minerals."
[58] "Diamond Mining and the Environment Fact Sheet," *Diamond Facts*, *World Diamond Council*, accessed March 14, 2016, http://www.diamondfacts.org/pdfs/media/media_resources/fact_sheets/Diamond_Mining_Environment_Fact_Sheet.pdf.

they affect the quality of available water, and the filtration and treatment regimens that must be completed prior to household consumption.

IX. Gaps in Water Supply

The Sierra Leone Waterpoint Survey reported 4,902 waterpoints in Bo District, 1,825 of which were in Bo Town. However, only 125 waterpoints in Bo Town were open to the public, and the remainder were for private use in households or compounds. Using data from this survey, broad problems with water infrastructure are identified. Figure 11 shows the functionality of all identified public and private waterpoints, with only 52% of systems providing potable water all year. The ProVictimis survey focused solely on public structures across Bo District and provided population data to assess overburdened systems and the number of needed systems in areas that have no infrastructure. While the Sierra Leone Waterpoint Survey includes more waterpoints in the district, the population data provided in the ProVictimis survey allows the supply gaps to be assessed at the village level. Therefore, the ProVictimis survey is more useful for the remainder of the analysis on supply gaps.

Common Problems in Bo District

Common problems associated with potable water access in Bo are unprotected waterpoints, partially constructed waterpoints, non-functional infrastructure, lack of filtration capabilities, and seasonality.

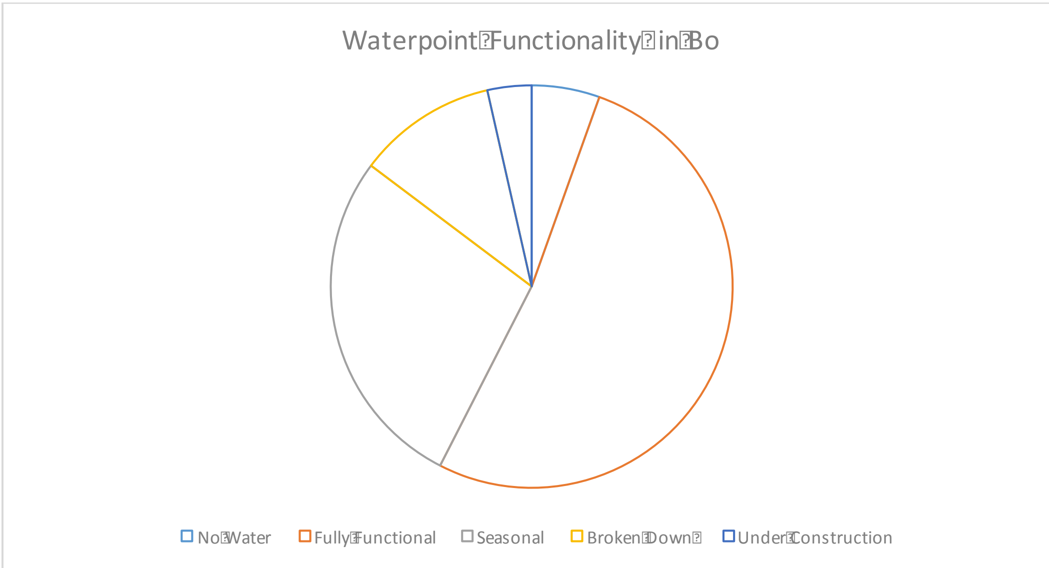


Figure 11*. Functionality of 4,902 public and private waterpoints identified in Bo District in 2011.*

The high proportion of seasonal wells, which dry up during certain months of the year, shows that there is limited technical knowledge employed during well construction. An InterAide study of the Kamaranka well which provided detailed rainfall information also studied the changes in the water table to identify the appropriate well construction timeline. It is important to sink wells when the water table is at its lowest point to ensure that they will be able to provide water throughout the dry season. Figure 12 shows the water table levels in the Kamaranka well, which vary by almost five meters throughout the year.

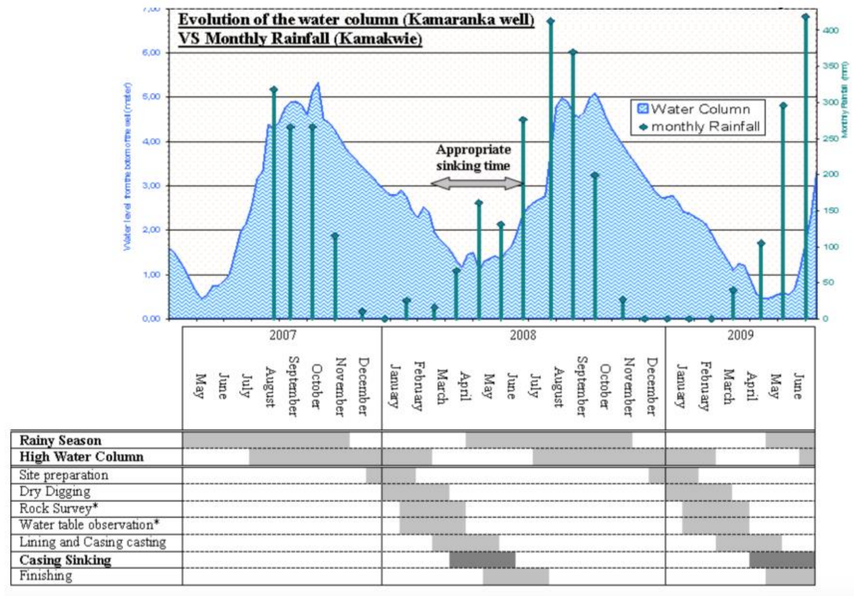


Figure 12. *InterAide Study of water table levels at the Kamaranka well, with well construction timelines suggested with an emphasis on sinking wells at lowest points.* [59]

There are 723 waterpoints that are listed as broken-down or under construction, making up 15% of the total identified waterpoints. These problems are indicative of an inadequate supply chain for parts like pumps for wells, and a failure to provide annual maintenance to the pumps to prevent breakdowns. These are common problems across Sierra Leone, and the Ministry of Water Resources has begun to address them by adopting the India Mark 2 pump as the standard for all waterpoints, and helping to expand access to spare parts in each district. Protected wells with no pump are the most common system in Bo, followed by hand-dug wells with pumps. Standpipes are the most often damaged.

The quality of water and access to treatment is another obstacle in the supply of potable water. The Sierra Leone Waterpoint Survey provided information on water quality; however, the mechanism for testing water quality during the survey was rudimentary, basing quality metrics

[59] Francois Bourgeois, "Why Wells Should Only Be Dug in a Specific Period of the Year?" (Sierra Leone WASH Sector Learning, January 2014), 2, accessed March 14, 2016, https://www.washlearningsl.org/why-wells-should-only-be-dug-in-a-specific-period-of-the-year/.

on the smell and taste of the water rather than taking samples to identify the presence of pollutants and particulate matter. Table 4 shows the availability of different maintenance and treatment options in Bo, with a specific analysis of public waterpoints as well. Fewer public waterpoints have access to a mechanic, spare parts, or chlorine treatments in comparison to private waterpoints.

Table 4. *Maintenance and Water Quality metrics on waterpoints in Bo.*

Maintenance and Quality	All Waterpoints	Only Public Waterpoints
Mechanic in Community	67%	65%
Residents pay for water (regularly or with breakdown)	7%	13%
Spare parts available in community	67%	41%
Chlorine treatment available	69%	57%
Water is not clean	11%	9%

Chlorine treatments are the only treatment option recorded in the survey because it is one of the only treatment mechanisms available in rural areas. Ideally, chlorination should be the last step in a multi-stage filtration system because it is used to destroy microorganisms in the water, but it has no effect on turbidity, suspended solids, arsenic, dissolved oxygen, or carbon dioxide—all of which can be removed by filtration processes.[60] However, there is no record of any filtration processes occurring in addition to the chlorine treatment in Bo District. Chlorine is very useful in developing countries due to its broad germicidal potency, persistence in water systems, the simplicity of applying the treatment, and the cost-effectiveness of the chemical. [61] Adding a basic filtration component to the treatment regimen, and encouraging the adoption of both treatments at all waterpoints would make a positive impact on water quality in Bo District.

Very few public waterpoints charge users for water, and those that do charge often only do so when there is a breakdown and new parts are needed. This creates challenges for

[60] Lara Fabrizi, "Water Supply in Small Communities," *LennTech Water Treatment Solutions*, accessed March 14, 2016, http://www.lenntech.com/small-community-water-supplies.htm#7._Water_treatment_%23ixzz42j3Gpk9l.
[61] Fabrizi.

maintenance of existing systems and expansion of delivery systems as populations grow, because there are no funds reserved for these expenses. Therefore, when systems break down they are either left unfixed, or will be opened and left unprotected so that water can be withdrawn by bucket instead of a pump. There is a reliance on foreign aid and NGO assistance to repair broken systems, as the community often cannot raise enough money to finance a repair.

Access to water in Bo varies widely across the district. Some areas have consistent access to potable water, which is enough to put Bo ahead of other districts in terms of need. However, there is a gross imbalance of water supply on the section level, with areas within and around Bo Town having much better access to potable water and fewer users per waterpoint than many rural areas in the district. Some areas of Bo still have no waterpoints at all, while others have overburdened waterpoints that are serving 500 - 1,000 residents (Figure 12). This imbalance indicates that supply gaps will also differ geographically.

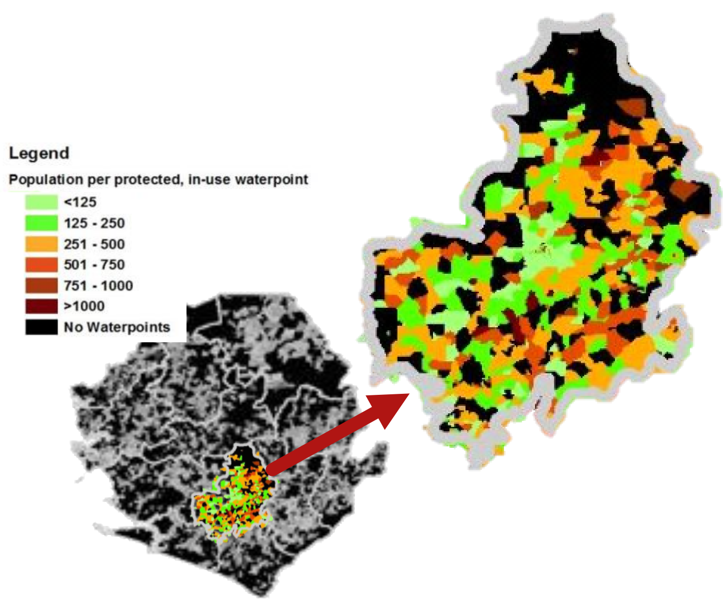


Figure 13. *Population per protected, in-use waterpoints including seasonal waterpoints by Enumeration Area.* [62]

[62] "Sierra Leone Waterpoint Report," 7.

Supply Gaps in Bo Town

On an aggregate level, Bo Town has 107 people per protected, in-use waterpoint. This is well below the standard recommendation of 250-500 users per waterpoint, so Bo Town does not appear to have supply gaps. There is a chance, however, that Bo Town may still have supply gaps that merit attention. Table 5 shows the North Ward has many fewer waterpoints per km^2 than the East and West Wards. If the population density in the North Ward is considerably lower than in the East and West Wards, this decrease in waterpoints would be logical. However, there is no available population data broken down by ward for Bo Town, so it is not possible to determine if the waterpoints in the North Ward are overburdened. Thus any potential supply gaps in Bo Town will not be further discussed.

Table 5. *Service levels in Bo Town based on protected, in-use waterpoints including seasonal waterpoints.*

Bo Town

Population	# of Waterpoints	Area (km2)	Pop/WP	WP/km2
208,885	1,948	23.2	107	84

Ward	# of Waterpoints	Area (km2)	WP/km2
East Ward	803	9.23	87
West Ward	858	7.79	110
North Ward	287	6.5	44

Supply Gaps in Rural Bo

Supply gaps in rural Bo can be segmented into four categories—areas with no water system; no functioning system; only seasonally functional waterpoints; and overburdened waterpoints. The supply gaps identify the scope of access problems, and as only 40% of rural Bo has full access to potable water, there are considerable improvements to be made. These gaps have largely been identified based on the criteria outlined by the National Water & Sanitation policy for rural communities, as the community populations are almost all under 5,000 residents. The criteria for assessment of full service provision in an area is if 20 l/c/d of water is provided within 250m of users, with no more than 250-500 users per waterpoint. In this analysis, it is assumed that waterpoints within a single village will meet the 250m distance requirement as there is no information to gauge actual waterpoint distance from users. The gaps in supply are summarized below in Table 6.

Table 6. *Gaps in the supply of potable water identified by type of available systems and affected populations and villages.*

Available Systems	Affected Population	*% of Total Population*	Affected Villages	*% of Total*
No System at all	72,401	*26%*	434	*42%*
No Functioning System	44,864	*16%*	117	*11%*
Only Seasonal	32,028	*11%*	91	*9%*
Overburdened WP	19,908	*7%*	630	*61%*
Fully Served	112,717	*40%*	316	*31%*
Total (not including Bo Town)	**281,918**	***100%***	**1027**	***100%***

The largest supply gap in rural Bo is also the most pressing, involving areas with no water infrastructure at all that are relying on contaminated surface reservoirs for their water supply. There are 434 villages in Bo with no system, making up 42% of all villages in the district. 96% of these villages have fewer than 500 residents, but in total, 72,401 people are in villages without a waterpoint (which is 26% of the total population). These villages are located in thirteen of the fifteen chiefdoms, illustrating that this problem is geographically diverse. It is unsurprising that many of the areas with no system have small populations, but in aggregate this is a pressing problem. To close this gap, 453 systems would need to be constructed in 434 villages. This shows that most villages have 500 or fewer residents, and can be satisfied with a single system. The villages with larger populations may require two or three systems to fully meet the needs of their residents, calling for additional systems to be constructed.

There are other areas in Bo that effectively have no waterpoints because none of the existing waterpoints are functional. While this is an easier problem to solve because some amount of infrastructure already exists, it remains a top priority as 16% of the rural population has no access to a functioning waterpoint (where all waterpoints are either broken down, under construction, or functional for less than 6 months per year). To bring all 117 villages to full access, 119 systems would need to be repaired or completed and 31 would need to be constructed. While the majority of this gap is filled with renovations of existing systems, several villages do not have enough existing systems to maintain fewer than 500 users per waterpoint if all waterpoints were renovated. Therefore, new waterpoints would need to be constructed in some villages to keep user levels within the service level standards.

The next biggest supply gap is caused by waterpoint seasonality. Fewer than half of the waterpoints in rural Bo are functional all year, and 18% of all waterpoints are only functional several months out of the year due to fluctuation in the water table between rainy and dry seasons that was not accounted for during construction. Of the 176 seasonal waterpoints documented in rural Bo, 146 are hand-dug wells. This indicates that it is much more likely for hand-dug wells to be seasonal than other systems, because while hand-dug wells make up 62% of all waterpoints in rural Bo, they account for 83% of all seasonal waterpoints. Figure 14 shows the distribution of seasonal and fully-functional waterpoints.

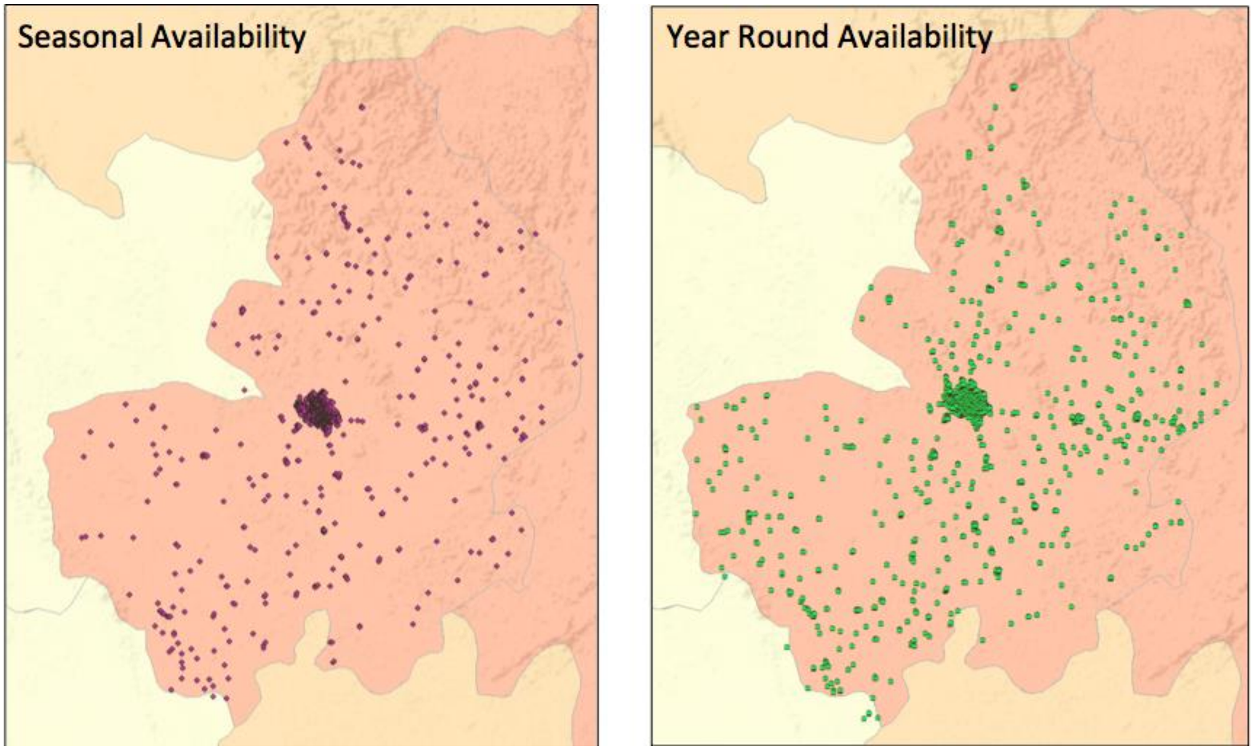


Figure 14. Distribution of seasonal and fully-functional waterpoints in Bo District.[63]

Seasonal waterpoints are evenly spread throughout rural Bo; therefore, seasonality is not a result of certain chiefdoms being underserved or having access to less technical knowledge during waterpoint construction, but rather a widespread and evenly shared problem throughout the district. The inconsistent functionality of waterpoints has left many people without access to a fully functional waterpoint, with 32,028 people in 91 villages relying solely on seasonal waterpoints. Bringing the villages with only seasonal waterpoints up to full access would require 97 seasonal waterpoints to be improved and 10 additional waterpoints to be constructed.

Overburdened waterpoints—defined as more than 500 users relying on a single waterpoint—are a problem throughout Bo. This problem is related to the other gaps in supply, because when a waterpoint is seasonal, broken, or under construction it adds the pressure of

[63] Katherine Ling, "Increasing Access to Potable Water in Sierra Leone: The Role of National and Local Governance" (working paper, Lawrence University, Appleton, 2016).

more users to the fully functional waterpoints. There are 36 sections across 14 chiefdoms that average more than 500 users per fully functional waterpoint. When seasonal waterpoints are included, 17 sections in 10 chiefdoms still have more than 500 users per waterpoint. However, when other supply gaps are removed from the analysis and assumed to be filled, there are 19,908 people relying on waterpoints that are already serving 500 users. To close this gap, 67 systems would need to be constructed in 47 villages. Larger villages often need more than one additional waterpoint to prevent their systems from becoming overburdened, while many smaller villages are fully served with one newly constructed waterpoint. Failing to reduce pressure on these waterpoints will increase rates of damage and need for system replacement as these rural waterpoints are not designed to be high capacity.

The fact that 53% of waterpoints in rural Bo are underperforming or unusable is troublesome, and reinforces the need for increased infrastructure investment in small communities, regular community maintenance, more consistent capital flows to ensure complete construction, and better technical knowledge to inform well construction at appropriate times of the year.

In sum, there are four main supply gaps in rural Bo. The most pressing are (1) communities with no system and (2) communities with no functional systems. In those communities, which cover 42% of the rural population, the only source of water is unprotected and likely contaminated. Less pressing supply gaps exist in the case of (3) seasonal and (4) overburdened waterpoints. These are still important, however, as they are preventing populations from access to potable water year-round, and, if left unresolved, could lead to increased rates of system breakdowns.

X. Potential Delivery Systems

There are five delivery systems that can be used to fill the supply gaps noted in rural Bo: hand dug wells, drilled wells, house connections, standposts, and rainwater harvesting systems. Currently, hand-dug wells and standposts are the most common delivery systems.

Hand-dug wells are an option in many areas, but their feasibility depends on the rock type and the depth of the lowest point of the water table during its yearly fluctuations. Drilled wells can be used in almost all situations, including those deemed unsuitable for hand-dug wells. If either type of well is relatively shallow and only taps into the unconfined aquifer, it is more susceptible to pollutants and contamination. If a well is drilled through an impermeable layer of rock so that water is obtained from a confined aquifer, it is less susceptible to contamination. House connections are piped systems that deliver water from its storage location to an individual building, where it can be routed within the building to provide water for sinks, showers, toilets, etc. Standposts are piped systems that end in a public tap rather than a house connection, and are often practical systems to supplement access when house connections are already in use in the area. Rainwater harvesting is the final system that can be quite useful in areas with aggressive rainy seasons like Sierra Leone; however, these systems often serve a single household or small area due to limitations of cost-effective storage capacity which makes them more expensive to implement on a broad scale.

These five systems will be evaluated on their ability to bring access to potable water in rural Bo up to 70%, using both cost-benefit analysis and feasibility criteria. System costs are incredibly location specific, and the process of projecting costs for a single system requires professional expertise. Slight changes in gradient, rock type, or pipe diameter can drastically change costs, but can only be determined once the specific pipe route or well site is known and surveyed. Therefore, unit costs have been endorsed by the WHO for use in cost-benefit analyses for rural water systems in developing countries and are the basis for the cost analysis of each system (Table 7). These costs are shown in 2011 U.S. dollars (USD). While these are not precise costs, they allow for comparison of the advantages and tradeoffs associated with each potential delivery system. The ranges listed in the first four columns of Table 7 provide some indication of scale economies, with the assumption that as population density increases, the cost per m^3 will be lower. A significant limitation of these unit costs is that there are no population parameters at which they hold constant. Therefore, in low density areas—such as the ones evaluated in this paper—it is difficult to know when these unit costs are accurate reflections of cost, and when they are serious underestimates. In an effort to reflect more accurate costs in the recommendations, individual demand is estimated to be 50 l/c/d rather than the National Water & Sanitation Policy recommendation of 20 l/c/d. This is in line with WHO recommendations and brings the estimates closer to desired values; however, the limitations of these unit costs cannot be ignored, and a more thorough cost estimation should be employed if recommendations are to be evaluated for implementation.

Table 7. *Average and high unit costs for potential delivery systems.*

System Type	Capital investment ($ per person)	Recurrent (% annual	System lifetime (years)	Water demand (Lppd)	Average Unit Cost (per m3)	High Unit Cost (per m3)
House connection	92-144	20-40	30-50	80-120	$0.43	$0.69
Standpost	31-64	0-10	10-30	50-80	$0.22	$0.39
Handpump on drill well	17-55	0-10	10-30	20-30	$0.40	$0.83
Dug well	21-48	0-10	10-30	20-30	$0.40	$0.72
Rainwater	34-49	5-15	10-30	20-30	$0.48	$0.77

XI. Policy Options to Reach 70%

Currently 40% of the population has its water needs fully met year-round. In order to meet the MDG target of 70% access to potable water, an additional 84,576 people must be granted access to a fully functional waterpoint. There are many ways to achieve this goal, and three potential policy options are outlined with regard to respective costs and benefits. The supply gap that addresses the population with greatest need is also the costliest to fill, while the gaps that address less pressing problems are significantly less costly. Thus, priority and cost must be balanced as the target levels are pursued, especially given the tight budget constraints of the Sierra Leonean government. The first policy approach is focused on greatest need, with priority going to areas with no infrastructure or no functional infrastructure. The second approach attempts to balance all the supply gaps evenly, closing each gap by 50%. The third approach is the lowest-cost approach, filling the least costly gaps until the MDG target is realized.

High unit cost approaches were selected because all of the communities in question are low density and have fewer than 3,500 residents. It is important to recognize that the costs are per m^3 of water, rather than single system implementation cost, and they incorporate depreciated capital costs over the system lifetime. Therefore, the annual operating cost of each of these systems is included, as well as the total cost incurred over the average system lifetime in 2011 USD. The lifetime cost is not a present discounted value calculation, but instead is a summation of annual cost over the system lifetime. There is no lower population bound for which these unit costs hold true; therefore, it is not possible to tell if this information is reflective of the actual system implementation cost for very small areas. However, it allows for valuable comparisons to be made between systems.

In addressing broken or non-functional systems, the repair is assumed to be the purchase of a new India Mark II pump because pump damage and theft are some of the most common problems causing waterpoints to be nonfunctional. The ProVictimis Survey documented that 26% of systems were nonfunctional due to absence of a pump or needed pump repairs, and that around 50% of surveyed systems used the India Mark II pump.[64] Extreme seasonality and other physical damages affect a substantial number of waterpoints, but the conditions are too variable to be generalized to a single cost or solution. Pumps are used on both hand-dug and drilled wells, but standposts, rainwater harvesting systems, and house connections do not require pumps at the point of distribution. A high proportion of waterpoints are hand-dug wells; therefore, the cost of repaired systems is estimated as the purchase of the pump and the recurrent costs of hand-dug well operation for one year. Capital costs are not included for these systems because it is assumed that these costs have been paid in full already.

It is difficult to estimate the cost of seasonal waterpoint improvement because the majority of these waterpoints are hand-dug wells, which are often built with manual labor and little material other than shovels and rocks to line the sides of the well. Extending the well vertically to reach the low point on the water table can be accomplished by a similar technique, and there is no available information on projected cost of a well extension. As most of the difficult work in constructing the well has been completed, it is a relatively simply matter to continue digging the well during the dry season. Therefore, it is estimated to be low cost, at $500 of expense per improved waterpoint in addition to the recurring costs of operation once the well is fully functional.

[64] Bourgois and De Cao, 10.

Policy Option 1: Priority

If the gaps in supply are addressed by greatest need, then the areas with no system at all will be brought up to 100% access, and 27% of the people without functional waterpoints would have their systems upgraded to fully-functional status, bringing overall access to potable water in rural Bo up to 70%. This requires 453 systems to be constructed in 434 villages with no system currently, and the 8 largest villages with nonfunctional waterpoints to be improved with 9 points being repaired or completed and 18 constructed. In total, this strategy would require 471 newly constructed systems and 9 repaired systems for Bo to reach the 70% target.

The costs associated with implementing the Priority Option through five potential delivery systems are outlined in Table 8. At the lowest cost, implementing standposts to fulfill the requirements of the Priority Option would cost $584,882 in the first year, and over the course of the twenty-year average system lifetime these gaps would remain filled for a total cost of $11,597,737. Hand-dug wells are the next most feasible option, with first year operation of waterpoints under the Priority Option at a cost of $1,071,084 and the twenty-year average lifetime operation cost of $21,321,789. Although house connections are the second least costly choice for one-year operation, costing $1,026,884, these infrastructure costs are intended to be shared amongst larger populations and are likely not feasible in villages with fewer than 500 residents.

Table 8. *Cost of the Priority Strategy to reach 70% access (bringing full access to villages with no system and 27% of those with no functional system).*

System Type	High Unit Cost (per m3)	471 New Systems (442 villages)	9 Repaired Hand Dug Wells	Total Cost for 1 Year	Total Cost for Average System Lifetimes
Standpost	$0.39	$574,603	$10,279	**$584,882**	**$11,597,737**
House connection	$0.69	$1,016,605	$10,279	**$1,026,884**	**$40,875,568**
Dug well	$0.72	$1,060,806	$10,279	**$1,071,084**	**$21,321,789**
Rainwater	$0.77	$1,134,473	$10,279	**$1,144,752**	**$22,795,130**
Handpump on drill well	$0.83	$1,222,873	$10,279	**$1,233,152**	**$24,563,140**
Cost of India Mark II:	$555	repaired systems	$4,995		

This policy option is the most expensive way to bring access in rural Bo up to 70% because it mainly involves the construction of new systems. These are capital intensive projects that cost more than renovation of an existing system. However, cost is not the only factor to be considered, and if the goal is to address the greatest need in the district then this becomes a compelling option.

Policy Option 2: Close each gap halfway

While addressing areas that currently have no system is a top priority, it is also the costliest gap to fill because the areas are low density and spread widely across the district. They are also harder to reach than more populated areas, and if it is not possible to bring equipment to construct new waterpoints into an area, the gap would be unable to be completely filled. Closing each supply gap halfway (*i.e.*, bringing access to 50% of the population that is currently affected by each supply gap) is the second policy option. This will entail constructing 165 new waterpoints, repairing 25 waterpoints, and improving 29 seasonal waterpoints across 136 villages for rural Bo to reach the 70% target.

The implementation and operational costs associated with the Halfway Option are shown in Table 9. Standposts are the least costly option, with a one-year cost of $513,137 and a twenty-year system lifetime cost of $9,695,241. Hand-dug wells are the second least costly option under the Halfway Option, with a one-year operation cost of $870,928 and a twenty-year lifetime cost of $16,851,060. Rainwater harvesting is the next best option for this strategy when house connections are excluded, with a one year operating cost of $957,321 and a lifetime cost of $18,578,923.

***Table 9**. Cost of the 50% Strategy to reach 70% access (bringing full access to 50% of the population affected by each supply gap).*

System Type	High Unit Cost (per m3)	165 New Systems (136 villages)	29 Improved Hand Dug Wells (23 villages)	25 Repaired Hand Dug Wells (23 villages)	Total Cost for 1 Year	Total Cost for Average System Lifetimes
Standpost	$0.39	$422,844	$45,459	$44,834	**$513,137**	**$9,695,241**
House connection	$0.69	$748,108	$45,459	$44,834	**$838,402**	**$32,401,062**
Dug well	$0.72	$780,635	$45,459	$44,834	**$870,928**	**$16,851,060**
Rainwater	$0.77	$834,846	$45,459	$44,834	**$925,139**	**$17,935,275**
Handpump on drill well	$0.83	$899,898	$45,459	$44,834	**$990,192**	**$19,236,333**
Extend Hand Dug Well:	$500	29 improved systems	$14,500			
Cost of India Mark II:	$555	25 repaired systems	$13,875			

The Halfway Option is significantly less costly than the Priority Option, with savings of nearly $2 million over 20 years relative to the standpost option. Many new waterpoints are still constructed, and renovated systems are more readily included under this policy option. For this split between new construction and renovation, rainwater harvesting systems are also a viable option, albeit costlier than standposts and hand-dug wells.

Policy Option 3: Lowest Cost

The third option does not take into account areas of greatest need or priority, but instead aims to bring access in rural Bo to 70% at the lowest total cost. The cost estimate for seasonal well improvement shows that it is the lowest-cost supply gap to fill. Therefore, the population relying on seasonal wells will have their needs fully met by this policy option, with 97 improved waterpoints and 10 newly constructed waterpoints. This is a relatively small population and does not bring Bo completely up to target. The next least costly gap to fill is broken waterpoints or those under construction. That group will be brought up to full access, with 119 waterpoints repaired and an additional 31 constructed. Even with this population served, the target level of 70% access has not yet been reached. The next least costly gap to fill is to to install new systems in the highest population areas that are either underserved or without any system, which would involve constructing 16 new waterpoints in 5 villages. In total, the Lowest Cost Option involves building 57 new waterpoints, repairing 119 waterpoints, and improving 97 waterpoints across 213 villages.

Costs associated with the Lowest Cost Option are shown in Table 10. Standposts are the least costly option, with a one-year operating cost of $342,743 and a twenty-year lifetime cost of $6,287,350. Hand-dug wells are the next least costly, with a one-year operation cost of $538,600 and a twenty-year lifetime cost of $10,204,505. The third best option is rainwater harvesting, assuming that house connections are not viable. Rainwater harvesting has a one-year cost of $557,373 and a twenty-year lifetime cost of $10,579,963.

__Table 10.__ Cost of Low Cost Strategy to reach 70% access (bringing full access to populations relying on seasonal wells or nonfunctional systems, and the largest communities who are underserved or without any system).

System Type	High Unit Cost (per m3)	57 New Systems (213 villages)	97 Improved Hand Dug Wells	119 Repaired Hand Dug Wells	Total Cost for 1 Year	Total Cost for Average System
Standpost	$0.39	$146,429	$125,363	$142,908	**$414,699**	**$7,726,483**
House connection	$0.69	$259,066	$125,363	$142,908	**$527,337**	**$19,958,461**
Dug well	$0.72	$270,330	$125,363	$142,908	**$538,600**	**$10,204,505**
Rainwater	$0.77	$289,103	$125,363	$142,908	**$557,373**	**$10,579,963**
Handpump on drill well	$0.83	$311,630	$125,363	$142,908	**$579,901**	**$11,030,513**
Extend Hand Dug Well:	$500	97 improved systems	$48,500			
Cost of India Mark II:	$555	119 repaired systems	$66,045			

The Lowest Cost Option is significantly less expensive than both of the other options, but it does not do as much for those currently without access because it results in the construction of the fewest number of new waterpoints. The Lowest Cost Option is nearly $4 million cheaper over the standpost lifetime than the Priority Option, and about $2 million cheaper per lifetime than the Halfway Option. These are significant savings, especially given the budget constraints that exist in Sierra Leone, but this policy option gives priority to meeting the MDG target over meeting the most pressing needs in the district.

It is apparent that standposts, hand-dug wells, and rainwater harvesting systems are the least costly options for new system construction. New system construction is the most expensive tool used to fill supply gaps, with system repair and renovation proving to be less costly. Depending on the balance between need and funding that must be struck, it is likely that a lower cost approach will be taken, such as those outlined in policy option 2 and 3. The gaps that are filled first will depend on the objective of the policy and Sierra Leone's priorities, mainly on whether meeting the MDG target outweighs meeting the most pressing needs in the district.

XII. Non-Cost Considerations

It is easy to see that the various systems and strategies have their own costs, but they each have unique benefits as well. The selection of systems to fill supply gaps in specific areas should go beyond broad cost analysis to ensure the optimal service in each area. There are undoubtedly population parameters that limit the feasibility of implementing certain systems, such as house connections, in areas with very small populations; however, that information is not available for any of the system types and could not be fully incorporated into the recommendations of this paper. The selection of appropriate systems to fill gaps should incorporate a multitude of criteria, but the first step is to find systems that work well given the geology and topography of the area. Some systems may seem cost-effective in the abstract, but once they are costed out with regard to local elevation changes, the hardness of rock types present in the area, and other technical specifications, the costs may rise rapidly and other systems will become more cost-effective in comparison. Also, accessibility to spare parts, chlorination, and maintenance for the chosen system is imperative to its sustainability. Underpinning each of these components of sustainability is funding, because without access to funds for recurring costs of maintenance and repair, the system will break down.

XIII. Funding

Funding must be attained for the initial implementation of new systems, and the repair or improvement of existing waterpoints. Sources of funding are individual contributions at the community level, government subsidies, and NGO involvement. The initial costs are high, because implementation is capital-intensive, and it is unlikely that individual household contributions would be able to cover these expenses unless capital costs can be amortized over the lifetime of the system. It is common for the government to heavily subsidize capital costs for new systems, and NGOs have built a large proportion of waterpoints in rural Bo as well, many of whom are contributors to the "Other" category below in Figure 15. Out of 2,187 waterpoints, almost 30% are privately installed, and while some of these waterpoints are strictly for private use, many charge usage fees for the public or resell water to the community. The government has funded a significant portion of the waterpoints; however, SALWACO, the government-run entity tasked with providing water to rural Sierra Leone, has only constructed 5% of the waterpoints.

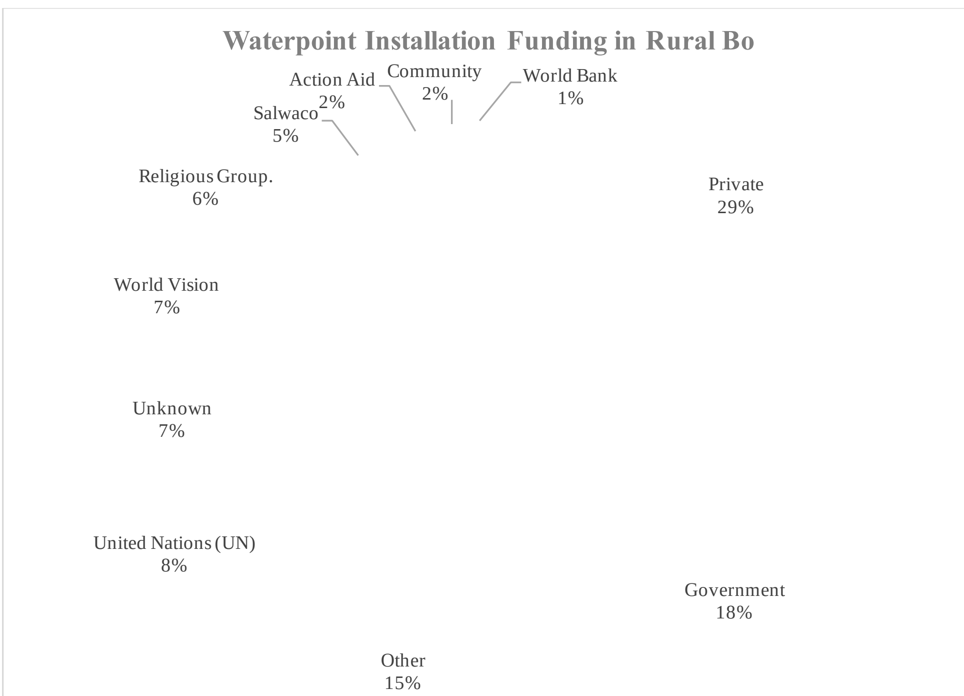


Figure 15. *Waterpoint installation by funding partner in rural Bo based on Sierra Leone Waterpoint Survey 2011.*

Although the cost of implementing a system is high, it is more common to receive large donations or subsidies for construction than smaller, regular amounts for system maintenance, water treatment, and distribution. Almost all waterpoints are constructed by government subsidies or NGOs, while less than 60% of public waterpoints have access to spare parts and chlorination. The most consistent way to fund recurring costs and ensure system sustainability is to implement a system of regular individual contributions on the community level through pricing or flat usage fees. Currently, 79% of waterpoints in rural Bo give away water for free. 10% of waterpoints charge only during a breakdown, likely charging a flat fee to each user relying on the waterpoint. However, this is less effective if there are other functioning waterpoints in the area that users can rely on, because they will be less inclined to contribute. Also, the users will not be paying based on the amount of water they consume, so even users who withdraw the smallest amounts will need to pay the same fee as the largest users. In general, users in Sierra Leone are accustomed to receiving their water for free. Currently, only 0.3% of waterpoints (6 systems in total) charge by the bucket or regularly for service. This shows that there will likely be some resistance to implementing a pricing system or contribution system to fund maintenance, filtration, and other recurring costs.

Individual contributions are critical to system sustainability, but the cost of water should not place unnecessary economic stress on the user. The UNDP has recommended that water costs should not exceed 3% of household income anywhere in the world.[65] A study of affordability in regard to American community systems meeting federal quality mandates concluded that the average cost of household water bills relative to median household income

---

[65] "The Human Right to Water and Sanitation," *UN News Center, UN Water*, last modified May 29, 2014, accessed March 14, 2016, http://www.un.org/waterforlifedecade/human_right_to_water.shtml.

should not exceed 2%, which shows that even in communities with a greater ability to pay, the cost of water should not be prohibitively expensive.[66] To evaluate the individual contributions that could be garnered from the hypothetical village, income figures will be compared with system costs. The costs that were estimated for each strategy were in 2011 USD. The World Bank recommends using GNI per capita to classify economies into income groupings, as it better reflects the full income of the residents rather than just economic production within country borders; however, it has some limitations, as it often fails to accurately reflect subsistence activities in low-income countries. GNI per capita in Sierra Leone in 2011 was $500 and increased to $700 in 2014.[67] These figures represent all of Sierra Leone, and there is no available information on Bo District specifically; so it was not possible to get more targeted income information. It is likely that the wealthiest people live in urban areas and that these GNI per capita measures are inflated by activities in Freetown and Bo Town, but for the purpose of this analysis it is assumed that GNI per capita remains $700 for all of Bo District. A comprehensive poverty investigation conducted by the World Bank in 2011 concluded that 50.7% of Bo residents live below the poverty line on less than $359 per year. Bo District also had the third highest Gini coefficient of all districts, showing unequal distribution of income amongst residents.[68] The concentration of wealth in Bo District explains why the average income would be nearly double the poverty line, even though half of the residents are known to live below it. It

[66] "Affordability Assessment Tool for Federal Water Mandates," *AWWA* (2013): 2, *American Water Works Association*, *US Conference of Mayors*, last modified 2013, accessed March 14, 2016, http://www.awwa.org/Portals/0/files/legreg/documents/affordability/Affordability-IssueBrief.pdf.
[67] "Sierra Leone Indicators," *World Bank Data*, accessed March 14, 2016, http://data.worldbank.org/country/sierra-leone.
[68] Himelein, 15.

is difficult to determine the affordability of different water systems in Bo from income information taken on a national scale, compared with poverty data taken on a district level.

However, if GNI per capita of $700 is assumed, and a contribution of 2% of each resident's assumed income is used for water ($14), some inferences can be made regarding affordability. A contribution of 2% was chosen to reduce the resistance of the local communities to adopting the pricing structure, and to account for the fact that GNI per capita in Bo is likely lower than $700. Table 11 shows the affordability of a single system to be implemented in the hypothetical village of 250 residents. 50 l/c/d is still assumed as demand. At high unit costs, house connections, standposts, and hand-dug wells can be fully funded by community contributions. Drilled wells and rainwater harvesting systems would require additional funding from government subsidies or NGO donations. It is probable that a high proportion of the population living under the poverty line is concentrated in rural communities dependent on subsistence agriculture. This would impact the affordability of the proposed systems, and require more assistance from the government or NGOs. If the GNI per capita for rural Bo was distinctly lower than $700, fewer systems would be affordable if funded solely by community contributions.

Community contributions can be most effectively used for recurring costs associated with system operation, such as maintenance, metering, staffing, and filtration equipment. These contributions can be established in a variety of ways. A pricing system could be implemented with either a flat rate per m^3 or a variable rate based on quantity. Flat rates treat all users equally, and in the rural village situation it may make more sense to establish a rate per bucket rather than m^3 because metering equipment is often unavailable. Variable pricing structures involve either an increasing block rate, a decreasing block rate, or a seasonal structure. The increasing block rate will charge a higher price per m^3 as the withdrawal increases, which incentivizes users to conserve water when possible and can reflect scarcity of the reservoir. A decreasing block rate allows users to benefit from the economies of scale associated with more water being provided from a single infrastructure investment, and therefore the price is reduced for larger quantities. This does not incentivize conservation, but in the rural village setting decreasing block pricing allows for businesses to profit from water resale, because larger quantities are received from a single waterpoint and resold to a variety of users at a market price. This may be a short-term solution for increasing access to the lower-income populations by encouraging resale from private taps in areas where public systems are not yet functional. However, it is harmful in the long-term as the country develops and wasteful behavior is encouraged and becomes difficult to change later because it has become the societal norm. A seasonal pricing structure would directly reflect scarcity during the dry season, with increased prices in months of low rainfall, and would reflect surplus during the rainy season with lower prices. This would encourage conservation during months of scarcity, and alleviate some of the stress caused by seasonal waterpoints and water shortage.

A usage fee is another option, where users are regularly (monthly or annually) charged for access to the waterpoint regardless of their withdrawal amounts. This fee structure is useful in small communities without metering technology or staff working to ensure that proper payment is received based on quantity withdrawn. Rather than relying on honesty, every user of the waterpoint is charged equally. In the systems evaluated, unit costs per m^3 are less than \$1, and recurring costs alone are less than \$0.10 per m^3 for all systems except house connections, where recurring costs are around \$0.20 per m^3. A resident of the hypothetical village demands slightly more than $1.5m^3$ each month, keeping costs low even for households with children. This would fall within the recommended contribution level; however, the usage fee would need to be assessed on a local level because system expenditures markedly differ based on location, and should be capped at 3% of local income levels, following UNDP guidelines. One of the more common contribution structures identified in Bo was soliciting payments in the event of a system breakdown; however, this is an unreliable funding source because it does not generate revenue for recurring costs outside of the emergency situation.

Once system costs for a specific location are identified, a pricing structure can be implemented that covers anticipated recurring costs over the system lifetime and amortized capital costs over the system lifetime. Assuming there is an initial subsidy of capital costs for the implementation of the first water delivery system, a sinking fund can be created to hold the amortized capital cost contributions that are included in the price. The sinking fund would not be accessible until the system needs replacement. This increases the probability of good governance of the contributions, and enough money would be saved through the amortized capital costs to implement a new system once the old system needs replacement. The sinking fund would ensure system sustainability, allowing government subsidies and NGO contributions to be directed towards supply system expansion rather than upkeep of current infrastructure. The recurring cost contributions would be spent on maintenance, spare parts, and water treatment to ensure that the system does not breakdown prior to its projected system lifetime. Whichever pricing structure is deemed most effective based on the technical capability of the waterpoints to measure withdrawals and the income level of the population, both the recurring fees and the amortized capital fees should be included to ensure system sustainability. This is a critical component to expanding access to potable water, because a sinking fund for system replacement ensures that progress made on expanding access is not undone with system failure and replacement. Scarcity rents can be included to incentivize conservation during the dry season, or to discourage large withdrawals throughout the year. As the pricing structure is developed, it is important that the total cost of water does not put undue economic stress on the household because affordability of potable water is a fundamental component to access.

Table 11. *Affordability of single system for hypothetical village of 250 residents.*

Even Income Distribution (GNI per capita of $700)												
For all 250 residents	January	February	March	April	May	June	July	August	September	October	November	December
2% of Total Income	$292	$292	$292	$292	$292	$292	$292	$292	$292	$292	$292	$292
HH Demand in m3	388	350	388	375	388	375	388	388	375	388	375	388
High Unit Cost												
House connection	$267	$242	$267	$259	$267	$259	$267	$267	$259	$267	$259	$267
Standpost	$151	$137	$151	$146	$151	$146	$151	$151	$146	$151	$146	$151
Handpump on drill well	$322	$291	$322	$311	$322	$311	$322	$322	$311	$322	$311	$322
Dug well	$279	$252	$279	$270	$279	$270	$279	$279	$270	$279	$270	$279
Rainwater	$298	$270	$298	$289	$298	$289	$298	$298	$289	$298	$289	$298
Average Unit Cost												
House connection	$167	$151	$167	$161	$167	$161	$167	$167	$161	$167	$161	$167
Standpost	$85	$77	$85	$83	$85	$83	$85	$85	$83	$85	$83	$85
Handpump on drill well	$155	$140	$155	$150	$155	$150	$155	$155	$150	$155	$150	$155
Dug well	$155	$140	$155	$150	$155	$150	$155	$155	$150	$155	$150	$155
Rainwater	$186	$168	$186	$180	$186	$180	$186	$186	$180	$186	$180	$186

Assumptions		
Annual Income	$	175,000
Amount/Month	$	14,583
2% to water	$	292

Community contributions are essential to system vitality, and basic income data suggest that standposts could be implemented and operated on 2% income contributions alone. However, high poverty levels and the frequency of subsistence agriculture in rural Bo make government subsidies or NGO involvement important for all new system implementations. The international community has recognized the need for improved water sources in Sierra Leone, with the African Development Bank and the OPEC Fund for International Development pledging $62 million, part grant and part loan, for improved water supply in the district capital cities of

Bo, Kenema, and Mekeni districts.[69] The Rural Water Supply and Sanitation Project has been financed by a mix of loans and grants totaling $42.27 million from the African Development Fund, Department for International Development (DFID-UK), and the Global Environmental Facility (GEF). This project will be run by SALWACO, and once completed it will benefit an estimated 625,000 rural Sierra Leoneans, increase access to potable water by nine percentage points and increase improved sanitation coverage by six percentage points.[70] Specific impact on rural Bo has not been identified, but the willingness of the international community to sponsor large-scale development programs is encouraging, and these relationships can hopefully be expanded or replicated to bring rural Bo up to 70% access to potable water.

Pricing structures are not being implemented to generate profits off of the water sector, but rather as a vehicle to ensure system sustainability and conservation of scarce resources. Instituting a pricing structure must be a joint effort between the community and the government, and there is likely to be resistance from community members at first. It will be important to explain to the community that prices are not directly charging users for water, but rather for the treatment, storage, and distribution of water. The appropriate pricing structure should be selected based on income levels, technical capabilities, and policy objectives. The easiest system to introduce would be usage fees assessed to every user on a regular basis regardless of withdrawal amounts, because in most instances there is no monitoring technology to ensure that block pricing is enforced. The price should allow for recurring costs to be covered, and should provide

---

[69] "ADB and OPEC Fund Aid Sierra Leone Water Project," *Terra Daily: News about Planet Earth*, last modified March 29, 2011, accessed March 14, 2016, http://www.terradaily.com/reports/ADB_and_OPEC_Fund_aid_Sierra_Leone_water_project_999.html.
[70] "Sierra Leone Water Company (SALWACO): Rural Water Supply and Sanitation Project (RWSSP)," *DEVEX*, accessed March 14, 2016, https://www.devex.com/projects/tenders/sierra-leone-water-company-salwaco-rural-water-supply-and-sanitation-project-rwssp/136574.

an adequate contribution towards amortized capital costs. This way, pricing ensures system sustainability, and by leveraging current government and NGO involvement in the water sector, supply network expansion can be prioritized.

XIV. Summary of Methodology

The methodology outlined in this paper is useful when identifying gaps in supply and evaluating potential solutions to water problems in areas with little available data. Supply gaps were successfully identified at the village level, and a proposed methodology for analyzing system costs was developed. While the cost data have significant limitations, more accurate data could easily be substituted into the framework posited in this paper to strengthen the recommendations and analysis. The above simulation determined that households are the only user type that significantly impact water demand in Bo District, while agricultural and industrial users impact water quality rather than water demand. This narrowed the scope of the analysis, and allowed for all supply gaps to be clearly defined and quantified. Out of the four main supply gaps identified—areas with no systems, areas with no functioning systems, areas relying solely on seasonal waterpoints, and overburdened systems—the gaps impacting the largest populations were both the highest priority and the most expensive to fill. Supply gaps are more complex than merely areas that have a delivery system and those that do not, and isolating the impacted populations of each supply gap provides clarity on the issue at hand, and the evaluation framework for policies that address these gaps. Three policy options were proposed to bring overall access in rural Bo up to 70%, in line with the targets of the Millennium Development Goals, and hopefully this progress could then be continued to meet the 100% target of the Sustainable Development Goals. The objectives of a water policy must balance cost and priority of needs, which are at odds in a scenario like Bo District. The policy evaluation framework that was developed identified the importance of a clear objective, because while the MDGs were adopted in the spirit of accelerating development and addressing needs in the water sector, policymakers must often choose between working to meet a target percentage and working to address the greatest need in their country.

Pricing was introduced as a method for ensuring system sustainability, with a sinking fund safeguarding portions of the regular contributions to finance the full replacement of the system at the end of its lifetime, and the other portions of community contributions covering regular maintenance and filtration costs. Once the cultural obstacle of introducing a pricing system is overcome, the water supply network will be able to operate independently, free from reliance on government subsidies and foreign aid. A key finding of this study is that it is possible to bring Bo up to 70% access to potable water with a combination of appropriately scaled water infrastructure funded from outside sources and a revenue raising structure for sustaining the system based on appropriate pricing.

XV. Discussion

This study aimed to bring clarity and direction to the water issues that currently impact 60% of rural Bo residents who do not have full access to potable water. The residents have little income or agency to inspire change in the government or to change their own situation. However, this study suggests that on a small community level, if each resident is able to contribute 2% of his or her income to water at the assumed GNI per capita of $700, it would be possible to solve the supply problem by instituting a standpost delivery system. The ability to be able to create change and solve one's own problems on a community level is critical in a nation like Sierra Leone, where patronage systems are commonplace and corruption is anticipated.

This study also aimed to show that even one of the poorest nations in the world, with development needs in every sector of society, can make progress towards the MDGs. If progress is slow, it is not necessarily due to lack of action, but rather may be explained by limited budgets being used to meet the greatest needs in the area instead of the least expensive options. When development is solely target-driven, people with the greatest needs may be the last to be served. With budget constraints and limited resources, more people can be granted full access to potable water on the same funds if they are directed towards fixing current systems and improving seasonal waterpoints instead of new construction.

This is not a surprising outcome, but it challenges the structure of international agreements like the MDGs and SDGs. When target-driven development incentivizes the easiest and least costly solutions, areas that are already well-served have their services improved and brought to 100% before communities relying on contaminated water sources are given a single system to provide potable water. This problem can slow development of the rural water supply, because when an aggregate target is the focus, it is much easier to increase access in a single urban area rather than address the same population spread amongst hundreds of smaller communities. A solution to this problem would be disaggregating these targets, and rather than challenging Sierra Leone to increase access to 70% country-wide, challenge it to increase access to 70% at the district level, or the chiefdom level, or better yet, the village level. Any of these steps would be an improvement, and would lead to results that match the spirit with which these agreements were created. Some may argue that any progress is good progress, with little reason to change the international agreements if they successfully motivate any progress on the issue.

Others may view this as a moral quandary, where it is uncertain if improvement for a single person is more valuable should they be rural instead of urban. However, what is indisputable is the importance of clearly stated policy objectives that identify the way in which greatest need will be balanced with the greater number of people impacted. There are many ways to reach a given development target, and the policymakers must prioritize and balance these potential paths to determine the policy objective at the outset.

XVI. Next Steps

To refine the recommendations of this analysis, many of the key indicators that have been estimated would be replaced with more accurate figures. It would be ideal to replicate the ProVictimis survey to receive updated population information and to see what progress has been made on the existing supply gaps. It would also be helpful to include GPS coordinates of each waterpoint, and to broaden the survey to incorporate private waterpoints that resell water in some way to the public. A closer analysis of Bo Town, given more refined population data and update information regarding private waterpoints will allow any existing supply gaps to be identified.

The cost estimates provided in this paper are based on broad averages, and would benefit from income or consumption data for communities across Bo District to determine affordability. A key limitation that should be resolved is the inclusion of analysis identifying how density and scale impact the recommended systems. Population parameters are needed for the unit costs in order to evaluate how the cost story changes in very small communities, and at what density benefits from scale begin to be realized. The goal for results on a district level is the development of a cost curve as a function of population density, with identified threshold points showing the transition between optimal systems for a given density range. With improved waterpoint information and economies of scale, the potential for hybrid systems and shared systems between villages could be evaluated as well. Shared systems are a common technique for small communities around the world, allowing them to receive the benefits of scale economies at lower population densities. Overall, system implementation costs are extremely specific to the location of installment, and therefore the results outlined in this paper can be deemed useful on a broad scale to determine feasibility district-wide.

This methodology used in this paper can be replicated and applied to other districts in Sierra Leone as well, depending on the levels of available data. This would allow for detailed supply gaps to be identified and potential policy options could be evaluated that would best serve each district population. Once district-level needs are identified, they can be combined into a comprehensive national policy regarding increasing access to potable water around the country.

Bibliography

"ADB and OPEC Fund Aid Sierra Leone Water Project." *Terra Daily: News about Planet Earth*. Last modified March 29, 2011. Accessed March 14, 2016. http://www.terradaily.com/reports/ADB_and_OPEC_Fund_aid_Sierra_Leone_water_project_999.html.

"Affordability Assessment Tool for Federal Water Mandates." *American Water Works Association, US Conference of Mayors*, 2013. Accessed March 14, 2016. http://www.awwa.org/Portals/0/files/legreg/documents/affordability/Affordability-IssueBrief.pdf.

Akiwumi, Fendi. "The Need for More Widespread use of Geological Criteria in Water Quality Assessment in Africa." *The International Association of Hydrological Sciences*. Accessed November 11, 2015. http://hydrologie.org/redbooks/a243/iahs_243_0359.pdf.

Barton, Alexandra. "Water in Crisis - Sierra Leone." *The Water Project*. Accessed November 18, 2015. http://thewaterproject.org/water-in-crisis-sierra-leone.

Bourgois, Francois, and Pietro De Cao. "Existing Water Access Points in the Districts of Bo, Koinadugu, and Tonkolili in Sierra Leone." *Fondation ProVictimas Geneve.* Last modified February, 2013. Accessed February 2, 2016. http://provictimis.org/download/provictimis_water_access_survey.pdf?lang=en.

Bourgeois, Francois. "Why Wells Should Only Be Dug in a Specific Period of the Year?" Sierra Leone WASH Sector Learning, January 2014. Accessed March 14, 2016. https://www.washlearningsl.org/why-wells-should-only-be-dug-in-a-specific-period-of-the-year/.

"Diamond Mining and the Environment Fact Sheet." *Diamond Facts*, *World Diamond Council*. Accessed March 14, 2016. http://www.diamondfacts.org/pdfs/media/media_resources/fact_sheets/Diamond_Mining_Environment_Fact_Sheet.pdf.

"Drainage and Major River Basins of Sierra Leone." In *Source Book for the Inland Fishery Resources of Africa Vol. 2 Country Files: Sierra Leone.* FAO Corporate Document Repository, Fisheries and Aquaculture Department. Accessed November 4, 2015. http://www.fao.org/docrep/005/t0360e/t0360e10.htm.

Excerpts from "Water Bodies Directory." In *Source Book for the Inland Fishery Resources of Africa Vol. 2 Country Files: Sierra Leone.* FAO Corporate Document Repository, Fisheries and

Aquaculture Department. Accessed November 4, 2015. http://www.fao.org/docrep/005/t0360e/t0360e10.htm.

Fabrizi, Lara. "Water Supply in Small Communities." *LennTech Water Treatment Solutions*. Accessed March 14, 2016. http://www.lenntech.com/small-community-water-supplies.htm#7._Water_treatment_%23ixzz42j3Gpk9l.

Farrell, Chris. "Time for a Serious Policy on Water Pricing." *Bloomberg Business*. Last modified October 15, 2014. Accessed November 17, 2015. http://www.bloomberg.com/bw/articles/2014-10-15/time-for-a-serious-policy-on-water-pricing.

Fisher, Franklin M., and Annette Huber-Lee. *Liquid Assets: An Economic Approach for Water Management and Conflict Resolution in the Middle East and Beyond*. Washington DC: Resources for the Future, 2005.

"GoSL Online Repository." *Ministry of Mines and Natural Resources*. Accessed March 14, 2016. http://sierraleone.revenuesystems.org/login/auth.

Himelein, Kristen. “A Poverty Profile for Sierra Leone.” *The World Bank Poverty Reduction & Economic Management Unit.* Last modified June, 2013. Accessed January 31, 2016. http://www.sierraexpressmedia.com/wp-content/uploads/2013/07/Poverty-Profile-Sierra-Leone.pdf.

"How Much Water Is Enough? Determining Realistic Water Use in Developing Countries." *Improve International*. Last modified April 27, 2014. Accessed March 14, 2016. https://improveinternational.wordpress.com/2014/04/27/how-much-water-is-enough-determining-realistic-water-use-in-developing-countries/.

"The Human Right to Water and Sanitation." *UN News Center*, *UN Water*. Last modified May 29, 2014. Accessed March 14, 2016. http://www.un.org/waterforlifedecade/human_right_to_water.shtml.

"Key Minerals." *Ministry of Mines and Mineral Resources*. Last modified May 14, 2014. Accessed March 14, 2016. https://slminerals.org/key-minerals/.

Larbi, Asamoah. "Country Pasture/Forage Resource Profiles: Sierra Leone." *Food and Agriculture Organization of the United Nations, International Institute of Tropical Agriculture*. Last modified August, 2012. Accessed November 17, 2015. http://www.fao.org/ag/agp/agpc/doc/counprof/Sierraleone/Sierraleone.htm.

"Liberia: Geology." *Aureus Mining Operations*. Accessed November 17, 2015. http://aureus-mining.com/projects/liberia-2.

Ling, Katherine. "Increasing Access to Potable Water in Sierra Leone: The Role of National and Local Governance." Working Paper, Lawrence University, Appleton, 2016.

"Map of Suitability to Manual Drilling." In *Feasibility Study for Manual Drilling, Mapping of Favourable Zones.* Unicef, Ministry of Energy and Water Resources. Accessed November 15, 2015. http://www.unicef.org/wash/files/Sierra_Leone_final_report_favorable_zones_(FINAL).pdf.

Moriba, Saffa. "Sierra Leone News: Sierra Leone Traders Union Meet Members of Agricultural Business Centers in Bo." *Awoko News*. Last modified July 30, 2014. Accessed March 14, 2016. http://awoko.org/2014/07/30/sierra-leone-news-sierra-leone-traders-union-meet-members-of-agricultural-business-centers-in-bo/

Musa, Joseph Alex. "Water Sanitation and Hygiene in Sections of Bo District: Problems, Challenges, and Recommended Solutions." *Weave SL Research in Sierra Leone Studies*, no. 2.1 (2014): 9-12. Accessed January 12, 2016, http://weavesl.org/ojs/index.php?journal=Weave&page=article&op=view&path%5B%5D=46.

"National Rice Development Strategy (NRDS) Sierra Leone." *Japan International Cooperation Agency, Coalition for African Rice Development*. Last modified 2009. Accessed March 1, 2016. https://www.yumpu.com/en/document/view/25761731/sierra-leone-national-rice-development-strategy-jica.

"Population Density Map of Sierra Leone (Projected 2014 Figures)." Digital Image, Reliefweb: MapAction. October 27, 2014. Accessed November 15, 2015. http://reliefweb.int/map/sierra-leone/population-density-map-sierra-leone-projected-2014-figures-27-october-2014.

"Principles for Borehole Construction and Rehabilitation in Sierra Leone." *Rural Water Supply Network Resources, Ministry of Water Resources of Sierra Leone*. Accessed November 11, 2015. http://www.rural-water-supply.net/en/resources/details/624.

Redmayne, Nick. "Sierra Leone." Digital Image. The Independent. Accessed May 2, 2016. http://www.independent.co.uk/travel/africa/how-tourism-can-help-sierra-leones-recovery-from-ebola-a6733131.html.

Reed, Tristan, and James Robinson. "Chiefdoms of Sierra Leone." *Michigan State University*. Last modified October 20, 2012. Accessed November 4, 2015.

https://www.msu.edu/~bernsten/PCSLReunion67/Documents%20(WP-Adobe)/Chiefdoms%20of%20SL(1).pdf.

"Rural Water Supply and Small Towns Strategy Document." *WASH Learnings SL*. Ministry of Water Resources. Last modified 2013. Accessed March 10, 2016. http://www.washlearningsl.org/wp-content/uploads/2015/03/Rural-Water-Supply-and-small-towns-strategy-document-2013.pdf.

"Rural water supply coverage" and "Urban water supply coverage." In *Water Supply and Sanitation in Sierra Leone: Turning Finance into Services for 2015 and Beyond*. World Bank Group Water and Sanitation Program. Accessed November 17, 2015. https://wsp.org/sites/wsp.org/files/publications/CSO-sierra-leone.pdf.

"SDG 6: Clean Water and Sanitation." *United Nations Development Programme: Sustainable Development Goals*. Accessed November 17, 2015. http://www.undp.org/content/undp/en/home/sdgoverview/post-2015-development-agenda/goal-6.html.

"Sewa River | River, Sierra Leone." *Encyclopedia Britannica Online*. Accessed November 4, 2015. http://www.britannica.com/place/Sewa-River.

"Sierra Leone Indicators." *World Bank Data*. Accessed March 14, 2016. http://data.worldbank.org/country/sierra-leone.

"Sierra Leone Location Map Topographic." Digital Image. Wikimedia Commons. June 23, 2012. Accessed November 10, 2015. https://commons.wikimedia.org/wiki/File:Sierra_Leone_location_map_Topographic.png.

"Sierra Leone Map." Digital Image. MapsOpenSource. Accessed May 2, 2016. http://www.mapsopensource.com/sierra-leone-map.html.

"Sierra Leone: Outline, districts, names." Digital Image. D-Maps.com. Accessed May 3, 2016. http://d-maps.com/m/africa/sierra/sierra35.gif.

"Sierra Leone Water Company (SALWACO): Rural Water Supply and Sanitation Project (RWSSP)." *DEVEX*. Accessed March 14, 2016. https://www.devex.com/projects/tenders/sierra-leone-water-company-salwaco-rural-water-supply-and-sanitation-project-rwssp/136574.

"Sierra Leone Waterpoint Report." *WASH Learnings SL* (2012). Last modified June 26, 2012. Accessed March 14, 2016. http://www.washlearningsl.org/sierra-leone-waterpoint-report-review-version-2012/.

Smith, Adam. *An Inquiry into the Nature and Causes of the Wealth of Nations*. London: W. Strahan and T. Cadell, 1776.

"UN Sustainable Development Goal 6: Ensure Access to Water and Sanitation for all." *Department of Public Information, United Nations*. Accessed November 17, 2015. http://www.un.org/sustainabledevelopment/water-and-sanitation/.://www.un.org/sustainabledevelopment/water-and-sanitation/.

"Water and Sanitation in Sierra Leone with the Minister of Water Resources."*Awoko Newspaper*. May 21, 2013. http://awoko.org/2013/05/21/water-and-sanitation-in-sierra-leone-with-the-minister-of-water-resources/.

"Water Scarcity." *United Nations Department of Economic and Social Affairs*. Last modified November 24, 2014. Accessed November 17, 2015. http://www.un.org/waterforlifedecade/scarcity.shtml.

"Water Supply and Sanitation in Sierra Leone." *World Bank Group Water and Sanitation Program, AMCOW*. Accessed November 17, 2015. https://wsp.org/sites/wsp.org/files/publications/CSO-sierra-leone.pdf.

"Water Usage in Rice." *Knowledge Bank*, *International Rice Research Institute*. Last modified 2007. Accessed March 14, 2016. http://www.knowledgebank.irri.org/ericeproduction/III.1_Water_usage_in_rice.htm.

"Workbook Page Two - what is a River Basin?" *NC Stormwater*. Accessed November 4, 2015. http://www.ncstormwater.org/pages/workbook_riverbasin.html.

Young, Robert A. *Determining the Economic Value of Water.* 2nd ed. Washington DC: Resources for the Future, 2005.

Zetland, David. *Living with Water Scarcity.* Lexington, KY: Aguanomics Press, 2014. http://livingwithwaterscarcity.com.