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Assessing the Viability of Desalination for Rural Water Supply: A Case Study of Chwaka, Zanzibar

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Abstract

Zanzibar has been struggling with water scarcity issues over the last few decades due to an increase in consumption on the island and a deterioration of existing supply infrastructure. Poor distribution has affected rural communities most, due to their absence of tourism development, which has gone hand in hand with infrastructure establishment. Foreign aid has begun to address the issue by investing in alternative forms of water supply. In November 2011, a solar and wind powered desalination unit was inaugurated in the village of Chwaka, which, previous studies have shown, suffers from salt contaminated wells. This study sought to assess the viability of this alternative source of water in Chwaka and found that the desalination unit installed is not a viable source of freshwater for the entire village of Chwaka compared to government piped well water. Installed with the best intentions for the people of Chwaka, the presence and purpose of the machine is unknown to most of the village and its production capacity could only hope to supplement drinking water. Relative investment costs of distributing similar volumes of water show that piped water is the cheaper option. The intentions of the project are nonetheless laudable and this type of innovative investment should be encouraged as long as the government is not asked to take the bill. Zanzibar has access to adequate freshwater resources and must look to efficient consumption before turning to alternative forms of water production.

Key words: Advantages; Alternative; Chwaka; Desalination; Disadvantages; Drinking; Freshwater; Supply; Tanzania; Viability; Water; Zanzibar

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INTRODUCTION

Essential to animal life, water is arguably the most important natural resource people need and the amount of energy and capital used to harvest this resource testify to its importance. The General Assembly of the UN Human Rights Council has established access to safe drinking water as a basic human right and the UN has named 2005-2015 the Water for Life decade, pushing governments worldwide to actively invest in effective water supply (Slade *et al.*, 2012). This study was born from an understanding of the increasing issues with rural water supply in Zanzibar and the emergence of desalination as an alternative source of freshwater to local coastal dwellers. Water scarcity in Zanzibar has been the focus of various previous projects, both Government supported and driven by NGOs. These projects were researched in order to gain a fundamental understanding of both the current and historical perspective on water distribution. As preliminary research indicated, desalination is predominantly located within large hotel resorts in Zanzibar and there are few known examples of machines installed for rural communities. This project sought to investigate the viability of desalination for Chwaka, where foreign investors recently installed a desalination pilot project specifically for local villagers.

Background on Coastal Freshwater Scarcity in Zanzibar

Like island communities all over the world, Zanzibar is almost entirely dependent on groundwater for its freshwater needs due to the absence of rivers or lakes big enough to supply adequate amounts of water (Hansson, 2010). Zanzibar's water supply consists of underground aquifers made up of freshwater lenses floating on a deeper layer of seawater, which are susceptible to disruptions in salt-fresh water balance and permanent saltwater contamination due to overuse and misuse (HALCROW Consulting Engineers, 1994). Recharge of this underground water supply relies entirely on rainfall, which is about 1500-1600 mm annually in Zanzibar, and research has shown that the underground aquifers lose water in the form of runoff into the ocean (HALCROW Consulting Engineers, 1994).

Though Zanzibar receives reasonably adequate rainfall, there are several phenomena that have been making water scarcity an increasingly pressing issue. Along with an influx of immigrants from mainland Tanzania, Zanzibar's population has steadily been growing by 3% annually (Hansson, 2010). This increase in consumers has led to an overuse of wells, which can lead to salt contamination if not properly managed (Shah, 2003). Over the last twenty years, Zanzibar has also experienced the inception and boom of a vibrant tourist industry, with 19,368 tourists in 1995 and 220,000 in 2011 as measured by the Commission for Tourism, the majority of whom stayed in resort-style hotels (Slade *et al.*, 2012). Tourists in coastal areas invariably consume more water than the locals and Zanzibar is no exception: the average tourist in Zanzibar uses 16 times the daily amount of freshwater the average local uses (Slade *et al.*, 2012). Industrial expansion or development ventures require large quantities of freshwater and, like other developing areas, Zanzibar is investing heavily in industrialization (Wagner, 2007). One study observes that water demand for the Zanzibar Town municipality in 1995 was 30,000 square meters and projects the demand in 2015 to be 90,000 square meters (Shah, 2003). With these as driving forces, it is no surprise that sustainable consumption of water has become an important issue in today's Zanzibar. It is recognized that as of now the problem is more pressing with regards to the deteriorating condition of the distribution networks rather than to the supply of the freshwater itself (Shah, 2003).

Historical Water Supply Policy in Zanzibar

Zanzibar gained independence in 1964 and the establishment of a local government arose along with promises of providing certain fundamental necessities gratuitously, such as free water available for domestic consumers (Suleiman, 2011). As water supply systems deteriorated, the Government began initiatives to reintroduce a tariff system, culminating with the Zanzibar Water Policy in 2004, and by 2008 a tariff was reintroduced after 26 years of free water services (Suleiman, 2011). The policy of providing free water to the people of Zanzibar has in many ways created an unsustainable situation that has led to a deterioration of the water supply systems and fostered assumptions that water should be a free service (Shah, 2003). This policy most likely stemmed from the idea that water is a necessity and therefore should be provided freely, but more so to assuage people's expectations from a revolutionary government. Changing this policy, however, presents problems when "widely held cultural and religious proscriptions against treating water as a commodity prevail (HALCROW Consulting Engineers, 1994)". Before independence, however, residents of Zanzibar paid for their water and, as will be further discussed, providing free water has had undesired long-term ramifications (Shah, 2003). The Zanzibar Water Authority (ZAWA) was created in 2006 to develop and enforce regulations made by the National Water Policy and to this day is in charge of construction, maintenance, and distribution of the water and subsequent infrastructure required (Suleiman, 2011). As mentioned already, the demand for freshwater in Zanzibar has increased significantly over the last couple decades keeping ZAWA busy maintaining current wells and slowing down salt contamination (Shah, 2003). The task becomes increasingly difficult in that the demand for freshwater often grows faster than the population due to a simultaneous increase in standards of living (Hansson, 2010).

The World Health Organization recognizes that there are no health-based standards for salinity in drinking water and that levels of acceptability for salinity vary according to individual tastes and preferences (Villholth, 2008). Research and testimonies from people of Zanzibar have indicated that the salinity levels of various wells along the coast of Zanzibar, including Chwaka, have been rising and have made the water undrinkable (Hansson, 2010). Minute salt levels are often tolerated but particularly on the east coast, salinity levels have increased enough to be unsuitable for drinking, cooking, and various other household chores (HALCROW Consulting Engineers, 1994). It is a common belief that overuse of these wells is leading to saltwater intrusion and the local people blame tourism for the increase in water consumption and consequential impacts (Shah, 2003). Once contaminated, natural sources of freshwater could take decades to return to their previous states and the contamination is often permanent (Hansson, 2010). This continued contamination means that many coastal settlements need to find other sources of water that often entail high transportation costs (Hansson, 2010).

Current Water Supply Policy in Zanzibar

The current system of water supply is similar to historical precedent but further deterioration of distribution networks means that more villages, Chwaka included, are no longer connected to freshwater through a pipeline but rely instead on trucks carrying water from nearby villages (Slade *et al.*, 2012). On areas of the island one can spot what could be described as "pipe graveyards", where pipelines and taps are visible but clearly no longer in use, dilapidated, and unmaintained. Due to the cost incurred by transportation, villagers not connected to a pipeline find themselves paying significantly more than they did when connected. Previous research shows that people in villages without access to a freshwater will prefer government piped water to transported well water (Hansson, 2010). This is due both to the reliability of access with a pipeline and to the fact that people think piped water is somehow cleaner due to some treatment they are not aware of (Hansson, 2010). It is clear that access to piped water is desired and considered best but the prevailing notion that water should be free often means people would not be willing to pay for a better service (Hansson, 2010).

As of 2008, when the first tariff policy was put into place, villagers with access to clean water were supposed to pay for the service but previous research has indicated that often lack of enforcement meant no money was collected (Hansson, 2010). As far as residents were concerned, they were suddenly required to pay for a service that had been given freely for decades with no apparent change to the service and accept a new tariff system as per ZAWA conditions. The first stage in charging for water has been the institution of a flat tariff, allowing virtually unlimited consumption for a fixed price (Slade *et al.*, 2012).

The rapidly growing tourism industry is consuming large amounts of freshwater and the fixed tariff allows for unrestrained use of freshwater by hotels for a minimal cost (Slade *et al.*, 2012). ZAWA has strictly prohibited hotels to create their own wells in an effort to protect the underground aquifer, which could be disturbed if hotels, which predominantly lie in coastal areas, drill boreholes from the fringe of the underground water "lens" (HALCROW Consulting Engineers, 1994). There have been cases of conflicts between villagers and hoteliers, which sometimes resulted in demonstrations and in severe cases the cutting of pipes (Slade *et al.*, 2012). Conflicts have risen from the fact that villagers and hotels are sharing a water source that is perceived to be finite and the government sometimes gives preference to the needs of large hotels (Slade *et al.*, 2012). It is clear that the system in place needs drastic changes in order to sustainably provide water to Zanzibar residents.

Desalination as an Alternative Water Source

While desalination itself is an old method to obtain freshwater from sea or brackish water, technological advances have reduced energy costs to make desalination a more viable alternative method of supplying water in regions facing water supply shortages (Semiat, 2008). As of 2010, there were approximately 12,000 desalination plants used worldwide, producing about 0.02% of global water consumption (Becker *et al.*, 2010). Most desalination units in the world are located in the Middle East, where an abundance and affordability of oil negates desalination's energy cost (Becker *et al.*, 2010). In Saudi Arabia, a 200-mile pipeline carries water from the desalination plant at Jubail inland to the capital city of Riyadh, supplying the arid region with desalinated freshwater (Conway, 2008). The majority of desalination plants used today since the 1950's utilize a distillation method to convert seawater into steam and then into freshwater (Wagner, 2007). Since 1979, (Wagner, 2007) however, the advent of reverse osmosis desalination and its lower production cost (a decrease of 80% over the last 25 years) have become more widely used (Becker *et al.*, 2010).

Reverse osmosis desalination is a type of membrane process in which the machine pumps saline feed water into semi-permeable membrane chambers under high pressure to separate the freshwater from dissolved salts. The result is a product of freshwater and a waste discharge of brine with a high salt content. Figure 1 provides a visual representation of how reverse osmosis works.

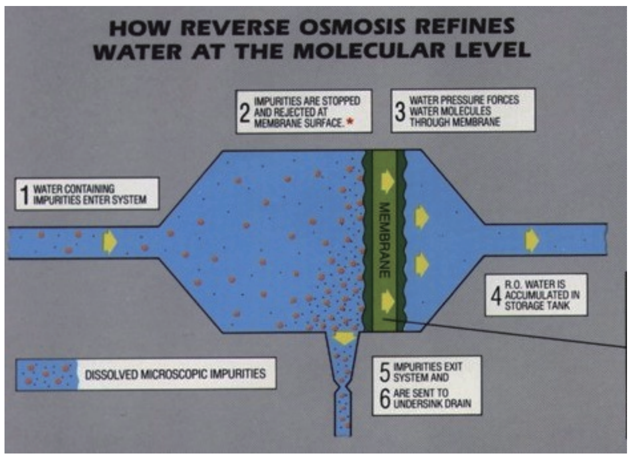

Figure 1
Reverse Osmosis Diagram
Source: Carolina Water Conditioners http://www.carolinawater.com/ro.htm

The advantage of desalination comes down to reliability and quality. Communities can reap this benefit so long as they are situated near or have access to the sea or brackish water. The sea provides an essentially unlimited supply of feed water, from which desalination plants can produce freshwater; and likewise for large reserves of brackish water. With only the geographic constraint of access to a saline body of water, desalination creates a freshwater source independent from the availability of ground or surface freshwater. For coastal communities, this is an advantage that eliminates dependence on pipelines from regions further inland. With the utilization of membrane technologies, desalination is capable of producing high quality drinking water (Becker *et al.*, 2010). This is especially important for rural communities where contamination of freshwater sources can often raise health concerns. Additionally, desalination can also convert a brackish water supply such as a salt contaminated river or aquifer back into one of high quality freshwater. The disadvantages of desalination can be broadly covered by the processes' consumption of energy and impact on the environment. According to Paul Brannan, "desalinated water is generally more expensive than natural freshwater, at least while the latter remains available for exploitation (Brannan, 2008)." In fact, for membrane-desalinated water, energy often makes up nearly half the production costs (Brannan, 2008). While the high-energy cost of desalination has drawn the attention of many skeptics of the process, the environmental impact of seawater desalination has also begun to attract research and evaluation. Due to the high salt concentration of desalination waste brine (63 K ppm compared to an approximate 35 K ppm of natural sea water), high temperature of the discharge relative to natural temperature of the sea, differing oxygen levels between the waste and the sea, the dumping of chemicals from feed water pretreatment, and other risks, the disposal of desalination waste water may pose significant harm to marine ecosystems (Becker *et al.*, 2010). While some of these impacts will vary depending on geographic locations of desalination plants, more quantitative studies on the exact impacts have yet to emerge in literature (Becker *et al.*, 2010). A study conducted to examine the impact of the Al Jubail desalination plant in Saudi Arabia on both marine life and water quality found significant impacts and suggested alternative solutions (Becker *et al.*, 2010). A similar study done in Tampa Bay, Florida, USA found causes for concern and concluded that desalination as a water source should be avoided when possible (Becker *et al.*, 2010). While these mentioned studies are associated with desalination's negative impacts on marine life due to the discharge of brine waste, desalination also affects air pollution and land use along coastal areas (Becker *et al.*, 2010).

Current Method of Desalination Used in Zanzibar

Preliminary research found that the primary method of desalination used in Zanzibar is reverse osmosis. A total of six desalination plants from five hotels within the villages of Nungwi, Kiwengwa, and Dongwe were visited and observed. The research revealed that all desalination units are owned and operated by tourist hotels, which use desalinated water for nearly all hotel water consumption functions except as drinking water for guests. It is clear that this form of water production is valuable to hotels in its ability to provide reliable freshwater independent of local infrastructure.

Introduction of Chwaka as a Case Study

Chwaka is known to have salt contaminated wells with high ammonia levels, as assessed by Erik Hansson during a previous chemical analysis (Hansson, 2010). The village, located on a peninsula protruding into Chwaka Bay, is not near any major aquifers and is considered to be part of the coastal fringe area without access to fresh ground water (HALCROW Consulting Engineers, 1994). The clean water sources available for purchase to local people are from water vendors transporting 20-liter jerry cans from nearby villages and purchasing water from the Mörk desalin® RO 100 SW desalination plant that was inaugurated November 15, 2011 at The Zanzibar Institute of Financial Administration (ZIFA) (Sultan, 2011). This represents a village therefore that has access to both a traditional water resource and to an alternative freshwater source in desalination available to the people of Zanzibar. Hansson believes that desalination in Chwaka could be an alternative if the machine were powered by solar energy and if the water were used for drinking and cooking purposes only (Hansson, 2010). Using this hypothesis, this study sought to assess the viability of desalination as a rural water supply option for the village of Chwaka.

Study Area

The Zanzibar archipelago is made up of two main islands, Unguja and Pemba, about 40 km off the eastern coast of The United Republic of Tanzania (Slade *et al.*, 2012). Field research for the study was conducted on the island of Unguja, which has a surface area of 2,577 square kilometers (Slade *et al.*, 2012). Unguja is composed of coral rag terrain, made up of fossilized coral and limestone which is porous and hydraulically connected to the ocean (Slade *et al.*, 2012). The area of focus was the village of Chwaka (GPS coordinates: -6° 9' 42.18", +39° 26' 12.47") marked on the map in Figure 2, which is located along the eastern coast of Unguja. Various regions of Unguja have desalination plants, though nearly all are for tourist hotel use only. The village of Chwaka was chosen as the main study site because it hosts the island's first known desalination plant installed for public use. Additional studies and interviews were done in Zanzibar Town (GPS coordinates: -6° 9' 50.48", +39° 12' 11.71"), located on the western coast of Unguja and also marked on Figure 2. The island of Unguja is often referred to as simply Zanzibar and this norm has been adopted for the entirety of this study to avoid confusion.

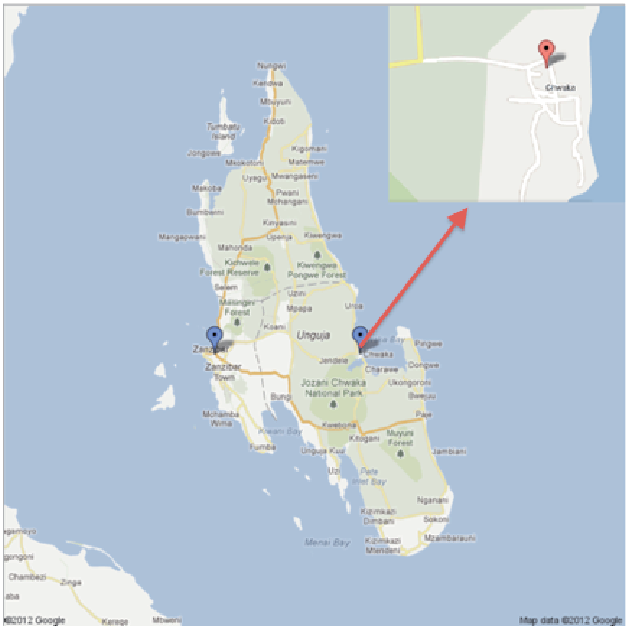

Figure 2
Map of Zanzibar with the Approximate Location of the Desalination Plant Marked in Red

METHODOLOGY

A mixture of questionnaire based surveys and semi-formal interviews were conducted in order to collect both quantitative and qualitative data. The interviews conducted at Chwaka were done over the course of four days with the help of a local translator. Total field research for the study was conducted and collected over a time span of 5 weeks during the months of March 2012 to April 2012. For all purposes of currency conversions, Euros were converted to U.S. Dollars using a currency exchange rate of 1.3 USD per one Euro and to Tanzanian Shillings using a currency exchange rate of 2,080 TSh per one Euro.

Interviews with Water Consumers

A standardized survey was compiled in order to better understand the water consumption patterns of the villagers in Chwaka. The questionnaire was created in order to establish the current quantities of water consumed, the source of water, any perceived problems with water, willingness to conserve water and the maximum willingness to pay for clean and reliable water from Chwaka. With a population of 4,206 people and an average household size of seven family members, Chwaka is estimated to have approximately 600 families. Identical surveys were used for 50 households (8% of total families in Chwaka) and with the help of a local translator, were conducted in various areas of Chwaka in order to account for differences in water source due to geographical location. People of various socio-economic levels were interviewed in order to account for any large deviations in patterns of water consumption based on family wealth.

A random approach was used in choosing households and respondents were predominantly female. This was the case because when told the survey would be about water consumption the household member often fetched the female head of the house. Also because interviews were conducted during the day, many male members of the family were out working. Because mothers are usually in charge of purchasing water and managing its uses during the day, this does not detract from the quality or validity of the results. Using a well-respected local translator also helped ensure that respondents more willing to assist and confirmed that all areas of Chwaka were covered during interviews.

Other Pertinent Interviews

A number of semi-structured interviews were conducted with various individuals involved with rural water supply. The village leader (Sheha) of Chwaka was interviewed in order to acquire a historical aspect of water in the village and general data of Chwaka. A source at PAMOJA Zanzibar was interviewed in order to learn about the desalination plant installed at Chwaka. Several officials at the Zanzibar Water Authority (ZAWA) were interviewed to acquire technical data regarding both the pricing of the water and the process of creating water supply infrastructure. A rural development and energy consultant, Gerard Hendriksen, supplied information on Zanzibar's energy costs and methods of distribution. An additional email correspondence with Mörk Water Solutions provided exact figures relevant to the desalination plant. All interviews were conducted in English and questions asked varied depending on the correspondent. The results of these interviews were mostly qualitative in nature, not data to be analyzed quantitatively but specific detailed information relevant to our research.

FINDINGS

Chwaka Historical Water Supply Overview

The village of Chwaka has a population of 4,206 people and has had salt contamination of its wells since 1950. Consequently, the village has historically acquired water through a government pipe that transported water from regions closer inland. In 1995, however, the pipe was declared unsafe for consumption due to salt contamination. From 1995 to 2009, the village received water from a pipe that connected from the village of Jendele to the village of Marumbi and then to Chwaka. The pipe failed in 2009 and the residents of Chwaka, including the Sheha himself, have since resorted to purchasing all of their freshwater from water vendors. On November 15, 2011, the Minister for Housing, Lands, and Water, Ali Juma Shamhuna inaugurated the Mörk desalin® RO 100 SW desalination plant as a freshwater source for the village of Chwaka (Sultan, 2011). The Sheha added that he believed many residents of Chwaka do not trust the quality of desalinated water and do not purchase water from the machine.

Household Demography

Table 1
Gender of Respondents

Gender of respondents	Frequency	Percent(%)
Male	17	34
Female	33	66
Total	50	100

Based on the survey, the mean household size of Chwaka was 6.8 or approximately seven people. The range of household sizes varied from two members to the largest recorded size of 15 people. As mentioned in the methodology section, a larger percent of females were interviewed as compared to males. Table 1 presents the exact figures of 34% male respondents and 66% female respondents.

The source of income for Chwaka families varied slightly, where a significant majority of households reported the sea as their main means of earning income. Figure 3 presents the various sources of income, in which income generated from the sea ranked the highest at 74% (combined with the section "From the Sea and Farming") A study previously done by Hansson confirms that most of Chwaka's income is generated through fishing or seaweed farming, both of which are dependent on the ocean (Hansson, 2010).

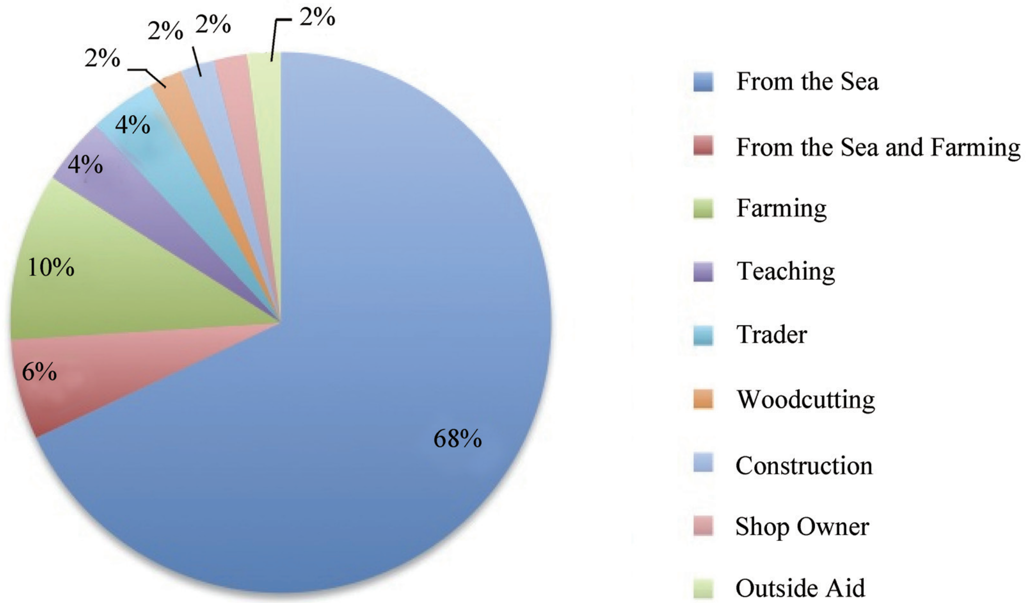

Figure 3
Sources of Income

Water Consumption

Due to a lack of household water meters to record accurate water consumption levels, Chwaka residents were asked to estimate their family's average daily water consumption. Survey results revealed a mean daily water consumption of 139.2 liters per household with a minimum of 40 and a maximum of 320 as shown in Table 2. Taking into account an average household size of approximately seven people, it can be further shown that the daily water consumption per capita for Chwaka is 19.9 liters, or approximately 20 liters. It is important to note that 100% of respondents stated that they supplemented their freshwater consumption with rainwater and salt-contaminated well water, indicating perhaps an even lower figure for daily freshwater consumption per capita.

Table 2
Water Consumption

Respondents (n)	Mean daily consumption (liters/household)	Standard deviation	Minimum (liters)	Maximum (liters)
50	139.2	62.4	40	320

Survey results also revealed that all of Chwaka's villagers purchased freshwater from water vendors that deliver at a price of 200 TSh per 20-liter jerry can, though the price was said to fluctuate up to 300 Tsh per 20-liter jerry can. Figure 4 presents the sources from which respondents bought their water. 86% of Chwaka residents purchased their water from the vendors of Jendele village exclusively, while other respondents bought water from Hanyegwa or Dunga. Residents also purchased water from Marumbi's vendors, but because the freshwater from Marumbi is piped from Jendele, responses for Marumbi were grouped together with Jendele. Out of all 50 respondents interviewed, only one stated that she purchased desalinated water, though she also purchased water from vendors as well.

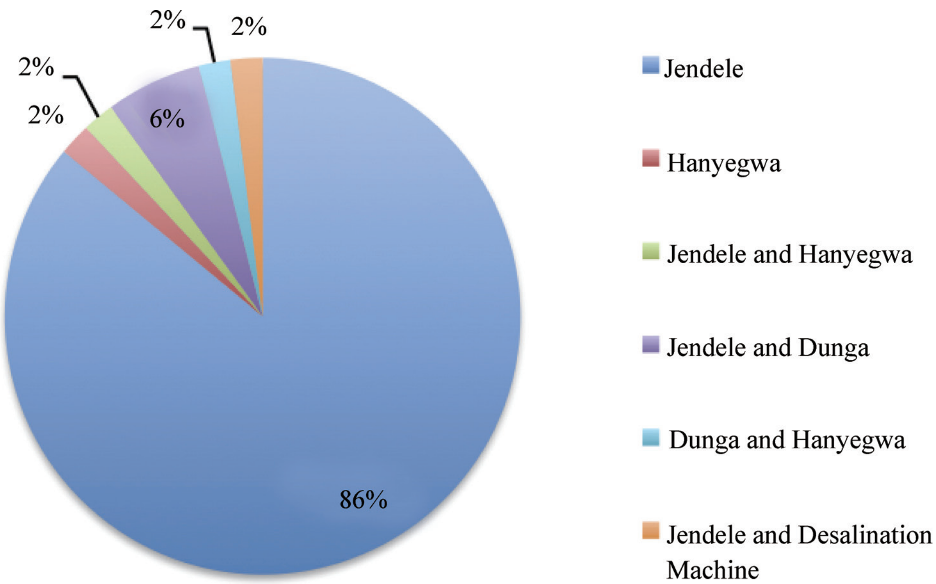

Figure 4
Sources of Water

Water Problems

The study found that 48% of respondents reported problems with their freshwater source. Of all the respondents that reported water problems, the only problem stated was the unreliability of purchasing water from water vendors. Residents then elaborated that water could not be purchased at night, during power outages, or when the pumps break down. When asked about their perceived cleanliness, taste, smell, and salt level of the freshwater they purchased, all respondents reported no problems at all.

Willingness to Conserve Water

A willingness to conserve water was qualitatively assessed through two questions asked during the survey. Do Chwaka residents save rainwater? Do Chwaka residents change their consumption based on the price of freshwater? 98% of respondents reported saving rainwater for household use, and 92% of respondents stated that their families changed their freshwater consumption based on the price of freshwater. Qualitatively, these responses provide a basic indication of not only the village's willingness to conserve water as a resource but also the demand elasticity of water as a commodity in Chwaka.

Willingness to Pay for Desalinated Water

This part of the study aimed to capture the overall willingness to pay for desalinated water in Chwaka. The questions in the survey asked residents first if they would be willing to pay for clean and reliable freshwater from Chwaka village, and if yes, what the maximum amount of money they would be willing to pay for it. The questions were posed in this way to allude to Mörk's desalination plant without explicitly saying the name of the machine. Additionally, the question was made with a major assumption that all well water in Chwaka is salt contaminated and that no Chwaka residents obtain any freshwater that originates from the village. As can be seen in Table 3, residents of Chwaka are willing to pay for clean and reliable freshwater from Chwaka. 88% of respondents stated that if they could buy freshwater that originates from the village, they would. Additionally, the mean willingness to pay was found to be 256.8 TSh per 20-liter jerry can.

Table 3
Willingness to Pay for Desalinated Water

Respondents(n)	Percent of respondents(%)	Mean WTP for dean and reliable water from Chwaka (TSh/20 L)	Standard deviation	Minimum WTP (TSh/20 L)	Maximum WTP (TSh/20 L)
44	88	256.8	157.8	50	500

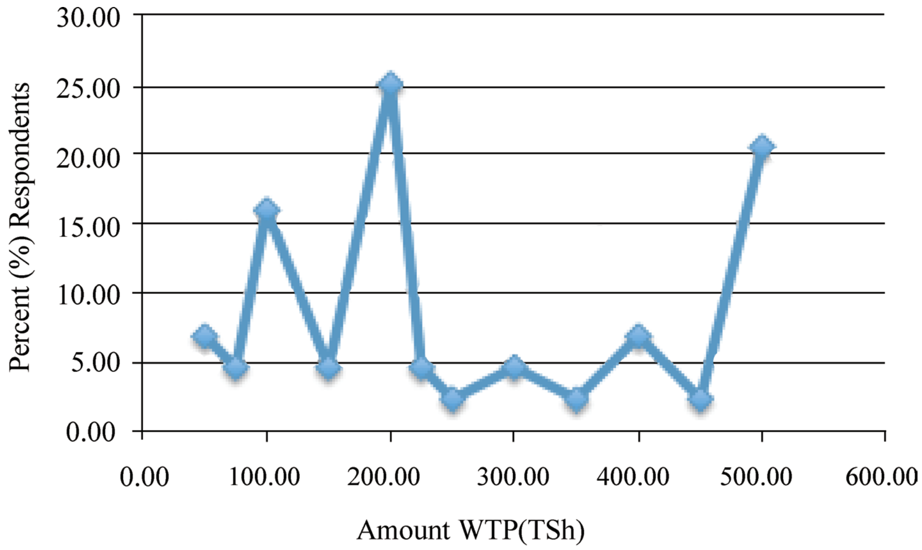

Figure 5
Willingness to Pay Distribution Graph

Six respondents interviewed refused to pay any amount of money for clean and reliable freshwater from Chwaka. Those who refused to pay all stated that the reason for their response was that if water was from Chwaka and for its villagers, then it should be free.

Knowledge of Mörk's Desalination Plant in Chwaka

This study also sought to find out how much Chwaka residents knew about Mörk's desalination plant. The survey posed a question that asked whether respondents knew of the machine, and if yes, whether they knew if the machine was for public use and the price of desalinated water per 20-liter jerry can. As can be seen in Table 4, 80% of respondents said they knew of the desalination unit, but few actually knew anything more beyond the existence of the machine. 28% of respondents knew that the machine's water was available for sale to the public, and only 4% of respondents knew the actual price of the machine's water. Additionally, some respondents expressed skepticism of the desalinated water, refusing to believe that seawater could be converted to freshwater.

Table 4
Knowledge of Mörk's Desalination Plant

	Knew of the machine	Knew that the machine is for the public	Knew the price of desalinated water per 20 liter jerry can
Respondents(n)	40	14	2
Percent of respondents(%)	80	28	4

Production Capacity and Price

An interview was conducted with a source at PAMOJA Zanzibar in order to gather specifications and general information on the desalination unit. As a pilot project for Zanzibar, Mörk desalin® RO 100 SW utilizes reverse osmosis membranes to desalinate water. With a production capacity of 100 liters per hour, the desalination plant was recorded on March 16th, 2012 to have produced a total of 14,809 liters of freshwater. Since its inauguration, the machine has produced on average of 123.4 liters per 12-hour day of operation. Additionally, four batteries connected to a solar panel and wind turbine power the desalination unit, making the machine independent of the electricity grid and energy costs.

The machine's water was available for sale to the public since November 15, 2011 at a price of 300 TSh per 20-liter jerry can, though prior to March 2012, the price was set at 1000 TSh per 20-liter jerry can. The price was lowered in March in an attempt to match the price of water sold from vendors and to attract more customers. As of March 2012, Mörk planned on selling the desalination unit to ZIFA (where the machine is currently housed) after a year for half the investment cost of the machine. At the time of the interview, Mörk was also in the process of constructing a second desalination unit on Pemba Island, with the intention of selling the machine to ZAWA after a year of operation.

Zanzibar Water Authority (ZAWA)

Brief interviews were held with sources at Zanzibar Water Authority to obtain general information on ZAWA and its role in providing access to freshwater for Chwaka residents. The interviews revealed that ZAWA technically owns all wells in Zanzibar (though many who dig their own wells do not pay for water), and ZAWA was in the process of constructing a new borehole in Jendele and pipeline to supply Chwaka and the surrounding area with water. The total project cost for the borehole and pipeline was estimated to be 589,038,360 TSh or 356,993 USD. ZAWA also planned to initially price the water at a flat rate of 2,000 TSh per month for each household until volumetric water meters could be introduced to the village.

Desalination and Energy Supply

An interview was held with Gerard Hendriksen, an energy and rural development consultant, in order to acquire an energy perspective of desalination and general water supply. The interview revealed that Zanzibar is supplied with electricity exclusively from mainland Tanzania through a large marine cable. That electricity is powered by natural gas, diesel, and hydropower. In Hendriksen's opinion, the cable is pretty reliable by African standards, though the Zanzibar government is nearing completion of a second cable to supplement the electricity supply. Zanzibar currently has little ability to generate electricity independently due to a lack of hydropower potential and insufficient wind. Energy in Zanzibar is heavily subsidized by the government, in which residents pay only 120 TSh per kilowatt compared to 190 TSh per kilowatt in Dar es Salaam on the mainland. The interview also revealed that ZAWA uses the most energy out of all of Zanzibar's government agencies. In Hendriksen's opinion, innovative projects like Mörk's desalination plant are welcome in Zanzibar as long as they are funded through external aid and not by the government.

Machine Costs and Cash Flow

The study utilized an email correspondence with a source from Mörk Water Solutions to identify exact cost figures for the desalination plant. The online interview showed that total investment costs for the desalination unit came out to be 42,000 € (54,600 USD or 87,360,000 TSh). Maintenance costs total approximately 700 € (910 USD or 1,456,000 TSh) per year, which includes yearly inspection and control of the desalination plant. The production cost for desalinated water is .01 €/liter (approximately 20.8 TSh), assuming the desalination plant is operating at maximum capacity producing 1,200 liters/day for 12 hours a day. Mörk's cash flow statement for the sale of desalinated water at .03 €/liter (approximately 50 TSh/liter at the time of the cash flow statement's calculation) is shown in Figure 6. It is important to note, however, that this price of 50 TSh/liter, or 1,000 TSh/20-liter jerry can, was lowered as of March 2012 to 15 TSh/liter, or 300 TSh/20-liter jerry can. With a selling price of 15 TSh/liter and price of 400 TSh/1.5 liters bottle, Mörk estimated that the cost of the machine would be recovered in 10 years as opposed to 5 years with the initial price.

Figure 6
Mörk's Estimated Cash Flow Statement

	1.year	2.year	3.year	4.year	5.year	6.year
lncome through selling water(3€cent)	12.780.00€	12.780.00€	12.780.00€	12.780.00€	12.780.00€	12.780.00€
Operator costs(700€/year)	700.00€	700.00€	700.00€	700.00€	700.00€	700.00€
lnvestment	42,000,00€					
Operation/maintenance costs	700.00€	700.00€	700.00€	700.00€	700.00€	700.00€
lnterest rate(13%)	5,460.00€	4,690.40€	3.820.75€	2,838.06€		
Cashflow	36,080.00	29,390.40€	21,831.15€	13,289.20€	1,909.20€	9,470.80€

DISCUSSION

Location Suitability

Chwaka has had unreliable access to freshwater since 1950 when the village first started experiencing saltwater contamination, culminating in the failure of the pipe system in 2009. This made Chwaka an attractive location for the Mörk desalin® RO 100 SW desalination plant as a freshwater source for the village. Because villagers have grown accustomed to purchasing water from vendors' trucks, they have an understanding of transportation costs associated with water services. This too makes the site an attractive option for an alternative source of water in desalination because the villagers, through their purchases of transported water, have revealed a level of willingness to pay for water.

Energy Subsidization

Hendriksen also confirmed that, like its water, Zanzibar's energy is highly subsidized. Subsidizing energy has its own set of problems in the same way that subsidized water does but while it lasts, cheaper energy is advantageous for any form of water production and supply that uses grid energy. Chwaka's current situation is unique, however, in that the desalination unit uses 100% self-produced sustainable energy. Subsidized energy prices diminish the value of Mörk's machine's sustainable energy. The higher the energy cost, the more valuable the solar and wind energy becomes. On the other hand, Hendriksen described a phenomenon that takes place when a resource is subsidized that is harmful to poor rural communities. Energy subsidization results in overuse by large industrial consumers, leaving little to none for poorer communities. Furthermore, subsidized resources often inhibit cost recovery, leading to unmaintained infrastructure. If funds are low, maintenance is focused on areas of worthwhile investments (tourist hotels and industry) leaving rural areas like Chwaka without adequate infrastructure.

Advantages of Sustainable Energy

One of Mörk's desalination plant's most important qualities is its ability to provide freshwater independent of both Zanzibar's water infrastructure and energy supply. The fact that 48% of people interviewed in Chwaka found the water vendors to be an unreliable source, in which they are unable to provide the needed service particularly during power outages, testifies to the importance of reliable water. Current energy supply from the mainland to Zanzibar is unreliable and though a new cable is being constructed, the island's energy access cannot hope to be as reliable as independently produced energy. Besides the obvious environmental benefits that using solar and wind energy provides (which fall out of the scope of this study), using independently produced sustainable energy allows for reliable water production. Particularly in a developing country, where energy supply can be erratic, the capacity to produce a resource independently is extremely valuable.

Government Water Pricing Policy

Based on several interviews with ZAWA, it is clear that villagers with access to clean water are supposed to be paying for the service but often a lack of enforcement means that this is not happening. The fee would technically entail a flat tariff because the water is not metered at delivery points but often times distributed water is not regulated and compensation is not actively pursued. ZAWA described that the fixed tariff method has always been viewed as temporary and that a volumetric charge would be adopted though this has not occurred in many parts of the island. Ultimately, providing free water has been a curse in disguise in that free water in the short term has meant deterioration of infrastructure in the long run. If managed properly, fairly priced services will provide sustainable long-term benefits (Shah, 2003).

In a similar manner, ZAWA plans to introduce a fixed tariff charge of 2,000 TSh for the water distributed by the new pipeline from Jendele to Chwaka and then transition to a volumetric charge policy. Currently all sources of water available to people in Chwaka have a volumetric charge. Both the water distributed by truck and the desalinated water have a certain fixed price per 20-liter jerry can. Beginning to institute a flat tariff for the piped water from Jendele would in all likelihood make desalinated water obsolete because villagers would then opt for the much cheaper option, which they perceive to be perfectly clean. Judging by the government's previous policy of subsidizing the price of water to fit into the budget of local people, it seems likely that even after the piped water is charged volumetrically, the price could be lower than what people currently pay (Shah, 2003). This means that if past policy implementation is any indication of what will happen, the desalination plant will have to drastically lower its price in order to even be considered by the villagers of Chwaka. This will disrupt the cost recovery that the machine aims to achieve.

Willingness to Conserve and Demand Elasticity of Water

Study findings show that almost all respondents are willing to conserve water and change their water consumption patterns with changes in price. That individuals are treating water like an economic good is positive for any water supply system in Chwaka. Due to the government's policy of free water, many residents of Zanzibar have come to take water for granted, skewing their perception of fair pricing. The results of this study, however, indicate that Chwaka residents have some understanding of the cost of water due to their current spending patterns for water. Based on respondents' willingness to change consumption with changes in price, it is possible to draw some qualitative conclusions on the demand elasticity of water in Chwaka. Demand elasticity measures the responsiveness of demand to changes in price. As a necessary good, water in a fair market typically commands a relatively inelastic demand, in which consumers will often continue to purchase water at a normal rate despite changes in price. In the case of Chwaka, however, respondents reported purchasing less freshwater when water prices were high, resorting to purchasing freshwater for drinking only and in some cases simply drinking less water. It is important to note that residents of Chwaka are accustomed to supplementing their water consumption with salt contaminated or rainwater, further adding to the notion that the villagers purchase less water during high price fluctuations. This relatively elastic demand for water provides evidence that when given two different prices for water, residents of Chwaka will purchase less (most likely none) of the higher priced product and more of the cheaper option.

Willingness to Pay and the Price of Desalinated Water

Based on respondents' reported price paid for water at 200 TSh per 20-liter jerry can, desalinated water sold at 300 TSh per 20-liter jerry can appears to be the comparably higher priced water. Additionally, water vendors deliver the jerry cans to villagers' homes, while desalinated water can only be purchased at the ZIFA campus. As residents of a rural village where poverty is prevalent, villagers of Chwaka are likely to opt for the cheaper option when it comes to purchasing water. Chwaka's relatively elastic demand for water supports this point. Furthermore 100% of respondents saw no problems with the vendors' water when it came to cleanliness, taste, smell or saltiness. Because of the high-level of filtration inherent to the reverse osmosis process, desalinated water is likely to be of higher drinking quality than the well water purchased from vendors. If the residents, however, see no problem with their current cheaper water source, it then becomes difficult for them to choose the more expensive though higher quality option in desalinated water. Despite this, respondents reported an average willingness to pay for clean and reliable water from Chwaka of 256.8 TSh per 20-liter jerry can. The average willingness to pay makes sense too, given that "the rural poor and resource poor tend to attach a higher value to the supply of water, to reduce drudgery (HALCROW Consulting Engineers, 1994)." This mean willingness to pay falls only approximately 43 TSh below the price of Mörk's desalinated water. Additionally, respondents also reported that vendors' water prices could fluctuate to as high as 300 TSh per 20-liter jerry can, matching the price of desalinated water. At a time of higher vendor prices, it is possible that the demand for desalinated water could increase. On the surface, the average willingness to pay for desalinated water (which is clean, reliable, and from Chwaka) does seem to support the idea that residents would be ready to purchase desalinated water. Based on the distribution graph of willingness to pay, however, 57% of respondents who were willing to pay were only willing to pay up to 200 TSh for clean and reliable water from Chwaka. Additionally, 12% of total respondents refused to pay at all because they believed that if water was from Chwaka then it should be free. This perception indicates an opinion that purchasing water from vendors only covered a transportation cost and not actually a cost for the water itself. Similarly, those who were only willing to pay up to 200 TSh were of the opinion that they were entitled to cheaper water if it originated from Chwaka and not transported from another source. Regardless, only less than half of the respondents that were willing to pay were ready to give up more than 200 TSh per 20-liter jerry can for water from Chwaka.

Consumers' Knowledge of Desalination

Results indicated that though a large majority of Chwaka was aware of the presence of Mörk's desalination plant, they were not aware of much else, including whether the machine is available for public use and the price of the water. Only 28% of the villagers interviewed were aware that the machine is for the public, and the remaining 72% said they either did not know whether it was for public use, or explicitly stated they thought it was installed specifically for the use of ZIFA. Villagers cited the machine's location within ZIFA's compound as an indication of it being solely for the school's use. Only 4% knew the current correct price of the water from the machine and another 4% knew the initial price, which was lowered in order to be more affordable. Various villagers were under the impression that the desalination plant only provided water sold by bottles, which are intended for the ZIFA students due to the high price relative to 20-liter jerry cans. This suggests that the presence and purpose of the machine, which was supposedly installed for the people of Chwaka, was not clearly advertised and marketed by Mörk and its partner organizations. The villager's little knowledge of the machine only confirms that even in the event of a price fluctuation to 300 TSh per 20-liter jerry can from vendors, it seems unlikely that residents would switch to the desalination plant as their water source. Some people commented that they had been told about the machine, about its intention for the public, and about the price, but that they had long forgotten and continued to buy from vendors. The failure of people to adopt a new source of water after being informed is not only due to poor marketing but also due to an unwillingness to change. Zanzibar has a culture that is very much entrenched in its traditions and there is a general desire for the status quo to prevail as opposed to modifying the way things have been done for years. The failure of desalination to catch on in Chwaka immediately may in large part be attributed to this fear of change and the unknown. Various respondents expressed skepticism of the technology itself. Without having even tasted the water, some explained how water that comes from the sea could not possibly be completely clean and safe to drink. These people made it clear that they would opt for transported freshwater over desalinated water solely for this reason. While this stems from a fundamental lack of understanding of desalination technology, it is also a manifestation of a conservative approach to change. Zanzibar has been using groundwater for centuries and the introduction of a new source of water is bound to be a slow process.

Cash Flow and Full Cost Recovery

Based on Mörk's estimated cash flow statement, the machine was installed and priced with the purpose of achieving full cost recovery. Given the Government of Zanzibar's track record of failing to collect water revenue from consumers other than industrial users, Mörk's machine and pricing mechanism appears to be a more attractive investment option than government supplied water (HALCROW Consulting Engineers, 1994). While Mörk has since lowered its initial price of desalinated water, cost recovery is still a goal in which the machine would ideally be paid off in 10 years. Based on the desalination plant's average daily production recorded during the study, however, it appears that Mörk's cash flow estimates are far overstated. The cash flow statement assumes a maximum daily production of 1,200 liters/12 hour day of operation. In reality, the machine's first five months of operation revealed average production of only 123.4 liters/12 hour day of operation. The low level of production is entirely due to minimal demand for the machine's water. Few families purchased the desalinated water, leaving only ZIFA students who purchase bottled water as the machine's customers. This suggests a high overestimation of cash flows, making it difficult to conclude whether or not the desalination plant is in fact operating with full cost recovery. It is important to acknowledge though that five months is a very short amount of time given the estimated life of the machine of over 10 years. The fact that many people do not know about the machine may very well explain the desalination unit's low daily production and perhaps if the machine were better advertised, it would experience greater success. Average daily production could very well change in the future to support full cost recovery. It is, however, hard to predict future consumption and sales of desalinated water. In the meantime, the machine's first five months of operation have revealed a daily production figure far below initial estimations, providing little evidence for successful cost recovery.

Desalination Production Capacity

Were Mörk's desalination plant to become a major freshwater source for Chwaka, it would not be capable of supplying water for the entire village. Calculations from survey results revealed average daily water consumption per capita for Chwaka residents to be approximately 20 liters. Granted that the villagers use freshwater conservatively and supplement their consumption with salt contaminated well water and rainwater, it is safe to assume that if villagers had access to adequate and affordable freshwater, it would be used for all household consumption needs. The village itself also has a population of 4,206 people, which according to the mean daily water consumption per capita of 20 liters, means that the village would ideally be using 84,120-liter of water per day. A previous study in Chwaka indicates that 5.5% of the water used per day goes towards drinking water, which means that a total of 4,627 liters/day go towards drinking water (Hansson, 2010). This figure reveals that even if the desalinated water were used solely for drinking purposes, Mörk's single desalination plant, with a production capacity of 1,200 liters/12 hour day of operation, would still only serve as a supplemental alternative source of freshwater and that a majority of Chwaka residents would not be able to depend on the machine. Additionally, The United Nation's targeted absolute minimum for daily water consumption per capita is 50 liters, a number far greater than Chwaka's figure of 20 liters per day (Shah, 2003). To put this figure into perspective, Zanzibar Town's daily water consumption per capita was found to be 30 liters, and Dar es Salaam's (the nearest major city) daily water consumption per capita was found to be 80.2 liters (Shah, 2003). Were Chwaka residents to meet the UN's targeted minimum, the village's ideal water consumption for drinking alone would be 11,567 liters daily. In order for desalination to become a major freshwater source for Chwaka, either more machines would have to be built, or a single machine would have to be built on a much larger scale.

Investment Costs

While Mörk's desalination plant is powered by sustainable energy with solar and wind technology, experts find that efforts to reduce energy costs often result in increased capital investment (Semiat, 2008). It is then important to compare the cost of Mörk's desalination plant to that of a borehole and pipeline supplying freshwater to Chwaka. ZAWA is, after all, in the process of constructing a borehole and pipeline from the village of Jendele to Chwaka for the purpose of rural water supply. In order to execute this comparison, a few major assumptions will be made. First, both the desalination plant and the borehole/pipeline need to adequately supply water to all of the village of Chwaka according to The United Nations targeted absolute minimum for daily water consumption. The UN's target is used because it is assumed that if water is to be supplied to Chwaka, it should be supplied adequately, and at the least with the aim of meeting UN standards. Second, the freshwater supply will be for drinking purposes alone because the people of Chwaka have become accustomed to using freshwater for drinking and cooking only and supplementing all other water needs with rain or salt water. And since Mörk only has one machine with a limited production capacity of 1,200 liters/12 hour day of operation, it will be assumed that that cost for Mörk to supply all of Chwaka with drinking water will entail the cost of 10 of Mörk's current machine to meet the demand of 11,567 liters/day. Granted that economies of scale would reduce the cost of a single machine with a larger production capacity, it is unfeasible within this study to do a comparison using a hypothetical machine of larger scale that does not exist.

As a single Mörk desalin® RO 100 SW desalination plant costs 54,600 USD to build and install, 10 of the same machine would cost 546,000 USD to construct and implement. This initial cost of capital would supply 12,000 liters/day of drinking water, or adequate drinking water supply for all of Chwaka. The borehole and pipeline from Jendele to Chwaka costs ZAWA 356,993 USD to construct and install. This borehole and distribution network is capable of producing adequate rural water supply (for drinking and all other consumption needs) for Chwaka. By investment costs, desalination totals a figure of 153% more than that of constructing a borehole and pipeline. The piped water would also have the capacity to supply much more water compared to Mörk's machine, which can only provide enough drinking water. The comparison falls short, suggesting that for a lower cost, ZAWA can supply Chwaka with adequate (and most likely affordable, due to the government's subsidized pricing) freshwater that residents are more inclined to purchase.

CONCLUSION AND RECOMMENDATIONS

At this point in time, current technology, current attitudes of local people, and current government policy have shown that desalination in the form of Mörk's machine is not a viable water resource for Chwaka compared to piped groundwater. The project itself has the noblest intentions while maintaining practicality but due to production capacity alone, could never hope to have a significant impact. Even if Mörk were to implement enough machines to meet water demands, the investment cost would be too high compared to the alternative impending borehole/pipeline from Jendele. The demand for desalination is also absent, where the price of desalinated water is comparably higher than other sources and villagers know little about the machine and its availability. Additionally, it is difficult to create an alternative water source in desalination that aims for full cost recovery when the government subsidizes its water distribution and eliminates competition.

While Zanzibar has an increasing issue of water scarcity, it stems more from mismanagement of the resource than from a lack of the resource itself. In light of this, it is more important for the government to manage available resources adequately rather than to invest in innovative alternative water sources such as Mörk's desalination. This does not, however, mean that companies such as Mörk should discontinue these types of investments. Like Hendriksen said, these types of well intended, innovative, and external aid-funded projects are welcome in Zanzibar, so long as the government does not have to pay for them. The government should focus on allocating its resources to transition towards fair pricing aimed at cost recovery and improved basic water supply infrastructure. Unlike many coastal areas around the wold, Zanzibar does have access to fresh groundwater, but Mörk's machine could be valuable as a water source for other places that struggle with water scarcity.

In the meantime, Mörk's desalination plant is already in place, and has the potential to become a supplementary source of drinking water for Chwaka. In order to achieve its aim at full cost recovery, the machine needs to have enough water demand to operate at maximum capacity. To do this, Mörk and its local partner organizations should organize and execute marketing and educational campaigns that actively involve the residents of Chwaka. This should entail free water tasting for those who might be skeptical of the quality of the water, as well as free promotional 20-liter jerry cans for randomly selected families for a limited time. Educational focus groups should be created to educate Chwaka residents on how high quality the desalinated drinking water is. Efforts should also be made to clearly communicate to villagers the price of the desalinated water as well as its availability to the public.

Finally, the price for desalinated water should be lowered even further, ideally below what residents are paying for other sources (vendors or in the future, the borehole/pipeline from Jendele). It should be accepted that upon the completion of the pipeline from Jendele, Mörk's desalination plant will lose all ability to compete for customers and will be unable to fulfill full cost recovery. Instead, since the machine has already been funded by foreign aid, it should supply low priced drinking water for the public. It should aim to minimally cover maintenance costs so that the machine can meet its intended purpose of supplying as much high quality drinking water as it can to the people of Chwaka.

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ACRONYMS

GPS – Global Positioning System
NGO – Non-Governmental Organization
SIT – School for International Training
UN – United Nations
TSh – Tanzanian Shilling
USD – United States Dollar
WTP – Willingness to Pay
ZAWA – Zanzibar Water Authority
ZIFA – Zanzibar Institute of Financial Administration

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