COST-BASED ECONOMIC VALUATION OF MINDU DAM WATER PROVISION SERVICE AND ITS DEPENDENCY TO MOROGORO MUNICIPALITY, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN ENVIRONMENTAL AND NATURAL RESOURCE ECONOMICS OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Accessible domestic water is a recognized basic human right. Reduced supply of water causes high financial and social costs. This study used cost-based valuation approaches to estimate the economic value of Mindu Dam water provision to Morogoro Municipality. It focused on assessing water accessibility, estimating the degradation cost and the replacement cost of water provision. It involved both quantitative and qualitative data that were analysed by descriptive statistics and content analysis respectively. The study found that 80% of respondents depend on non-public water sources (boreholes, wells, rainwater and other sources), lacking metered connections to portable water as compared to 20% with access to metered connections. Due to pollution, the municipality loses about 1 168 756 011 TZS per year for water treatment while the public suffer from sanitation and hygienic problems as social costs due to inappropriate water supply. By using boreholes alternative, the replacement cost of Mindu Dam is 64 074 304 515.07 TZS in the investment year and 39 828 547 584 TZS per year thereafter. The water supply across the study area was insufficient and partly unaffordable with increasing costs of water treatment that are not accounted for decision-making. Finally, the study recommends to the government and relevant authorities to make use of the economic analyses and valuation data to refine decision making to manage sustainably natural ecosystems for water provision to avoid degradation and the due socio-economic costs and loses.

DECLARATION

I, **Antidius Raphael**, declare to the Senate of Sokoine University of Agriculture that, this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

The accomplishment of this research work is in honour of, and thus dedicated to my parents (Raphael E. Kasimbazi and Matidona M. Kasaizi) and my siblings. My parents spared their time and limited resources to ensure that I move forward with academic journey since I started my primary education in 2003. They struggled tirelessly for my school fees and wellbeing through prayers together with my siblings to furnish my academic journey. I have nothing to reimburse, may endless God’s blessings be upon them.

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LIST OF ABBREVIATIONS AND ACRONYMS

EUWI	European Union Water Initiative
FBD	Forest and Beekeeping Division
GDP	Gross Domestic Product
GWP	Global Water Partnership
m^3	Cubic metres
MEA	Millennium Ecosystem Assessment
MNRT	Ministry of Natural Resources and Tourism
MORUWASA	Morogoro Urban Water Supply and Sanitation Authority
N	Numbers of observations (Counts)
NERC	Natural Environment Research Council
NRC	National Research Council
Qty.	Quantity
SPSS	Statistical Package for Social Sciences
TZS	Tanzanian Shillings
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
URT	United Republic of Tanzania
WB	World Bank
WBG	The World Bank Group
WEO	Ward Executive Officer
WHO	World Health Organization
WRBWB	Wami/Ruvu Basin Water Board.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Water is an important aspect for socio-economic development, life sustenance and ecological systems. Safe and adequate fresh water is undoubtedly necessary for human livelihood and social welfare (Turpie *et al.*, 2005; Lalika, 2017). It is crucial for public health, used domestically for; drinking, cooking, gardening; ecologically to sustain agro-ecosystem integrity and industrial purposes. Unfortunately, water pollution and aquatic ecosystem problems have been prevalent. They arise due to technological advancement and industrialization (Millennium Ecosystem Assessment (MEA), 2005; Turpie *et al.*, 2005) which interfere with sustainable flow of ecosystem services (Sjaastad *et al.*, 2002; Lalika, 2017). This has made freshwater one of the worlds' threatened ecosystems due to impairment of water quality which reduce the utility value (Global Water Partnership (GWP), 2003; World Bank (WB), 2004; MEA, 2005; Fo¨rster *et al.*, 2019). Alongside ecological impacts, this has led to economic implications to the entire population and managerial bodies due to higher pollution abatement cost in treating water to meet standards suitable for human consumption (Dearmont *et al.*, 1998; Vorosmarty *et al.,* 2010; Shrestha *et al.*, 2018). It is due to this reason that effective management need to consider economic concerns in making decision to attain sufficient water quality and other ecosystem services provision. The economic quantification of water provision services becomes of great importance to disclose their economic value and significance in decision making in relation to socio-economic livelihood (Jackson *et al.*, 2014; WB, 2004).

Valuation enables to describe ecosystems goods and services in monetary value (Sjaastad *et al*., 2002). Common freshwater ecosystem services valuation methods are restoration cost, damage cost and replacement cost, generally as cost-based valuation approaches (Mavsar *et al*., 2013; Jackson *et al.*, 2014). They use cost of actions incurred to restore degraded ecosystems, to remedy damaged ecosystem functions as the ecosystem's economic value (World Bank, 2004; Mavsar *et al*., 2013).

Mindu Dam, the major water reservoir supplying water in Morogoro Municipality is one of the freshwater sources impaired by pollution due to anthropogenic influence, whose economic value is not yet established. The upstream face high rate of erosion due to cultivation on steep slopes leading to high rate of sedimentation in the dam (Kihila, 2005; Ngonyani and Nkotagu, 2007; MORUWASA and WRBWB, 2019). This led to water quality impairment, reduce productivity and ability to perform its role effectively. Therefore, this study attempted to estimate the perceived economic value of Mindu Dam related to its water supply role to Morogoro Municipality.

1.2 Problem statement

Various forms of anthropogenic-driven degradation including sedimentation and water pollution, leading to water supply problems, have over time threatened Mindu Dam (Kihila, 2005; Mero, 2011; MORUWASA and WRBWB, 2019). Pronounced dam pollution and sedimentation has reduced its utility value thus several studies on it have focused on water quality (Mero, 2011). This is because the dam is the great contributor to the economy and the general livelihood of Morogoro Municipality by providing a great part of the overall water requirement. Albeit it's remarkable role, the quantification of its economic value is uncertain as most and documented valuation works to water related ecosystems have been focusing on catchment forests and forest products (FBD, 2003) using contingent valuation approach (Acampa *et al*., 2019) which are in most cases hypothetical. Consequently, the economic value of most water reservoirs services to be considered during sustainable management decisions are not yet well established (Sjaastad *et al*., 2002; Mwaura *et al*., 2016; Shrestha *et al.*, 2018). The absence of monetary value estimates is presumably leading to continued degradation, pollution (MORUWASA and WRBWB, 2019), unnecessary costs and overlooking economic analysis in decision-making (Turpie *et al.,* 2005; Grizzetti *et al.,* 2015; Root-Bernstein and Jaksic, 2017; Fo¨rster *et al.*, 2019). It was thus important to conduct Mindu Dam water provision economic valuation to Morogoro Municipality through cost-based approaches to estimate its economic value in terms of providing public water that unless immediate management and rehabilitation interventions are in place, will be costing the municipality.

1.3 Problem Justification

The study findings provide insights to Morogoro Urban Water Supply and Sanitation Authority (MORUWASA) and Wami Ruvu Basin Water Board (WRBWB), decision makers and the public an estimate of Mindu Dam’s (water provision service) monetary value. The yearly damage cost found by this study indicates the estimated amount of money that is lost in treating polluted water. Prolonged pollution and degradation of Mindu Dam may lender it unable to provide required amount of water in sufficiency. In that manner, the best alternative substitute that the population is willing to pay was boreholes. Under that circumstance, the replacement cost provides the estimated amount of money that the mandated authority and thus the Municipality would incur so as to provide equivalent amount of water (that could have been obtained from Mindu Dam) to feed the population of the Municipality. The costs are in the basis of the current population, may thus be increasing following population growth from time to time.

The estimates are of use to authorities and decision makers to design and implement conservation projects and initiatives to reverse degradation and enhance a perpetual water availability, as one of the determinants of livelihoods in Morogoro Municipality.

1.4 Research objectives

1.4.1 Overall objective

The overall objective of the study to estimate the degradation costs and the economic value of Mindu Dam water provision service by using cost-based valuation approaches.

1.4.2 Specific objectives

The specific objectives of this study were to:

i. Assess the accessibility of domestic and portable water in Morogoro Municipality;
ii. Examine the cost incurred by Morogoro Municipality due to degradation of Mindu Dam;
iii. Estimate the perceived cost of replacing Mindu Dam water supply service.

1.4.3 Research questions

This study intended to answer the following questions

i. Does Morogoro Municipality have sufficient supply of domestic and portable water?
ii. What is the cost implication of Mindu Dam degradation?
iii. What are estimated costs of replacing Mindu Dam water supply service?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Availability and accessibility portable water

2.1.1 Water availability global perspective

Safe, affordable and adequately available water is among the indicators of socio-economic wellbeing and human welfare both in developed and developing countries, rural and urban centres for human livelihoods (WHO, 2016; Masanyiwa *et al*., 2017). Clean and quality drinking water supply is of great importance for public health and social welfare (WHO, 2017; Dusabe *et al.*, 2019). It also spurs economic development (WBG, 2018). Access to adequate clean domestic and drinking water is recognized by the United Nations not only as the essential for realization of, but a basic human right in its own (Masanyiwa *et al*., 2015; WHO, 2016; Masanyiwa *et al*., 2017).

This study adopted the WHO definition of domestic water as, that used for domestic purposes including consumption, bathing and food preparation (Masanyiwa *et al*., 2017). While the 2015 WHO estimates showed that 91% world population had safe and improved domestic and drinking water, the situation was different in sub-Saharan African countries (Tanzania being the among). In Rwanda and Tanzania for instance, clean and safe water is compromised by anthropogenic conducts (Dusabe *et al.*, 2019), and becoming inadequate. Part of population was still lacking safe and adequate clean water for drinking and domestic uses (Kayser *et al*., 2013; UNICEF and WHO, 2015; WBG, 2018). The situation is attributable to lack of secure connectivity to water supply system and inappropriate infrastructures (Masanyiwa *et al*., 2015) which are mostly centralized to public than private ownership (Prasad, 2006). Public sources dependent population resorts either to water purchasing from private providers usually at higher prices or directly consuming contaminated water (Prasad, 2006; Masanyiwa *et al*., 2015; IIED, 2016).

Adequacy is in countries like Tanzania defined as, having access to household connection, public stand pipe or borehole with water from a water service provider authorized by the regulatory framework, and when the time taken (going, waiting, collecting and returning) does not exceed 30 minutes (Pauschert *et a*l., 2012; URT, 2019). The URT (2010) national demographic and health survey found only about 77% of urban population have access to portable drinking water while in rural areas being as low as 46% only. Out of 77%, only 65% of Tanzanian urban population had connections to improved domestic and portable water while about 15% lacks access to improved water (WBG, 2018). This makes some urban dwellers become dissatisfied of the available water supply service due to poor continuity of water service delivery among the piped households, making them to depend on other sources at the same time (Smiley, 2016).

Studies in most sub-Saharan African countries reveal that 28.2% of population live below the poverty line (Pauschert *et a*l., 2012), spending over half of their earnings on food (IIED, 2016; Kayser *et al*., 2013). Consequently, most households have less purchasing power on accessing portable water service which together with inappropriate infrastructure make water shortage more severe (Kayser *et al*., 2013; Smiley, 2016; Masanyiwa *et al*., 2017; WBG, 2018). Where access to portable water is available, water provision in low-income urban communities remains unaffordable due to cost implication (WBG, 2018). Moreover, water accessibility tragedy persists due to scarce information on the overall and household daily water demand and distribution channels among the urban Tanzanian poor communities (Pauschert *et a*l., 2012; IEED, 2016; Smiley, 2016). This study assessed households' water access and consumption in the municipality of Morogoro.

2.1.2 Sources of water in urban Tanzania

Compared to rural areas, most cities and townships in Tanzania have water supply systems connections. The main source of urban drinking water is according to the World Bank Group (WBG, 2018) piped water (49.6%) of which 26.3% have piped connections in their premises and the remaining 23.3% depends on neighbour's connections next to their premises. Other common sources include boreholes (14.3%), public tap (11.8%), traditional wells (5%), tanker trucks and carts (4.9%) and other minor sources (14.4%) including dams, springs, river, pond, natural caves and rainwater (Smiley, 2016; URT, 2017; WBG, 2018).

The authorized public entities for water supply are in most cases overloaded, as the production lags behind the actual water demand (Pauschert *et a*l., 2012; Masanyiwa *et al*., 2015; IIED, 2016). To fill the remaining gap, informal (non-public) service entities provide approximately 50% of drinking water consumed by urban population. The most common forms of informal water service providers in Tanzania include private run schemes (24%), neighbourhood sales (31%) and mobile vendors (10%) with tankers and carts (Pauschert *et a*l., 2012). The informal sector plays a significant role but face the challenge of lacking formal regulation and monitoring, thus not ensured on whether they draw water from safe and secured sources. Consuming water from unauthorized, non-monitored and thus uninsured sources contribute to prevalence of sanitation and hygienic problems in urban Tanzania (Prasad, 2006; URT, 2010; Pauschert *et a*l., 2012).

2.1.3 Insufficient water supply problems

Lacking reliable and affordable water services lead to health and hygienic services (WHO, 2016; WBG, 2018). UNICEF and WHO (2015), Plasad (2006) and Masanyiwa *et al*., (2015) reported about 842 000 deaths due to diarrhoea by drinking unsafe water.

According to WHO (2017), more than two billion people lack access to safe drinking and domestic water, thus consuming contaminated water. The shortage of adequate supply of clean drinking water makes some people in urban to consume polluted (contaminated) water without prior treatment (URT, 2010; Kayser *et al*., 2003; IIED, 2016). The practice is reported as the major pathway for the eruption and spread of water borne and hygienic diseases including but not limited to dysentery, typhoid, cholera, fever, schistosomiasis, intestinal worms and diarrhoea (WHO, 2016; UNICEF and WHO, 2015) which account for about 60% - 80% of outpatients un urban cities (URT, 2019). As of URT (2010) and UNICEF and WHO (2015), over 20 000 children fatalities occurs in Tanzania each year due to water-related diseases.

There is also wastage of time by moving long distance for domestic water collection. Women and young generation including girls who are mostly responsible to collect water travel long distances to get water due to its increased inaccessibility (URT, 2019). As a result, other production activities may cease. Due to insufficient safe water, available water needs treatment prior to its consumption, leading to financial losses (WBG, 2018). Moreover, limited sources are also attributable to social conflicts among users with different interests and demands. Lacking sufficient and clean water lead to accelerated poverty, public health and food security problems, political conflicts and economic development retardation (Plappally and Lienhard, 2012a, b).

2.2 The Concept of ecosystem valuation

Ecosystem valuation is the approach used to assign monetary value to the ecosystem goods and services whether marketable or non-marketable (Groot *et al.*, 2010). It aims at underpinning the underlying benefits essential for economic performance and human well-being (MEA, 2005). It is also an approach to correct the current markets that cast value to only a sub-component of the ecosystem services priced and incorporated in transaction as either commodities or services and show-up direct in a physical market system (UNESCO, 2002; EUWI, 2017; Vannevel and Goethals, 2020). The inability of conventional market strategy to capture and quantify most of the ecological services leads to informational and market failure (Carson and Bergstrom, 2003; Groot *et al.*, 2010). Hence, valuation relate how human decisions and the functionality of ecological systems affect each other and expresses the value of ecosystem functioning in monetary term to allow their inclusion in public decision-making processes (Mooney *et al.*, 2005; MEA, 2005; Fo¨rster *et al.*, 2019). The value assigned reflects the distribution of wealth and income, the state and significance of natural environment and future expectations in a financial and natural resources perspective in a multitude of socio-ecological conditions and preferences (Carson and Bergstrom, 2003).

2.3 Cost-based valuation approaches

Cost-based approaches rely on the estimated costs incurred (or to be incurred) if the needed ecosystem services are to be artificially recreated (Carson and Bergstrom, 2003; MEA, 2005). These are appropriate in valuing regulation services commonly water regulation and purification ecosystem services. Several techniques exist including the damage cost and replacement cost (Jackson *et al.*, 2014; Hernández-Sancho *et al.*, 2015; EUWI, 2017) as described hereunder.

2.3.1 Damage cost method

The damage cost method estimates the value of ecosystem service in terms of the cost incurred to remedy the damage due to their loss (MEA, 2005; Chaikumbung, 2013; Hernández-Sancho *et al.*, 2015; Fo¨rster *et al.*, 2019). It relates the costs incurred to provide a certain service in the absence of the normal functionality of the natural ecosystem by estimating potential damages and calculating associated potential costs (Carson and Bergstrom, 2003). The value of water treatment by natural ecosystem is thus related to the costs incurred to treat polluted water that would be purified by natural ecosystems if were to remain intact (Dearmont *et al.*, 1998; Renzetti and Kushner 2004; Hernández-Sancho *et al.*, 2015; Choi *et al.*, 2017; Root-Bernstein and Jaksic, 2017).

Due to inadequate economic valuation studies, many policy and decision makers are still not aware of watershed's economic value (MEA, 2005; Mwaura *et al.*, 2016; Fo¨rster *et al.*, 2019). This has been a big hindrance to environmental conservation by overlooking the economic facet of the ecosystems in management decision matrix hence continued degradation (MEA, 2005; Musamba *et al.*, 2011). In African countries for instance, regardless of large number of freshwater sources, about 5% of annual national Gross Domestic Product (GDP) is lost due to polluted water treatment (Schwarzenbach *et al*., 2010; Plappally *et al*., 2011; Plappally and Lienhard, 2012b; Renzetti and Kushner 2004). This defines the economic value of water for public use.

Reportedly, unsustainable human activities conduct in a place without considering the natural ability of that locale leads to severe financial resources loss due to degradation and pollution of water bodies and captivity sites, requiring high-level treatment (Schwarzenbach *et al*., 2010; Plappally and Lienhard, 2012a, b). Alternatively, there is adoption of aquifer pumping and vehicular water importation when treatment seems almost impossible, regardless of higher cost (Plappally and Lienhard, 2012a). Moreover, experience from existing literature denotes inadequate technical examination and economic valuation of water treatment financial cost (Acampa *et al*., 2019). Lacking monetary estimates on the financial losses due to degradation and treating polluted water may intensify the problem. Even where previous cost estimates are available, they could still not be simply applicable to reflect current situation due to rapid technological advancement, increased contamination level and population pressure which interactively have led to emergence of new contaminants (Plappally and Lienhard, 2012b; Renzetti and Kushner 2004). This poses a great challenge in water treatment's economic studies, requiring regular studies to achieve on-time valid cost estimates. It is in that aspect that, assessing water treatment cost in consideration of the available processes and technology is of paramount importance to redirect water provision planning and making feasible cost prediction based on the situation at hand (Acampa *et al*., 2019).

2.3.2 Replacement cost method

This is an approach of assigning a monetary value to ecosystem services based on possibilities to substitute a specific ecosystem role with man-made alternatives equivalent to a specified ecosystem function (Jackson *et al.*, 2014). In this case, the cost of the potential replacement technique provides estimates of the economic value of the ecosystem. The cost of replacing an ecosystem service with the engineered substitute in this method is a measure of its economic value (Sandberg, 2004; MEA, 2005). For this to be effective, it must be possible to identify a suitable substitute whereas, both the cost of investment (installation cost) and maintenance costs need to be taken into consideration. This technique has proven appropriateness in valuing flood protection of wetlands by using artificial coastal defence costs and water purification by considering the cost of engineered water treatment plants (Hernández-Sancho *et al.*, 2015; Choi *et al.*, 2017; NRC, 2004). For example, the value of drinking water provision by a natural reservoir or spring in a well-managed catchment relates to the cost of constructing boreholes (FBD, 2003; Groot *et al.*, 2010).

2.3.2.1 Important consideration

Since the application of Replacement Cost in ecosystem valuation relies on equivalent substitutes to specific service provision, its validity and effectiveness follow the satisfaction of three major pre-requisite conditions. When these pre-requisites are satisfied, this method become a valid measure and estimate of the economic value (Sandberg, 2004; Jackson *et al.*, 2014). These are *perfect substitutability, cost-effectiveness and individuals' willingness to pay*.

- **Substitutability**

The Perfect substitutability requires that a perfect substitute to replace the ecosystem service to be present. The substitutes should suit to provide equivalent functions to the ecosystem service of concern. It is un-doubtful that in a real and changing environment it becomes difficult to meet the perfect substitutability criterion due to complexity of ecosystem processes, interactions and functions. While this still hold as a criticism to this method, several ecosystem services continue to experience alarming scarcity due to degradation and overexploitation making the situation and its valuation even worse. In such thought, economists and ecologists have attempted to justify this criticism in a sense that; instead of having the entire complex ecosystem, close equivalent substitutes that do exist are equally used to find estimated value of ecosystem service. (Jackson *et al.*, 2014). This is to ensure that some ecosystem services are not underestimated.

- **Cost-effectiveness**

This criterion requires replacing technique to be available, affordable and able to provide equivalent ecosystem service at a significantly lower cost. Different possible replacement alternative is subject to comparative examination. Since in practical terms, it is unlikely to examine every available technique thoroughly, it becomes reasonable to select the most feasible techniques for examination and comparison such that the least cost-effective one is adopted (Sandberg, 2004).

- **Willingness to pay**

Individuals must be willing to pay and incur potential costs for that specific substitute if the ecosystem service is no longer available (Hernández-Sancho *et al.,* 2015). It thus requires a substantial evidence that the public would demand the service if it was to be provided by the least cost-effective alternative to ensure the replacement cost value obtained do not overstate the actual value of the ecosystem service (Jackson *et al.,* 2014).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Description of the study area

3.1.1 Geographical location

This study was conducted in Morogoro Municipality (Fig. 1), one of the nine districts of Morogoro Region in Tanzania. Consideration was on Mindu Dam, the main source of water in the Municipality located in Mindu Ward, 60° 51'S to 60° 52'S latitude and 37° 30'E to 37°40'E longitude in the Ruvu Catchment southeast of Ngerengere River valley between the Uluguru and Mindu Mountains 16 km West of Morogoro town in Tanzania (Kihila, 2005). It provides industrial and domestic water supply (Ngonyani and Nkotagu, 2007) while supporting fishing. The municipality is administratively sub-divided into 29 wards, each with a varying number of streets.

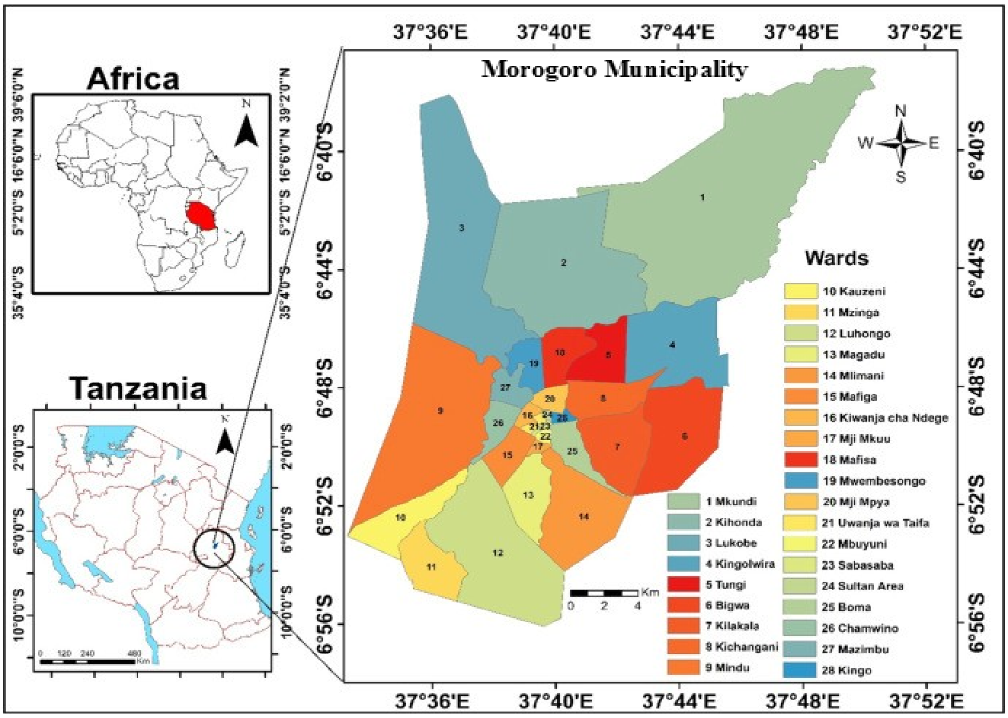

Figure 1: Geographical location of Morogoro Municipality in Tanzania

Source: Adopted from Sumari *et al*. (2020)

3.1.2 Climatology

The mean annual temperature varies between 18^0 C on the mountains to 30^0 C in valleys, hotter from July to September. Precipitation ranges from 500 mm on the west arid plains to 1700 mm on the eastern-forested slopes between November and April with the annual rainfall ranging from 600 to 1200 mm in low and high lands respectively.

3.1.3 Drainage

The drainage of Mindu Dam consists of major five rivers namely Mzinga, Mlali, Mgera, Lukulunge and Ngerengere - which flow both in and out of the reservoir. The main purpose was to supplement the over increasing demand of water supply for both industrial and domestic purposes. It had the original volume capacity of 20.7 million m^3 and currently estimated to be 13 million m^3: 11.28 million m^3 and 2.02 million m^3 active and dead volume not accessed for use respectively. The lowest level by volume reaches 50% during the dry season (Kihila, 2005; URT, 2012).

3.1.4 Study population and socioeconomic profile

The projected population of Morogoro Municipality is 400 155 people based on 2012 population census and a three percent growth rate (URT, 2012) with main five ethnic groups (Waluguru, Wasagara, Wakaguru, Wandamba and Wapogoro). The major activity is crop farming (maize, rice, sorghum, cassava, sugarcane and vegetables). Some involve in domestication of goats, and cattle by the Maasai living 20 km from the dam most during the dry season (when most parts are unfavourable for livestock keeping due to shortage of pasture) and fishing supported by Mindu Dam (MORUWASA and WRBWB, 2019).

3.2 Sampling procedure and sample characterization

3.2.1 Sampling procedure

This study used three-stage sampling technique with random sampling to offer an equal chance, reduce biasness and enabling reliability of the study findings (Kumar, 2005). The first stage involved random sampling of wards then streets in each ward as the second stage. The third stage involved sampling households from each selected street. Since the population of the study area was more than 10 000, sampling intensity was 10% at each stage (Neuman, 2014). The study selected wards (Bigwa, Chamwino and Mindu) at the first stage and streets (Bigwa barabarani Street from Bigwa Ward, Shule Street from Chamwino and, Mindu and Mikoroshini Streets from Mindu Ward) at the second stage. Household sampling marked the third stage. All stages of sampling involved rounding off to the nearest whole number rule of rounding decimal numbers, proportions that resulted in decimals. The table below summarizes study sample distribution by wards and streets.

Table 1: Distribution of study samples by wards and streets

Ward	**Street**	**No. households**	**Sample size (10%)**	**Percent**
Bigwa	Bigwa barabarani	240	24	25.8
Chamwino	Shule	182	18	19.4
Mindu	Mindu	297	30	32.2
	Mikoroshini	209	21	22.6
Total		**928**	**93**	**100**

For data relevancy and accuracy, the study used purposive sampling to select key informants from MORUWASA and WRBWB.

3.2.2 Description of study sample

The study sample composed of both male (30.1%) and female (69.9%) whose education and occupations are as presented by Fig. 2.

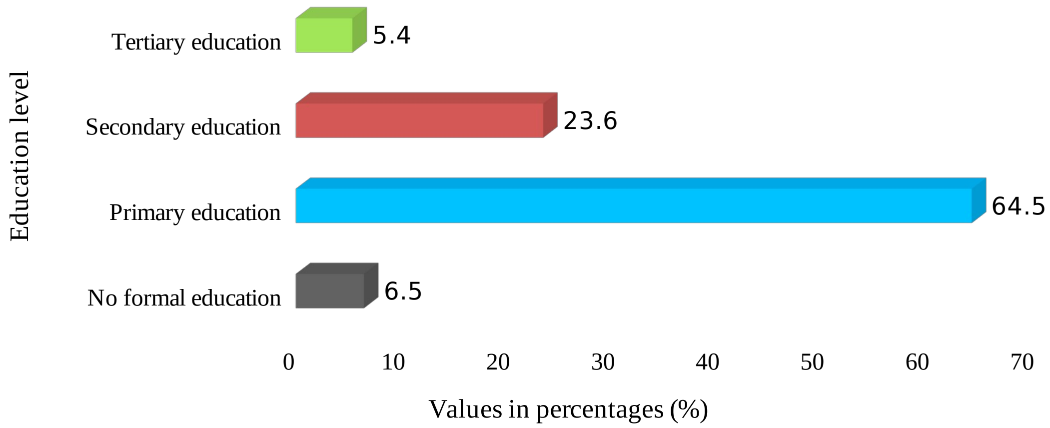

Figure 2: Education profile of study sample

Respondents included farmers practicing horticultural cropping, and irrigation, self-employed individuals (in car-washing, garaging, welding, plumbing, masonry and catering services, and some as motorists). Casual workers with no specific works, cutting-across in any work, mostly physical were also included. These performed activities such as saving in catering services, water collection and distribution to those with no metered connections or away from the water source, and mainly domestic servants assistants in self-employed category. Jobless individuals (retired, former government employees and elderly) also participated in this study. Government employees ranked the last (lowest) in terms of representation because sampling and household surveys were done during weekdays where a large group of government employees (like teachers, doctors and nurses and government officials) residents were attending their job stations.

3.3 Data collection

3.3.1 Key informants' interview

The study used key informant's interview to collect water treatment (initial, equipment installation and maintenance) costs from MORUWASA (technical department) officials to enable computation, and quantification of water treatment cost. It was also used to gather boreholes drilling and installation cost from WRBWB (Hydrogeology and Drilling department) to enable estimation of running boreholes in case the dam stops operation. With the support from the technical department, further secondary cost data were obtained from relevant record keeping documents at MORUWASA headquarter to complement collected primary data.

3.3.2 Household interview

The study used this method to collect socioeconomic data by means of household questionnaires among respondents from each selected household. The questionnaire aimed at capturing information on water supply ranking, main source of water, daily water requirement (consumption), water bills, alternative method that communities are willing to pay for effective water provision situation and the costs associated with water supply problems. The interview also explored further details including the extent of water availability, ranking of water provision service by MORUWASA on their localities and alternative means for obtaining water during scarce period.

3.3.3 Observation

The study used direct observation on the field to obtain additional information that complemented responses from field survey. This method was meant to supplement and validate questionnaires survey and interview collected data. Observation was based on the available means of water access, whether appropriate infrastructure are present or not.

3.4 Data analysis

The study used descriptive analysis for socio-economic data regarding water demand and other non-valuation data with the aid of Statistical Package for Social Science (SPSS) and Microsoft Excel for output presentation. Household survey data related to water demand were analysed for descriptive statistics (frequencies, maximum, minimum and means) across the sampled streets in respective wards. Cost data related to water treatment and boreholes were analysed by cost-based valuation approaches, damage cost and replacement cost respectively as expressed mathematically by eqn. (*i*-*iv*).

$$C_{wtrt} = ¿ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Where: $C_{wtrt} = ¿$ Total water treatment cost

C_{init} = Initial cost

$C_{\}¿¿}$ = Operating cost

C_{mtnc} = Maintenance cost

$$Initial\,cost = \sum \left(\frac{C_{prc} + C_{ist}}{S_d} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

C_{prc}: Cost of purchasing devices

C_{ist}: Installation cost

S_d: Span of the device

$$C_{opr} = \left(C_{pw} + C_{wg} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

C_{opr}: Cost of operation

C_{pw}: Power cost

C_{wg}: Labour wages cost

$$C_{mtn}=N_w\left(N_d \times P_{dm} \times C_{fy}\right) \qquad \text{.........(iv)}$$

C_{mtn}: Maintenance cost

N_w: Number of workers

N_d: Number of days used

P_{dm}: Per Diem

C_{fy}: Yearly clean-up frequency

$$Replacement\,Cost=\frac{Q_w \times H_n}{C_{bh}} \times \left(\frac{C_{eqp}+C_{ins}+C_{mtn}}{T_d}\right)+C_{srv} \qquad \text{.........(v)}$$

Q_w: Average daily household water consumption

C_{bh}: Borehole capacity (number of households fed by a unit borehole)

H_n: Number of households

C_{eqp}: Cost of equipment purchase

C_{ins}: Installation cost

C_{mtn}: Maintenance cost

T_d: Span of installed devices in years

C_{srv}: Cost of hydrogeological survey

Qualitative data from observation, key informants' interviews and some open-ended questions within the household questionnaire were all analysed by content analysis to identify basic themes and patterns with respect to the study questions and objectives. With this study, both quantitative and qualitative data were mutually dependent, complementing to one another. The presentation and reporting style of the study findings has thus weaved them all together.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Water availability and accessibility

4.1.1 Available sources of domestic water

Household domestic water access was determined based on water source type, daily water consumption, monthly water bills and monetary cost spent on water during scarce period. The main available sources of domestic water include MORUWASA pipe connections, boreholes and wells, and rainwater (Table 2).

Table 2: Distribution of major water sources in three wards of Morogoro Municipality

Means of accessing water	Ward (%)			Total
	Bigwa	**Chamwino**	**Mindu**	
MORUWASA	1.1	19.4	0.0	20.4
Boreholes and wells	3.2	0.0	5.4	8.6
Rain water harvesting	21.5	0.0	1.1	22.6
Other sources (streams, ponds, caves)	0.0	0.0	48.4	48.4
Total				**100.0**

The main domestic water source varied across the wards (Table 2). Rainwater harvesting was prevalent in Bigwa (21.5%), other sources (48.4%) including streams and direct intake from the dam and ponds in Mindu. This reflects inappropriate public water supply connectivity among peripheral areas. MORUWASA was the only available means in Chamwino (Table 2). This might be due to it being located away from the mountain ranges (compared to Bigwa and Mindu) to enable harvesting water from the uphill by gravitational pull. Consequently, Mindu Ward inhabitants had opted to buy water from private wells and distributors due to absence of public connections (Table 2). The study findings indicate inadequacy of available public water supply in the municipality.

Several studies report similar findings on the problem of public water supply in other parts of Tanzania townships and urban centres (Masanyiwa *et al*., 2017; Pauschert *et a*l., 2012) and other developing countries (Prasad, 2006; Garcia-Valinas *et al.*, 2010). The shortage of public water supply was also reported by other studies (URT, 2012; Smiley, 2016) and calls for private water service providers and suppliers to intervene and work together with public entities to improve efficiency in urban water supply.

It accounts for a reason why several households in such urban centres opt to invest in their own private water supply. These findings correspond to other studies (Mussa *et al*., 2019) that reported on the use of rainwater harvesting and boreholes (Martínez-Santos *et al*., 2017, 2020) to supplement inadequate piped portable water supply or its mere absence in urban townships.

4.1.2 Water accessibility and delivery ranking

Due to increasing water demand following population increase over time, water supply delivery dynamics has been prevalent in the municipality. The water service delivery is for those depending on public sources determined by weekly water shares (Table 3).

Table 3: Responses on households' weekly water access

Weekly water access	Ward (%)	Total

frequency	Bigwa	Chamwino	Mindu	
Always	11.8	3.2	51.6	66.6
3-5 days	7.5	5.4	3.2	16.1
Twice	1.1	9.7	0	10.8
Once	1.1	1.1	0	2.2
Undefined	4.3	0	0	4.3
Total				**100**

The study reflected a lacks of constant supply of water as 26.8% access water shares two to five days a week (Table 3). Chamwino depending only on MORUWASA, declared of receiving water shares twice a week. Some (4.3%) reported an irregular and undefined pattern of water shares with some who only depend on MORUWASA (Table 2) reporting of staying the whole week without accessing water due to the limited infrastructure and irregular water flow on the connected premises. Problems in water accessibility frequency is also known to impact on social welfare as households spends much times in collecting water, reducing time available for other household's productive and domestic activities (Pauschert *et al*., 2012; IIED, 2016; Masanyiwa *et al*., 2015, 2017).

An ensured and constant access to water (66.7%) was common among respondents who either owned water source commonly boreholes, wells and rainwater-harvesting system installed or had direct access from the dam and natural sources (Table 2). The remaining population opts for private suppliers to get water at the convenience time to meet their needs. These findings are in line with those of Prasad (2006) and Masanyiwa *et al*. (2015) that recommended non-centralized private water supply to complement public water supply inefficiencies (Smiley, 2016; WBG, 2018). Other studies (Garcia-Valinas *et al.*, 2010; IIED, 2016; Masanyiwa *et al*., 2017) linked such inappropriate water access in peri-urban areas to poor infrastructure. Masanyiwa *et al*. (2017) also found that, households with unsecured access consume water from unsafe sources that do not guarantee public health.

The extent of water provision in the study area was ranked based on respondents' perception as tabulated in Table 4 below.

Table 4: Community responses on public water supply ranking

Respondents' perceptions on water supply condition	**Ward (%)**			**Total**
	Bigwa	**Chamwino**	**Mindu**	
Very poor	19.4	9.7	52.7	81.7
Reduced	6.5	6.4	0	12.9
Optimal	0	2.1	2.2	4.3
Good	0	1.1	0	1.1
Total				**100**

Study respondents reported inefficient water supply service with time, as reflected in the current water delivery by MORUWASA here in as a public water supply agent (Table 4). Approximately 95% of respondents were not satisfied with the current supply of water, they ranked the service as reduced (12.9 %) to very poor (81.7%) (Table 4). These results comply with the reported cultivation in the catchment upstream and chemical pollution from the Mzinga military area industrial discharge (Ngonyani and Nkotagu, 2007; MORUWASA and WRBWB, 2019) and sedimentation (Kihila, 2005) due to population increase (URT, 2012). Recognizing such reduction in water supply, MORUWASA established Mambogo treatment plant to increase the rate of water treatment and delivery to the public.

4.1.3 Household water demand

These findings indicate that, households consumes about 144 litres of water in average (Table 5) that meet only basic needs like drinking and food preparation. This is within the WHO established levels of 20 litres per person per day (Masanyiwa *et al*., 2017). Due to a many utility, this amount was inadequate for hygienic practices like hand washing, laundry and bathing. This reflect the idea developed ever before that, water sufficiency may differ across areas depending on the extent of activities that available water is used for (UNICEF and WHO, 2015; WHO, 2017). A few households (14%) ranked the level of public water access as optimal to good; it therefore implies that public water supply does not meet their demands (Table 4). These findings complement to previous studies (Garcia-Valinas *et al.*, 2010; Kayser *et al.*, 2013) across sub-Saharan countries that found it difficult for public water supply to meet demand of the entire urban population in sufficiency to guarantee better public health.

The monthly water bills counted zero only for households with private water source like domestic borehole or just have installed private water harvesting system in their premises. The bill and cost of accessing water during scarce period was high up to 70 000 and 90 000 TZS maxima respectively (Table 5) especially in areas with no portable water connections. Following the observed situation and respondents’ arguments on water supply, the household water uses and costs for respective time of stay in the municipality were as presented in Table 5.

Table 5: Household water consumption and spending

Parameter	**Unit of measure**	**Statistic**		
		Minimum	**Maximum**	**Average**
Household size	N	1	17	5
Daily water consumption	Litres (L)	30	1400	144
Monthly water bill	TZS	0	70 000	15 976
Scarcity monetary cost	TZS	0	90 000	24 595

In places like Mindu and Mikoroshini, majority of households used to buy water from private vendors, and some from privately owned boreholes (which are also scarce). Experience from native dwellers and study respondents showed an increase in prices with years due to inappropriate public connectivity to portable water. Inappropriate public water supply increase reliance on private water suppliers. This tendency causes financial losses due to elevated price levels as reflected by scarcity monetary value (Table 5).

This available amount (144 litres) was slightly enough for basic utilities like cooking, but insufficient for other uses. The amount of water accesses and consumed daily is a rough reflection of distance, time, reliability and water cost. Although there is no formally agreed universal amount of water holding to meet domestic uses, several reference levels have been established (Masanyiwa *et al*., 2015; IIED, 2016). While WHO justified 20 litres per person per day (IIED, 2016), the Tanzania water policy recommends a minimum of 25 litres per day per person (URT, 2012). Although, the average water consumption per household complied with both the WHO and Tanzanian levels, it was still insufficient due to increased activities that depends on water availability and a large disparity between the household sizes. The interpretation of the observed difference between the two levels implies that, the appropriate amount depends on the specific area of concern.

To cope with the situation, Chamwino and Bigwa wards had installed reservoir tanks to harvest rainwater and groundwater for use during scarcity with some operational charges of up to 200 TZS per 20 litres gallon. During low flow and water-scarce period, the costs become even much higher such that some people are unable to pay for the service. When the Mindu Dam volume is low, the distance to access water for those who directly outsource water from the dam also increase especially in peripheral areas with no ensured access. A similar situation is common in unplanned peri-urban areas making them victims of water access and some operations cease, leading to urban water poverty (Pauschert *et al*., 2012; Masanyiwa *et al*., 2017). Moreover, water prices go up due to the reduction in the well yield and the number of days that individual household access water (Table 3). Fig. 3 illustrates the monthly water access monetary costs across the wards (Bigwa, Chamwino and Mindu), to meet their demands during scarce period.

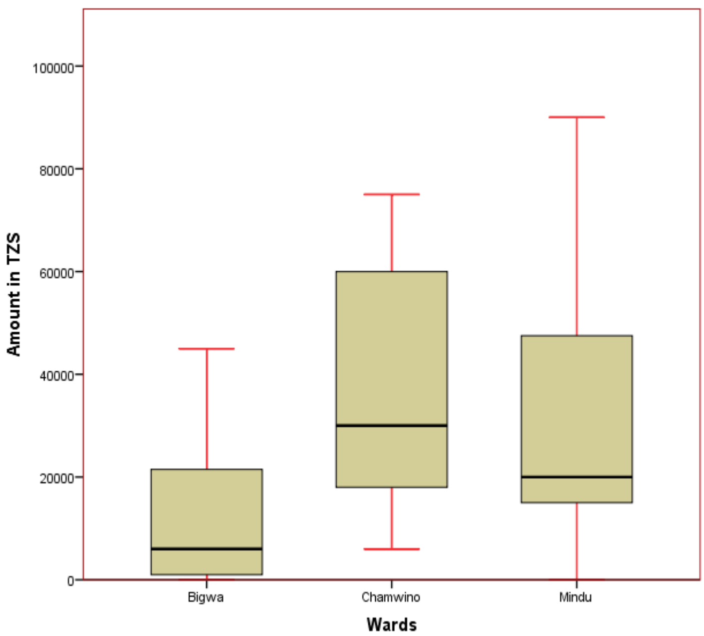

Figure 3: Distribution of monthly water scarcity costs by wards

The overall cost was significantly lower (22 000 TZS) for Bigwa Ward that depends mostly in harvesting rainwater uphill and boreholes in their domestic places. Mindu ward that depend mostly on other sources like ground excavations and partly (5.4%) from private boreholes (Table 2) had higher costs (48 000 TZS) compared to Bigwa. The observed costs in Mindu Ward regardless of having direct access from the dam is attributable to reported progressive sedimentation (Kihila, 2005). Sedimentation reduce the operational capacity by lowering depth and volume of Mindu Dam. Largely depending on public water connection from MORUWASA, Chamwino counted for the highest values both for minimum (18 000 TZS) and maximum costs (60 000 TZS) associated with water accessibility. Higher costs in Chamwino Ward was due to both some defaults in their connections leading to unrealistic bill counts (sometimes) and unplanned dwellings leading to difficulties in being accessible even to private vendors, hence high costs. Following the high-water costs, some households are unable to access domestic water because they cannot afford to pay. Unaffordability of domestic water is among the causes of households losing their right to access water (Garcia-Valinas *et al.*, 2010; WHO, 2016; IIED, 2016; Masanyiwa *et al*., 2017).

4.2 The perceived cost of Mindu Dam degradation

4.2.1 Services provided by Mindu Dam

Apart from water provision, the dam also hosts several livelihood activities to the surrounding communities defined by different uses. Domestic water use including washing, cooking and drinking marked the highest (50.8% and 27.7% respectively) both for areas with and without metered connections to MORUWASA portable water systems (Table 6).

Table 6: Responses on main services provided by Mindu Dam

Service (Water use)	**Responses**	
	Frequency	**Percent**
Cooking and washing	66	50.8
Drinking water	36	27.7
Fishing activities	19	14.6
Gardening	7	5.4
Commercial uses	2	1.5
Total	**130**	**100**

Apart from providing domestic use water, the dam host fishing activities (14.6%) to adjacent communities. Some people who have employed themselves depend on the dam for irrigating crops and running catering services, garaging and car-washing services (Table 6). This is similar to Lufingo (2019) who reported severe degradation in freshwater sources that support fishing apart from providing water.

Due to the perceived and revealed reflection of pollution to water supply, respondents had different perceptions (Table 7) on whether the dam's pollution directly affects water supply.

Table 7: Community perception on the effect of dam pollution to water supply

Mindu Dam pollution affect water supply	**Frequency**	**Percent**
There is a significant effect	65	69.9
No revealed effect	3	3.2
Not aware	25	26.9
Total	**93**	**100**

According to the respondents, degradation and pollution of Mindu Dam affect approximately 70% of the population in terms of water supply (Table 7) with approximately 96% (Table 8) of the study respondents declaring to experience the effect of water scarcity.

The study investigated whether the population felt the effects of water scarcity. The proportions of response are as indicated in Table 8.

Table 8: Proportion of respondents directly affected by water scarcity

Water scarcity effect	**Frequency**	**Percent**
Directly affected by water scarcity	89	95.7
Not directly affected	4	4.3
Total	**93**	**100**

Study respondents declared of being faced by water scarcity from time to time. The effect was more pronounced among those relying on public supply from MORUWASA. Such a reduced supply was linked to several factors including population increase, degradation and sedimentation of the dam (Kihila, 2005). Water treatment is thus essential.

4.2.2 MORUWASA water treatment devices

MORUWASA initially installed a major treatment plant at Mafiga, and Tumbaku booster station that operated until 2014 when Mambogo treatment plant started operation due to the increase in population and water demand. MORUWASA technical department reported that “about 71.56% of the municipality population is under metered connection with a total coverage of 81% of established networks”. To achieve the desired levels of domestic water use, water from the Dam and other sources are treated using a set of different devices. The devices used for water treatment process are indicated in Table 9.

Table 9: Characterization of water treatment devices

Device	Reagent used	Purpose
Al Hypocride dozing pump	Aluminium Hypocride	Settling dissolved and suspended particles
$CaSO_4$ dozing pump	Calcium sulphate	Kills germs and bacteria in raw water
Algae dozing pump	Algae or lime	Quick settling and pH regulation

Source: MORUWASA

The Aluminium dosing pump draws a specified volume of reagents (depending on the extent of turbidity of water to be treated) from the mixing tank to the water treatment tank. Aluminium Hypocride (coagulant) facilitate settlement of dissolved mud, dusts and suspended particles (Dearmont *et al*., 1998; Acampa *et al*., 2019). Reportedly, turbidity presents a major form of pollution indicating the presence of suspended matter (fine organic matter, clay, silt, algae and other microbes). The technical department reported that, "when raw water to be treated is highly polluted with high degree of turbidity especially in rain season, Aluminium Hypocrite only does not suffice for coagulation". Alternatively, using algae to enhance particle and mud settling rate followed by Lime solution or soda ash to stabilize pH of the settled water has been common. Dearmont *et al*. (1998) acknowledged the use of lime and soda ash in water treatment and recommended potassium permanganate, caustic soda and polymer for coagulation.

4.2.3 Water treatment economic costing

To quantify the MORUWASA water treatment cost, this study examined the initial (equipment's purchasing and installation), operating and maintenance costs in (Table 10).

Table 10: Initial costs of water treatment

Device	Qty.	Operating time[+]	Unit price*	Purchasing costs*	Installation cost*
Al Hypocride pump	2	3	70 000 000	140 000 000	56 000 000.3
$CaSO_4$ dozing pump	2	3	60 000 000	120 000 000	48 000 000
Algae dozing pump	2	3	90 000 000	180 000 000	72 000 000
Total	**6**		**220 000 000**	**440 000 000**	**176 000 000**
Overall cost*			**205 333 333.3**		

Figures expression: *TZS, [+] years

Source: MORUWASA, 2021

The MORUWASA technical department characterized water treatment devices indicated in Table 10. The Aluminium dozing pump draws a fixed amount of alum from the reagent tank to the water treatment tank. The pumped alum provides for a coagulating role, settling dissolved mud, dusts and suspended particles. Dearmont *et al*. (1998) accounted for similar roles. Since each device set-up can last for up to three years before being replaced, the initial cost becomes 68 444 444.43 TZS per year.

Water pollution arise due to human interactions either direct or indirect. Being a universal solvent that dissolves and absorb most of the materials with which it comes in contact with, it contributes to high financial costs to treat water (Plappally and Lienhard, 2012b). The demand for safe and clean water transforms the water scarcity from social to economic one causing a loss of up to 5% of GDP in some African countries (Plappally and Lienhard, 2012a) by treating polluted water for public use. According to Dearmont *et al*. (1998) and Acampa *et al*. (2019), the cost of treating polluted water following diminished water quality forms an important component in accounting for the costs of water pollution to the society. It is against this, that consideration of the costs related to water treatment chain was an important component in this study.

4.2.4 Operating and maintenance costs

The water treatment operational cost brings in the cost of power (fuel) and maintenance of the plant and treatment facilities. These costs are according to Dearmont *et al*. (1998) and Hernández-Sancho *et al*. (2015) of important consideration in computing the cost of water treatment. The following table details daily and yearly treated amount of water by MORUWASA.

Table 11: Production capacities of MORUWASA water treatment plants

Plant	**Daily water volume (m^3)**	**Daily volume in Litres**	**Yearly volume (Litres)**
Mafiga	27 000	27 000 000	9 882 000 000
Mambogo	6 000	6 000 000	2 196 000 000
Other sources	2 000	2 000 000	732 000 000
Total	**35 000**	**35 000 000**	**12 810 000 000**

Source: MORUWASA, 2021

To effectively run the installed treatment systems (Mafiga and Mambogo treatment plants, Tumbaku booster station), and achieve the above amount, electrical power is used.

Available devices are 90% efficient, which utilize the average yearly electrical power costing 871 711 566.4 TZS. Several studies have reported the need for inclusion of power cost in water treatment costing (Dogot *et al*., 2010; Hernández-Sancho *et al*., 2015).

Regular maintenance (three times a year) costs are as described in Table 12.

Table 12: Characterization of operating and maintenance cost of water treatment

Particular	Units	Value/Figures
Labour	N	20
Per diem /Rate	TZS	15 000
Days taken	N	2
Clean-up frequency per year	N	3
Total cost	**TZS**	**1 800 000**

Source: MORUWASA technical department and field data

A team of 20 workers (9 for Mafiga, 6 for Mambogo and 5 for Tumbaku) runs the system and mounts to a total annual cost of 226 800 000 TZS for all stations inclusive. Summing the power and labour charges, the annual operating cost becomes 1 098 511 566.4 TZS which is equivalent to 31 386 TZS per m^3.

Maintenance is by cleaning water treatment tanks, involving 20 workers in two days consecutively, costing about 1 800 000 TZS. Summing up the yearly initial, operating and maintenance cost, the overall cost used in water treatment becomes 1 168 756 011 TZS per year, equivalent to 91.24 TZS per m^3. This might be subject to increase following human conducts and population increase in the study area that may exceed the production capacity of treatment plants. Junior *et al*. (2012) found similar increasing trend of water treatment cost with progressive reduction in capacity of water treatment sector in developing world.

Notwithstanding the fact that this study has quantified the cost of water treatment, the value is not conclusive and might not be comparable to other places but may provide an overview. This is due to the reported variation in the approaches and the types of costs that the study attempts to address (Dogot *et al.*, 2010; Hernández-Sancho *et al.*, 2015). While other studies consider quality influent and effluent parameters, some focus on the volume of water treated (Hernández-Sancho *et al.*, 2015). This study adopted the same as it based on the volume of water treated in relation to the available population. Regardless of the adopted approach, the incorporation of both investment and operational cost is vital (Dogot *et al.*, 2010; Hernández-Sancho *et al.*, 2015).

4.2.5 Water supply inadequacy social costs

Beside the quantified monetary cost incurred by MORUWASA (Table 10, 12), the public also incur additional cost due to shortage and water supply problems especially pollution and scarcity as illustrated in Table 13.

Table 13: Responses on the community social costs due to water supply problems

Revealed social costs	**Responses (N=93)**	
	Frequency	**Percent**
Hygienic diseases	56 (93)	31
Financial loss	49 (93)	27
Time wastage for water collection from distant	41 (93)	22
Stopping some activities	21 (93)	12
Severe water shortage	16 (93)	9
Total response	**183**	**100**

Prevalence of pollution and shortage of adequate clean water has been leading to eruption of hygienic diseases including cholera and typhoid amongst societal costs. The cost become much higher to those who has no access to portable water (Table 2). They use water direct from the dam without any treatment due to prevailing scarcity and poor water supply service (Table 4). The shortage is increasing due to pressure exerted on the dam ecosystem by the surrounding communities for various services. The social costs incurred by the societies are due to the activities and services (Table 6) that Mindu Dam provide to the surrounding communities. The findings support existing investigations that related the incidences of water borne and hygienic diseases to unsecure water (Renzetti and Kushner, 2004; WHO, 2016; WBG, 2018; URT, 2019). Difficulties in water accessibility to the public implies social costs (Shrestha *et al.*, 2018).

All the social impacts and complications from inappropriate urban water supply problem links to the reported incidence of urban poverty (Pauschert *et al*., 2012). As shown by a schematic pathway (Figure 5), leading complications (Table 13) including health and sanitation problems (31%) associated with insecure water (9%), declining production activities (12%), and wastage of time and financial resources (27%).

Additionally, too scarce water implies additional financial cost to outsource water from distant sources. The loss of such money and time retard some activities as much resources and energy that could have been used in other investment activities are exploited (Pauschert *et al*., 2012). Part of the study respondents (12%) claimed of postponing some relevant activities like irrigated agriculture when water supply is reduced. Consequently, their household income gets reduced too. This is because, when the supply is limited, people become selective on what they use available water for, by foregoing some of the uses as reported by Shrestha *et al.* (2018). The linkage and impact pathways of water shortage especially in urbanized areas can have different routes (Fig. 4) but they all lead to a major economic difficulties related to urban poverty as shown below.

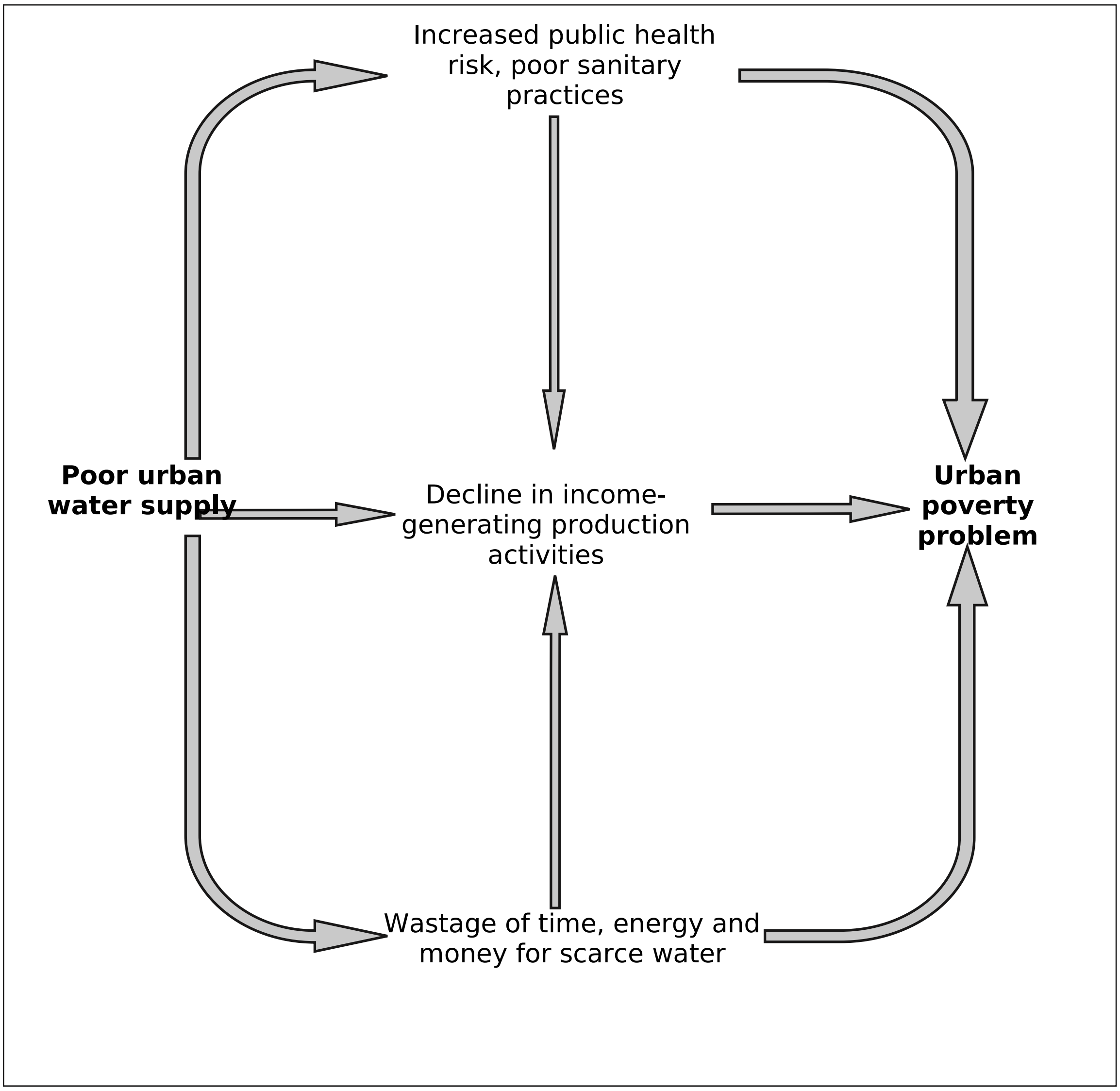

Figure 4: Schematic impact pathway for poor urban water supply

4.3 Replacement cost of the Mindu Dam water provision

4.3.1 Water supply situation during scarcity

The following cross-tabulation (Table 14) show the water scarcity period defined by months with respect to the sampled wards. These provided data that were used to estimate the overall estimate for the municipal population that MORUWASA has to serve.

Table 14: Response on water scarcity periods by wards

Water scarce period	**Ward response (%)**			**Overall**
	Bigwa	**Chamwino**	**Mindu**	
September - December	58.3	44.5	27.5	43.4
May – August	37.5	11.1	17.6	22.1
January – April	0	11.1	3.9	5
No specific time	4.2	33.3	51	29.5
Total				**100**

The results reveal that, water scarcity runs from May, becoming severe from September to December (43.4%). This period is characterised by low amount of rainfall with prevailing high temperature rising up to 33ºC (URT, 2016). The period is associated with low flow in the Mindu Dam. About 22% of study respondents reported scarcity in the period from May to August (Table 14). This complements with the reported low amount of rainfall from June through August when the rain become as low as 11 mm (URT, 2016). The situation reflects uneven nature of water supply problems across the municipality. Some (29.5%) reported no specific time of scarcity due to irregular changes from time to time, thus unpredictability.

Previous studies (Mwamila *et al*., 2016; Martínez-Santos *et al*., 2020) have recommended wells and boreholes as a practicable alternative to providing domestic water. This made boreholes an important consideration for implementation following reported scarcity in the study area. Table 15 presents the responses on the most to least practicable alternatives among the study population when water become scarce. To find out whether boreholes was the right alternative in case it is opted to have other means of getting water for increased performance, available alternatives were explored (Table 16).

Table 15: Responses on means of obtaining domestic water during scarcity

Source of water during water-scarce period	Frequency	Percent
Buying from private sources	39	41.9
Boreholes/Ground excavation	8	8.6
Water bowser	4	4.3
Nearby public source	3	3.2
No any supplementary source	39	41.9
Total	**93**	**100**

A great proportion of the study sample (41.9%) gets water by buying from private sources. Boreholes (8.6%) ranks second preceding water bowser (4.3%) while 3.2% depends on public source especially in Chamwino Ward. Regardless of such alternatives, about 41.9% are without any working alternative than limiting their available water use (Table 13).

To reduce overreliance on Mindu Dam, the responsible authorities and the public need several water supply alternatives. The study respondents identified boreholes (67.7%) as the best practicable means for water supply in the municipality followed by harvesting rainwater (8.6%) (Table 16). However, harvesting rainwater is not efficient due to its limited availability especially when there is no rain (Lufingo, 2019). Such operational challenge makes rainwater harvesting a technology to sustain agricultural activities rather than for domestic water supply in many places (Mwamila *et al*., 2016; Lufingo, 2019).

Table 16: Recommended water supply alternatives

Recommended water supply means	**Frequency**	**Percent**
Boreholes	63	67.7
Rain water harvesting	8	8.6
Water bowser	1	1.1
Any alternative	21	22.6
Total	**93**	**100**

Nevertheless, prolonged public water supply in Bigwa Ward (Table 2) with no alternative, the system of harvesting rainwater serves as a working alternative for domestic water supply as ground water is saline. Being strategically situated downhill, gravitation-driven water harvesting from uphill has been saving a large part of population therein. In the same setting, being the only locally available means, it attracted much attention and thus ranked the second recommended alternative (Table 16).

Some of the previous studies in Tanzania (Mwamila *et al*., 2016; Lufingo, 2019) found rainwater more vulnerable to pollution compared to well-maintained boreholes. This reason combined with the highest recommendation (67.7%), made boreholes a best and suitable alternative among the study area (Table 16). In that regard, following breakdown of Mindu Dam and reduced ability to provide required amount of water to the municipal population, boreholes could be used to supplement water availability. Following such recommendation, the study examined communities' willingness to pay for boreholes (Figure 5).

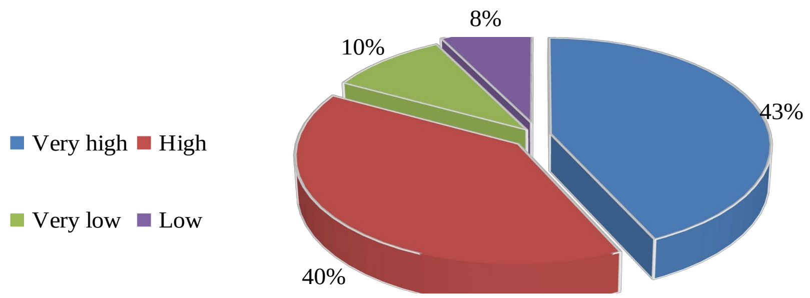

Figure 5: Responses on communities' extent of willingness to pay for boreholes

About 83% of the study respondents were willing to pay for boreholes for efficient water service provision. It follows that, upon going for the other means of effectively supplying water to Morogoro Municipality, the public will be more willing to pay for boreholes compared to other means (Fig. 5). These findings complement other studies (Martínez-Santos *et al*., 2020) that found boreholes as affordable and effective means for water provision among sub-Saharan countries for socioeconomic community wellbeing. The high-level of communities' willingness to pay for boreholes implies the unreliability of public supply is some areas of the municipality, thus requiring boreholes as an alternative. However, this may not imply the suitability of boreholes throughout the country. This is because, the alternative opted for are according to Mussa *et al*. (2019) context specific and depend on other factors including hydrogeology, equipment and technical expertise (Martínez-Santos *et al*., 2017; 2020).

4.3.2 The boreholes equivalency for water supply

The Wami/Ruvu Basin-hydrogeology department pointed out that, successful borehole construction assumes two basic procedural steps: hydrogeological site survey and then drilling for borehole installation. The initial procedure (hydrogeological survey) is an explorative process aimed at assessing the availability of harvestable ground water for pumping and utilization. The survey also examines site accessibility for the drilling rig and other equipment (Danert *et al*., 2010; UNICEF, 2013). This is commonly by either electrical (resistivity) or magnetic method involving examination of the nature of site rocks, depth and quality (salinity) of groundwater. A successful survey lead to drafting of the drilling plan that in most cases recommends site that is free from flooding and away from waste water pits. The drilled site should be free from contamination as far as practicable as possible (UNICEF, 2013). The drilling method depend on the nature of the underlying rocks, this can be mud-rotary circulation method in soft rocks or air-rotary method in hard rocks. Once the survey is successful and harvestable ground water detected, drilling begins. Well casing and pumping test precede drilling to estimate the borehole yield. The well yield may vary from one location to another depending on the aquifer saturation and thus its estimation is essential (Danert *et al*., 2010). The test is useful in estimating the borehole productivity and thus the required size of the pump for installation. While Danert *et al*. (2010) suggested from four to six hours of pumping test, experience from the hydrogeology department revealed that, two hours are enough in Morogoro Municipality if the hydrogeology survey recommended abundant harvestable groundwater. The final stage is the platform casting and pump installation depending on the yield capacity (Danert *et al*., 2010; UNICEF, 2013).

Based on experience of boreholes in the Morogoro Municipality, the estimated average depth of accessing harvestable groundwater is about 150 m deep. Costing the drilling process in Morogoro Municipality is by quoting the cost per unit meter of hard rock which costs about 100 000 TZS. Danert *et al*. (2010) recommended this method due to its effectiveness and applicability. After drilling and installation, other required devices for casing include seal (cement), gravels for pre-filtration of water entering the case, and compressing machine for continuous maintenance and removal of rock cuttings (remnants) after drilling. The estimated values and requirements for successful borehole installation are presented in Table 17.

Table 17: The costs associated with boreholes

Particular	**Units**	**Value**
Standard borehole yield	Litres/day	180 000
Equipment purchase cost	TZS	27 240 000
Equipment installation cost	TZS	15 000 000
Maintenance cost (5 years interval)	TZS	6 000 000
Total survey cost	TZS	30 000 000

Source: Field data and WRBWO

With the average of 144 L (daily water consumption) per household (Table 5) and borehole yield of 180 000 L (Table 17), a unit borehole can accommodate a maximum of 1250 households. These data suggest that, to accommodate 71.56% (57 622 households) of the municipal population with metered connectivity to MORUWASA portable water, about 6 638 boreholes are to be installed. The estimated unit cost are 27 240 000 TZS, 15 000 000 TZS, and 6 000 000 TZS for equipment purchase, installation (drilling) and maintenance respectively and 30 000 000 TZS for hydrogeological survey. The initial (first year) cost of boreholes sums to 64 074 304 515.07 TZS. After successful installation, the yearly operational costs drop to 39 828 547 584 TZS after deducting the fixed start-up cost. The values reflect the cost of replacing the equivalent Mindu Dam water provision with boreholes in case it become unable to provide water to the public due to degradation.

With a borehole's life span of five years until maintenance (Table 17), by using Mindu Dam water instead of boreholes, the municipality saves about 38 659 791 573 TZS per year that could be spent to operate boreholes. This is equivalent to 3018 TZS per m^3 of water obtained from Mindu Dam compared to drawing the same amount using boreholes. However, the cost may still vary from time to time and place to place due to several factors. For instance, the nature of the underlying rocks (geology), availability and depth of groundwater (Danert *et al*., 2010) and aquifer's hydrodynamic parameters (Martínez-Santos *et al*., 2020). The cost may also increase further depending on the required diameter of the borehole as the function of the anticipated use (Martínez-Santos *et al*., 2020). Depending on the flow rate, apart from providing drinking water, boreholes may also provide water for other utilities including irrigation that depend on water thus underpinning economic development perspective. In such situation, a large diameter borehole is required for an increased flowrate, hence reflecting further costs.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The findings of this study have indicated a limited access to domestic water supply across the study area due to low water supply coverage and unaffordability to pay for the service among households depending on public water supply authority. The average daily water consumption amount (144 litres per day per household) just suffice basic utilities, but does not guarantee public health and welfare, leading to water related and hygienic diseases.

Due to degradation and Mindu Dam's pollution, MORUWASA incur about 91.24 TZS per m^3 of water treated, summing to 1 168 756 011 TZS per year to feed 71.56% of the municipality population. The operating cost accounts for highest costs associated with water treatment.

If Mindu Dam operation ceases such that it cannot further provide public water, the municipality will need to find out alternative feasible means. Opting for boreholes to provide the equivalent amount of water to the municipality population will cost 64 074 304 515.07 TZS to install 6638 boreholes. Operating them will further cost 39 828 547 584 TZS per year causing additional cost of 3018 per m^3 to be made available. In practice, it cost higher to install boreholes for water provision as compared to using Mindu Dam as the source of water.

5.2 Recommendations

In view of the study findings and the aforenamed conclusions, the following recommendations were made;

(i) For an improved, affordable and accessible water supply in Morogoro Municipality, there is a need for service extension to connect uncovered peri-urban areas and finding alternative sources in case Mindu Dam water do not suffice. This might foster household's ability to pay for the services and increase the extent of population connected to ensured public water supply.

(ii) Following observed financial and social costs of Mindu Dam pollution and degradation, to avoid further costs, responsible authorities and local communities need collective efforts to control, reduce or stop human activities on the upstream that affect water supply, lead to dam pollution and high social and economic costs. This should include designing conservation projects that will ensure not only the continued functioning and revival of the dam but also reduce unnecessary costs of installing boreholes to be able to feed the same population as compared to using water from the Mindu Dam.

(iii) The Ministry of water and mandated authorities should use the estimated values of water provision costs following degradation of Mindu Dam ecosystem to refine decisions on its appropriate management having known how much it could cost to supplement water provision in case it become non-operational. This also implies a need for regular economic analyses and valuation works for updated values.

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APPENDICES

Appendix i: Households Questionnaire

Background:

Dear Respondent, I am Raphael, Antidius – MSc. Environmental and Natural Resources Economics student (Sokoine University of Agriculture). As a compulsory part of my studies, I'm researching Mindu dam's water provision Economic value to Morogoro Municipality. Mindu dam is the greatest water reservoir in Morogoro providing domestic and industrial water and other values to the Municipality but also known of being degraded and polluted over time, as a result its ability to function properly has been reduced. This research thus attempts to find a way of capturing its economic value to enhance livelihoods support continuum to its dependants via appropriate management.

With assurance of confidentiality, you are requested to be an important part of this study by responding to the following:

A. Identification Variables

1. Personal particulars

Position in the household	Gender (1: Male, 2: Female)	Age	Education level	Family type	Household size	Main occupation
Husband						
Wife						
Other ……...						

Labels:

Education level	1= No Formal education, 2 = Primary, 3 = Secondary, 4= Tertiary
Family type	1= Couple, 2 = Nuclear, 3 = Single parent, 4= Extended
Household size	Number of people in a family
Main occupation	1 =No occupation, 2= Farmer, 3 = Government employee 4= Non-Government employee, 5= Self-employed

2. Residential Information

Ward	Street	Time stayed (yrs)

B. Water Accessibility

3. What is the means for you to access water? (Tick where appropriate
   01) MORUWASA
   02) Bore-holes
   03) Water bowser
   04) Rain-water tapping

05) Others ………..

4. What are your 3 main water uses? Just list.

01). ………………………………………
02) . ……………………………………..
03) . ……………………………………..

5. How do you get water during scarce period? ……………………………………….

6. What is your family daily water consumption amount? (Litres/Quantity) ……………….

7. How would you rank the current availability and effectiveness of water supply from MORUWASA? (Tick where appropriate)

1) Very poor
02) Reduced
03) Optimal
04) Good

8. How often do you access water share per week? (Tick where appropriate)
01) Always 02) 3-5 times 03) Twice 04) Once

9. Which method do you think might be appropriate for efficient and sufficient water supply instead of depending on Mindu dam? (Tick where appropriate)

01) Bore-holes 02) Water bowser 03) Tapping rain water 04) Others………………

10. Do you think that pollution of Mindu dam affect significantly the quality and amount of water supply in your area? (Tick where appropriate)

1) Yes 2) No 3) Not aware

11. If water provision infrastructure is to be restructures for efficient service by using boreholes, what would be your willingness to pay for it to maintain your water demand? (Tick where appropriate)

01) Very low 02) Low 03) High 04)Very high

C. Social Costs

12. How do you benefit from Mindu dam? (Tick all appropriate response)

1) Irrigation
2) Navigation
3) Fishing
4) Gardening
5) Water for livestock
6) Drinking water
7) Domestic water use
8) Recreation
9) Others………

13. What are other services do you think Mindu dam ecosystem provide apart from water provision? (Tick all appropriate response)

1) Micro-climate regulation
2) Biodiversity enhancement
3) Beautiful scenery
4) Carbon dioxide sink
5) Education and Research opportunities

6) Waste dilution

.14. Do you access water service from MORUWASA?

1) Yes (go to Qn. 15)   2) No (go to Qn. 16)

15. What is your maximum monthly water bill? ………….

16. Have you experienced water scarcity (reduction in water supply)?

1) Yes (go to Qn. 17)   2) No (go to Qn. 18)

17. At what time periods is the scarcity more pronounced?

01) Dry season   02) Farm preparation season

03) Currently throughout   04) No specific time

18. What do you think might have been the sources for water supply reduction?

1) …………………………..   3) ……………………………
2) …………………………..   4) ……………………………

19. How do you strategize during water scarce period?

1) …………………………..   3) ……………………………
2) …………………………..   4) ……………………………

20. What is the estimated monetary cost you incur to get water during scarce period? ………………………….…..

21. What do you think might be the adverse effects of safe and clean water shortage to social welfare?

1) ………………………………   3) ………………………………
2) ………………………………   4) ………………………………

Thank you for your attention and cooperation

Appendix ii: Checklist for MORUWASA Officials

Date of the interview ………………………...

Name:	Contact:
Section/Dept:	Position:

1. What amount of water do MORUWASA harvest from Mindu dam?
2. What is the proportion of Morogoro Municipality fed by MORUWASA?
3. What has been a trend of water quality in relation to anthropogenic conducts with time?
4. What anthropogenic-driven degradation has been impacting Mindu dam functionality?
5. How do you deal with the named degradation(s)?
6. What method is used by MORUWASA to treat polluted Mindu dam water to suit for application?
7. Give out a list of equipment that MORUWASA has put in place for effective water treatment, outlining the quantity, individual price and installation cost.

Device	Life span	Quantity	Unit price (TZS)	Installation cost

8. What is the estimated efficiency of the installed equipment, and so (if any), what is the replacement frequency (estimated lifetime)?

Consumable	Category	Quantity	Unit price (TZS)	Replacement frequency

9. What are consumable (reagents, devices) used in the process? How often are they replaced?
10. What is the estimated amount of fuel and/or electricity used (daily/weekly/monthly) for water treatment process?
11. What is the unit cost of each fuel measure and/or electricity unit you purchase?
12. How much water does the treatment plants accommodate and yield per day?
13. How does paying workers cost monthly? What are other associated costs?

14. Taking account of anthropogenic influences around Mindu Dam and its reduced water supply ability. With the anticipation that such activities may worsen the availability of Mindu dam and hence efficient water provision service to Morogoro Municipality, how would you consider construction of boreholes as an alternative means to ensure availability of safe, clean and sufficient water to your client?
15. Is there any ongoing program to rehabilitate water provision infrastructures/systems/means in Morogoro Municipality? Please elaborate in detail.

Thank you for your attention and cooperation

Appendix iii: Checklist for Wami/Ruvu Basin Water Board

Date of the interview ………………………...

Name:	Contact:
Section/Dept:	Position:

1. What are the main rivers that drains to Mindu dam?
2. What are the main anthropogenic conducts/influences associated with each river before emptying its water to Mindu dam?
3. How far have these rivers been affected by the named influences?
4. What is the current ecological/conservation status of each river?
5. Is there any bioassessment work that has been previously done?
6. a) If there, what was the outcome and its implication?
   b) If Not, how is the monitoring done, what are the strategies used to assess the status of these rivers with change in time?
7. Is there any ongoing strategy to act on the anthropogenic changes in relation to affected rivers?
8. Is there any plan to rehabilitate Mindu dam? Please elaborate clearly if any.

Thank you for your attention and cooperation

Appendix iv: Checklist for Hydrogeologists and Borehole specialists

Date of the interview ………………………...

1. For how long have you engaged in boreholes construction?
2. How can you gauge performance of boreholes in provision of water?
3. What are the basic equipment required for a successful borehole installation?
4. How much does the purchase of each equipment cost?
5. What is the estimated yield of a standard borehole per day?
6. How many people can a unit standard borehole accommodate in average?
7. What are the probable maintenance services required for a progressive working of a borehole?
8. How much does the services cost?

Service / Maintenance	Estimated cost (TZS)

9. Is there any replaceable equipment/device with time?
10. If there, what are they? What is the respective per unit cost and replacement frequency?

Thank you for your attention and cooperation

Appendix v: Field Photos

Figure: 1. Groundwater harvesting and storage in Bigwa, 2. Traditional rainwater harvesting, 3. Well screen, 4. Public water source in Chamwino, 5. Household head interview, 6. Private water distribution means in Mindu