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Use of engineering economic equivalence tenets to prioritize water source(s) for use by households, 'The Case of Mbeya City – Tanzania'

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ABSTRACT

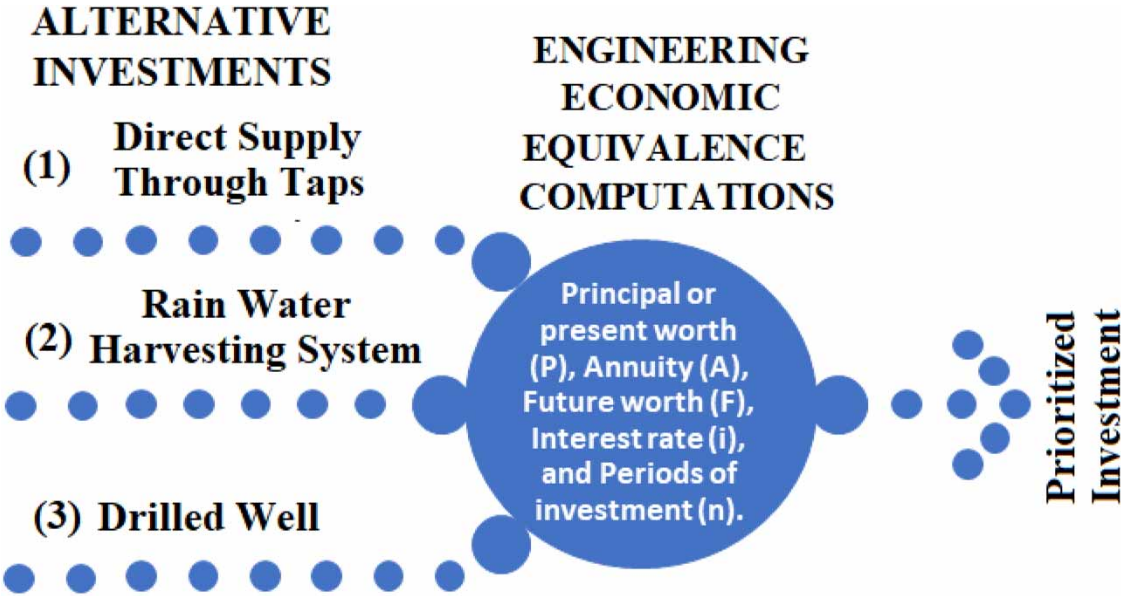
In Tanzania, inadequate access to water affects 26% of urban and 38% of rural populations, who depend on piped water systems and are often subject to rationing. Low-income households face the significant burden of high water bills and (sometimes) poor water quality. Alternative water sources such as gravity-fed, rainwater harvesting, and drilled well systems are often overlooked, primarily due to the absence of evaluations based on engineering economic equivalence (EEE) principles that determine their viability due to prioritization. This study addresses this gap by analyzing existing literature and utilizing data from Mbeya City, focusing on households relying on tap water, rainwater harvesting, and drilled wells. Engineering Economic Equivalency computations were used to assess the present worth of these water sources, with values determined at Tshs 11,009,424/- for tapped water systems, Tshs 10,283,000/- for rainwater harvesting, and Tshs 12,099,940/- for drilled wells. While rainwater harvesting appears cost-effective, it was found unsuitable for drinking, and tapped water systems incur variable consumption costs. Consequently, the drilled well system is the most sustainable option for ensuring reliable household water access. Households in Mbeya are urged to deploy the engineering economic equivalence principle to prioritize their water-for-own-use.

Key words: harvesting water, piped water, water accessibility, well water

HIGHLIGHTS

- Literature lacks water source investment evaluation, particularly using engineering economic equivalence principles.
- This study applies these principles, offering insights for prioritizing household alternatives.
- Drilled wells are prioritized for reliable, safe drinking water in Tanzania amidst cost and quality concerns.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water access is a basic need of all humans. In recent times, about 844 million people worldwide lacked access to safe water in 2015 (WHO & UNICEF 2017). According to Graham, more than 90% of households in rural areas in 13 countries among the 24 being studied lacked access to water (Graham *et al.* 2016). The poor access to water affects human development. Inadequate access to water leads to poverty and poor health, especially if no proper attention is paid.

In 2010, it was recognized by the United Nations (UN) General Assembly and United Nations Human Rights Council that water and sanitation are human rights that must be addressed through the progressive realization of universal access to sufficient, safe, physically accessible, and affordable water and sanitation services (The United Nations Department of Economic & Social Affairs 2015). Through this effort, the UN's General Assembly Summit conducted in September 2015 established 17 Sustainable Development Goals (SDGs) to be achieved by each country by 2030. This study attributes to achieving goal number six of this Agenda, i.e. 'ensuring availability and sustainable management of water and sanitation for all'.

The problem of water access generally relates to households: getting smaller amounts than they need (quantity), their health is affected when unsafe water is utilized, more time is wasted fetching water, children not attending schools, and community members participate in little time on other income generating activities, among others. Globally, women and girls are responsible for water collection in the community and they spend around 40 h every month collecting water from distant water sources (Mowo 2020). Fetching water from distant sources hurts human health as it may lead to fatigue, spinal pain, and damage to small tissues within the body (Geere *et al.* 2010). Furthermore, lack of access to water has socio-economic impacts (UNDP 2016).

The efforts to ensure access to water have been successful mostly in developed countries (Sherry *et al.* 2019). In Tanzania, efforts to improve water access to people have been tried. The National Water Policy of 2002 set a goal of providing clean and safe water to the population within 400 m of the households (URT 2002) and, according to the National Water Plan 2016–2021, monitoring results indicate that the water access and quality have improved substantially in recent years, although further improvement is needed.

Despite the 1991 National Water Policy's goal set for ensuring all people got enough and safe water at a distance of 400 m by 2002, only about 50% of the rural population had access to a reliable water supply service such that due to operational and low maintenance arrangements, over 30% of this population had water supply schemes not well functioning (MWLD 2002). Likewise, in urban areas, the coverage was only 73%, with their water supply systems becoming inadequately treated due to malfunctioning treatment plants (MWLD 2002). In 2006, only a third of the households were reached by the piped water system; most households purchased water from those with pipe connections or private boreholes (Kjellén 2006). Furthering these developments, the proportion of the rural population with access to clean water increased to 61.3% in 2009 from 55.7% in 2006 (ADB 2010). According to TWAWEZA (2017), approximately 38% of people in rural areas and 26% in urban areas, on average 32% of the population, do not have access to clean water.

The challenges related to water access for Tanzanian households include rationing and high water costs for low-wage groups, with some households not yet connected to tap water. Additionally, there is a heavy reliance on the tap water system, often with little or no knowledge of alternative water sources. The tap water system sometimes allows contaminated water to be supplied, or water gets contaminated during handling (Pickering *et al.* 2010; Smiley 2017, 2019). Despite the persistence of these challenges, the evaluation of water use through alternative sources such as gravity-fed systems, wells, and rainwater harvesting is rarely or inadequately conducted. The concept of conjunctive use of multiple water sources has been recognized as a means to improve water quality and supply security (Foster *et al.* 2010; Templer & Urban 2011; Shamsuddin *et al.* 2014; Stahn & Tomini 2016).

While various water sources are available in the country, they remain underutilized. In contrast, the engineering economic evaluation (EEE) principles are extensively applied in highway investment projects (Markow 2014). The application of EEE principles in water investment projects has historically focused on the design and analysis of wastewater treatment systems (Dole 2002) and the evaluation of the economic and financial feasibility of municipal and industrial water projects (Piper 2009). However, there is a notable absence of engineering economic studies that prioritize household water source investments. This study aims to address this gap in the literature.

This study addresses three interconnected challenges: Tanzanian households struggle to access safe water, there is limited awareness of water source availability and performance, and the principles of Environmental, Economic, and Equity (EEE) essential for prioritizing water sources are not widely practiced. To frame this problem with independent and dependent variables, we consider principal costs, annual costs, and future costs for a water source (independent variables) and their impact on the optimal water source (dependent variable), including factors such as water quality, effective cost, and required amount. Therefore, this study developed a framework with three dimensions: (i) deploying water accessibility indicators, (ii) evaluating the costs and consequences of water sources, and (iii) applying EEE principles for prioritizing water sources for households. This framework aims to enhance water accessibility for households in Tanzania and other developing countries.

2. MATERIALS AND METHODS

2.1. Methodology and design

This study is primarily descriptive, with some quantitative data collected and analyzed. It involved reviewing and evaluating literature on water accessibility, water sources, and engineering economic equivalencies for prioritizing water sources, using an exploratory research approach (Kothari 2004). Exploratory research is employed to investigate problems that are not well-defined, insufficiently studied, or poorly understood (Bernard 2006). Exploratory research in this study had helped to explore facets of water accessibility indicators and their performances, evaluate water sources as well as facets of engineering economic equivalencies.

A quantitative study was conducted after collecting and describing the data through an exploratory study. The research focuses on this area as both researchers work and live in Mbeya City. Given the study's goal of using detailed data within a limited timeframe and budget, exploratory concepts related to water accessibility, measurement indicators, and the principles of EEE were applied. The study aimed to provide insights into prioritizing water sources based on real household data in Mbeya City. Only three water sources were selected for the study due to their uniqueness, availability, and comparable variables. For example, only one rainwater harvesting project was available in the study area.

2.2. Data collection

Three households in Mbeya City were chosen for this study based on the researchers' prior knowledge of their water source projects. By 2020, one household's drilled well project was nearing completion. Another household had already completed a rainwater harvesting system, while the third was still working on pipe and fitting installations for a water tap supply project as of March 2021. Data for all three projects were collected and compiled after their completion in 2022.

2.3. Data analysis

After each dataset for three projects were meticulously identified, collected, categorized, and assigned, contemporary costs were identified per each project variable of the EEE perspective: the Principal (P), Annuity (A), and Future values (F).

Note that, principal (project capital) relates to costs that are either owned or borrowed and used for making up an infrastructure project, i.e. all costs pertaining to building up a product before project commencement. Annuity refers to all cash flows (cash in and cash out) during the project lifetime and future costs relate to receipts after the project design life is elapsed. The costs utilized reflected the recent market rate for that time, i.e. during 2019–2020 periods.

Using exploratory research data on water accessibility indicators, water source performance, and the elements and costs associated with EEE aspects and their utilization, a framework was developed to prioritize water sources for households in Tanzania. This framework incorporated insights from the collected data and EEE principles. An interest rate of 15% was used, as recommended by Black & Tarquin (2012) and Luiu *et al.* (2018).

2.4. A framework for prioritizing water sources by households

A framework developed highlights on the types or categories of indicators developed, water sources and facets of EEE including aspects of principal, annuity, and future values.

2.5. Validity and reliability

This study utilized both exploratory and typical data collected from households in Mbeya City. The exploratory data were obtained by reviewing and evaluating literature, including textbooks, journal articles, and conference proceedings authored by water management and engineering economics experts. This literature provided valuable content validity by addressing relevant research topics. Furthermore, typical data were collected from three household projects (drilled well, rainwater harvesting, and water tap supply systems). These data were developed according to EEE principles and reflect current market conditions, ensuring their credibility and validity.

2.6. Data analysis

The data analysis in this study was done in two stages. The first stage involved exploratory data, in which the water accessibility indicators were identified and evaluated; water sources and EEE tenets were also studied and evaluated. Stage two entailed analyzing exploratory data and collection of typical qualitative data from households on drill wells, rainwater harvest, and tap water supply. Using EEE principles, elements of principal, annuity, and future values were used for assignment of costs that were then used in the computation of the optimal value for prioritization of water source project.

3. LITERATURE REVIEW

The reviewed works cover three main subthemes: (i) indicators for water accessibility, (ii) water supply sources and their components, and (iii) EEE tenets.

3.1. Water accessibility indicators

3.1.1. General overview of indicators

An indicator serves as a methodological instrument to quantify, signal, or delineate various phenomena with varying degrees of precision, as elucidated in the Oxford Dictionary. It embodies a comprehensive means of expressing concepts like ‘how much’, ‘how many’, ‘to what extent’, or ‘what size’ (Jessen 2012; Dennison 2020; Grunkemeyer & Moss 2020).

In the specific discourse regarding water accessibility within Tanzanian households, these indicators are tailored to encompass a spectrum of perspectives. They are designed to evaluate the multifaceted dimensions of water accessibility, drawing upon a global framework that guides households in assessing their water resources for domestic utilization (Mwamaso 2015).

These indicators facilitate a nuanced understanding of the intricacies involved in water accessibility, offering households a standardized measure to gauge the adequacy and reliability of their water supply for various needs. By providing a systematic approach, they empower households to make informed decisions regarding water management. Sections 3.1.2 to 3.1.6 provide a succinct overview of these indicators, delineating their key attributes and implications for household water security.

3.1.2. Proximity or physical access to water point

Accessibility relates to the water supply service coverage by the water utility, the population served, and the distance between the households and water collection points (Kansal *et al.* 2017). This indicator is determined through distance or walking time from the user’s home to the source, where, with diverse contexts and conditions, the optimal distance varies across nations and between international institutions. For example, the ‘water source has to be within 1,000 meters from user’s home and collection time should not exceed 30 minutes’ (Nygren *et al.* 2016). In Tanzania, the national water policy sets

400 m as the maximum distance to a water point; and provides no more than 30 min of collection time – go, wait, collect, and return (URT 2002). As per the requirement of the national policy fostering to supply of water at a distance of 400 m or less and allowing a 30-min water collection, this goal may be appropriate for this study. The accessibility indicator interacts with other indicators such as reliability in case of wasted time for fetching water due to unreliable supply, water quantity since less quantity of water is usually collected in long water collection trips, and water quality because the water collection time increases perhaps to find the alternative source when the water source is polluted (either during collection, transport, or storage) (Kayser *et al.* 2013).

3.1.3. Water quantity

Water quantity refers to the availability of an adequate and uninterrupted supply of water for various personal and household activities, encompassing drinking, personal hygiene, laundry, food preparation, and maintaining cleanliness within the household (The U.N. Special Rapporteur 2014). Optimal access to water in terms of quantity is typically defined as an individual utilizing between 50 and 100 liters per day (Howard *et al.* 2003).

In the context of Tanzania, different categories of consumers are allocated varying minimum daily per capita water supplies. For individuals classified as low-income consumers, the daily supply ranges from 20 to 70 liters, while for medium-income consumers, it ranges from 90 to 130 liters. Those classified as high-income consumers are provided with a minimum daily per capita water supply ranging from 150 to 250 liters (Ministry of Water 2020). These allocations aim to ensure equitable access to sufficient water resources across different socio-economic strata within the country.

3.1.4. Affordability

The affordability indicator serves to assess the relationship between a household's annual water expenditure and its total annual income (Hutton 2012). Furthermore, echoing this sentiment, the U.N. Special Rapporteur (2014) emphasized that the price individuals pay for water services should not impede their ability to afford other essential goods and services, which are guaranteed by human rights. The indicator aids households in procuring water services at rates that align with their income levels. While it is crucial to shield the most economically vulnerable members of society from exorbitant water charges, it is also vital to implement reasonable fees for these services to minimize or eliminate subsidies provided to water supply utilities. This approach is fundamental for ensuring the sustainability of water supply services (WHO 1997; Kayser *et al.* 2013; Kansal *et al.* 2017).

3.1.5. Serviceability and reliability

Serviceability and reliability indicators for water supply are crucial metrics used to assess the effectiveness and dependability of water provision systems (The U.N. Special Rapporteur 2014). Serviceability pertains to the ability of a water supply system to meet the needs of users, including factors such as water pressure, flow rate, and consistency of supply (Kayser *et al.* 2013; Kansal *et al.* 2017). It encompasses aspects such as accessibility, adequacy, and functionality of infrastructure, ensuring that water is readily available and accessible when needed. On the other hand, reliability focuses on the consistency and predictability of water supply, evaluating factors such as frequency and duration of service interruptions, as well as the system's resilience to disruptions such as natural disasters or infrastructure failures. Both indicators are essential for ensuring that water supply systems can meet the demands of users consistently and effectively, thereby contributing to public health, economic development, and overall well-being (Kayser *et al.* 2013; Kansal *et al.* 2017).

3.1.6. Water quality and safety of use

Water quality and safety indicators for water supply encompass a comprehensive array of parameters essential for evaluating the suitability of water for consumption and various other uses (The U.N. Special Rapporteur 2014). These indicators are broadly categorized into physical, chemical, and microbiological parameters.

Physical parameters include color, which serves as an indicator of substances like organic matter; turbidity, measuring water clarity and indicative of sediment or microbial contamination; and temperature, affecting the water's capacity to hold dissolved oxygen and influencing aquatic ecosystems (Omer 2019; Gunnarsdottir *et al.* 2020).

Chemical parameters, such as pH levels, reveal water acidity or alkalinity, impacting taste and aquatic life support. Additionally, dissolved oxygen levels are vital for aquatic organisms' respiration (Omer 2019; Jaffar *et al.* 2020).

Microbiological parameters encompass the presence of pathogens and indicator organisms like *Escherichia coli*, which signify fecal contamination and the potential presence of harmful microorganisms (Omer 2019; Gunnarsdottir *et al.* 2020).

Therefore, ensuring water is appropriate for consumption and other uses necessitate comprehensive testing and treatment to meet the requirements of all these parameters.

3.2. Water supply sources

3.2.1. Rainwater harvest system

Rainwater harvest is a way of catching rainwater whenever it falls. It is referred to as a process of collecting and storing rainwater in a scientific and controlled manner for future use (Singh *et al.* 2022; Lee & Kim 2023). This system requires the following components for it to work appropriately: enclosed and cemented area/corrugated iron sheet's (CIS) catchment area, gutters, rainwater storage tank, sand filter, filter for making the water ready for use, and the tank for storage purposes (Che-Ani *et al.* 2009; Syed Azizul Haq 2016; Alim *et al.* 2020). This system is used where rain is well distributed and surface and groundwater is scarce (Yannopoulos *et al.* 2019; García-Ávila *et al.* 2023). The city experiences a moderate climate, with an average annual rainfall of 1,200 mm, primarily occurring from November to May (Mgimba & Sanga 2016). When the system is installed, it allows for a straightforward approach to water requirements, mitigates the effects of drought, reduces runoffs, reduces flooding on roads, and is cost-effective (Matos *et al.* 2015; Syed Azizul Haq 2016; Alim *et al.* 2020). The incorporation of key components like corrugated iron sheets, gutters, and downpipes into the building structure results in a reduction in the initial cost of the rainwater harvesting system. This integration eliminates the need for extra expenses, as the total costs are directly tied to these existing elements. With these components already in place within the building framework, the usual financial burden associated with procuring them is alleviated, thereby contributing to a decrease in the overall initial cost of the system (Mgimba & Sanga 2016).

3.2.2. Surface water supply

This system relies on water sourced from various natural bodies such as streams, rivers, impoundments (reservoirs and ponds), springs, lakes, and dams (Ministry of Water 2020), collectively referred to as the piped/tapped water supply in this study. The primary water supplier through this source typically is the water authority of a specified country. While these sources provide large quantities of water, they often contain organic and inorganic impurities that must be treated by the responsible owner, typically the water authority. Mbeya City primarily sources its water supply from 13 locations, including springs, rivers, and streams. The springs are Ivumwe, Nsalaga, and Nzovwe. The rivers include Imeta, Sisimba, Mfwizimo, Lunji, Mwatezi, Hajihalewa, Nzovwe-Iyela, Iduda, and Kiwira. The stream is Hazya.

Water is usually diverted from its source, such as a river, to various treatment plants before being distributed to users. In most cases, households apply for their water requirements through the authority, which then conducts surveys and connects water to the households for initial costs set by the authority. One advantage of this system is that the water authority handles all processes related to obtaining and distributing water to households, requiring relatively low capital compared with other sources (Perrone & Rohde 2016).

However, there are drawbacks to consider. Sometimes, water may be rationed, leading to inconvenience for users, and customers may face unexpectedly high bills that require extra efforts for settlement. Additionally, there is a risk of receiving contaminated water, among other issues (Abubakar 2016; Zvobgo 2021). Surface water sources are particularly vulnerable to pollution, necessitating expensive water treatment systems (Simeonov *et al.* 2003; Chigor *et al.* 2012; Edokpayi *et al.* 2017).

3.2.3. Water drawn from the well(s)

A well is a hole created by digging, driving, boring, or drilling, designed to extract water from underground aquifers (Ministry of Water 2020). Wells are categorized based on their construction methods into four types: dug, driven, bored, and drilled wells (Voudouris *et al.* 2019; Kan-uge *et al.* 2023). Each approach has specific characteristics that make it suitable for different situations. For example, a driven well is preferred for slightly shallow depths and moderately firm ground conditions. It may include activities such as surveying, drilling, pipes installation, pumping, treating, and storing water. The major disadvantage is that shallow wells may be contaminated by percolating contaminated water (Rutkovienë *et al.* 2005; Olabisi *et al.* 2008; Orebiyi *et al.* 2010); however, this depends on location. In Mbeya City, dependable groundwater resources are generally accessed at a minimum average depth of approximately 35 m. This depth indicates where aquifers with a consistent and sufficient water supply are typically located, ensuring a reliable source. The four wells studied had depths of 45, 50, 50, and 55 m.

3.2.4. Water supply through gravity

A gravity water supply system refers to a water supply system whereby water falls from the source located at a higher elevation to the distribution points at lower elevations using potential energy acquired by the water due to its elevation (Arnalich 2010; Swamee & Sharma 2020). It may be adopted in either of the two approaches. Firstly, a reservoir is constructed in the hilly area and supplies water through pipes from this source to the down-level points, on which treatments and storage infrastructures are secured. Secondly, the water is conveyed through pipes from the hilly area to a reservoir placed at the down-level point, followed by installing other elements and adopting procedures such as treatments and storage. The method allows water to flow by gravity, eliminating the need for pumping into storage tanks (Nganyanyuka 2017). A challenge in this system is where a premise (served community) is located on a no-hill area that could allow the supply through gravity.

Generally, four types of water sources, construct components, use, advantages, and disadvantages are discussed briefly. It appears that no one is more appropriate than the others. The knowledge explored here helps households widen their understanding and provides the easy task of evaluating and assigning costs that, in turn, helps to prioritize the water source. These water sources have components with different characteristics that influence water accessibility and affordability: cost, quality, and sufficiency. For water sources to be prioritized for selecting the optimal one, the tenets of EEE can be evaluated and integrated. The EEE concepts are described in brief below.

3.3. Tenets of EEE

3.3.1. Overview

Engineering economic analysis is the study usually adopted on the utilization of capital projects. Since capital projects incur a vast amount of money, two fundamental aspects are utilized and interrelated, i.e. design and economy. Project investment is evaluated in terms of its physical properties, principles, and engineering judgments, and it reflects predictions and forecasts of the future (Piper 2009). EEE assists as a tool for aiding decision-making among investment projects. Stages adopted include: project investments are firstly identified and evaluated explicitly, their consequences, both present and future values evaluated and compared, and one that is found to be economical is prioritized (Piper 2009). With EEE principles, investors are guided not to commit to a single option without critically evaluating several available alternatives. This approach helps ensure that investments are made in the most suitable project and avoid investing in a suboptimal one (Zoghi 2015). Newnan *et al.* (2004) and Piper (2009) provide two steps to aid decision-making through the adoption of EEE: (i) choose the types of investments to be invested and (ii) look at how to predict the performance of investment into the future (Piper 2009).

EEE is defined mainly by three variables (Park 2007): P – a sum of money at a time zero, on which, for purposes of analysis, it is also termed as present value or present worth; F – a future sum of money at the end of the analysis period. A – a sum of money that may be specified as payments or receipts in a uniform annual series that continues for n periods under specific interest rate i (Dole 2002; Newnan *et al.* 2004).

EEE study uses sets of mathematical techniques that simplify economic comparisons. It requires an understanding of project investments in detail – from conception through to maintenance periods, in which one engages with: formulating, estimating, and evaluating outcomes of economic projects to make prioritization (Piper 2009; Zoghi 2015). The concepts would help households prioritize the optimal water source required.

3.3.2. Principles of EEE

Four principles of EEE exist (Newnan *et al.* 2004; Park 2007), they include: (i) identification of project investment alternatives that are explicitly described for clarity, (ii) consideration of 'consequences' while considering that expected consequences of the various alternatives occur in future, (iii) determination of the critical issue regarding the consequences from the perspective of either the lender or the borrower, and (iv) commensurability – ensure that the items are commensurate with one another in so far as practicable. Further, they should be expressed in numbers and the same units.

3.3.3. EEE formula, cash flow diagrams, and uses

As introduced earlier, EEE uses five variables: principal or present worth (P), annuity (A), future worth (F), interest rate (i), and number of time/periods of investment (n). For computations, the expressions used are deployed through the use of tables as well as the cash flow diagrams as summarized (Newnan *et al.* 2004; Park 2007).

- $F_n = P(1+i)^n$ used to calculate the future single payment, given P, i, and n. It is designated as $F = P(F/P, i, n)$ when making computations using a table.
- $P_n = F[1/(1+i)^n]$ used to calculate a single present worth, given F, i, and n. It is designated as $P = F(P/F, i, n)$ when making computations using a table.
- $F_n = A[(1+i)^n - 1/i]$ used to calculate future single payment given A, i, and n. When the table is used, this is designated as $F = A(F/A, i, n)$.
- $A = F[i/(1+i)^n - 1]$ used to calculate future single payment A given F, i, and n. This is designated as $A = F(A/F, i, n)$ when using a table.
- $P = A[(1+i)^n - 1/]/i(1+i)^n$ used to calculate future single value P given A, i, and n. This is designated as the $P = A(P/A, i, n)$ when the table is used.
- $A = P[i(1+i)^{n\prime}(1+i)^n - 1]$ used to calculate A given P, i, and n. When using the table, it is designated as $A = P(P/A, i, n)$. The cash flow diagram is presented in Figure 1. In this figure, P is the principal amount borrowed or owned and invested during time zero. A_s indicates the annual flows indicating the cash-in and cash-out, while F denotes the future value at the end of the investment period (Newnan *et al.* 2004).

In summary, the EEE study compares alternative capital projects to help investors invest in the right project and obtain optimal economic investment (Piper 2009). The five essential parameters of EEE include principal, annuity, future value, interest rate, and investment time. It is a tool to help households invest in prioritized water projects among alternative investments designated as $A = P(A/P, i, n)$.

4. STUDY FINDINGS AND ANALYSIS

For a household to access safe, clean, and affordable water for its use, three essential parameters can be evaluated and implemented: identification and evaluation of water needs' indicators, identification and evaluation of water sources, components and cost consequences, and use of EEE tenets to prioritize water source needed.

4.1. Water accessibility indicators

A household needing to measure its level of water access can deploy the following measures: (i) a household should estimate/measure the water per capita per day, week, or per month that is also used to estimate the total demand for a specified family

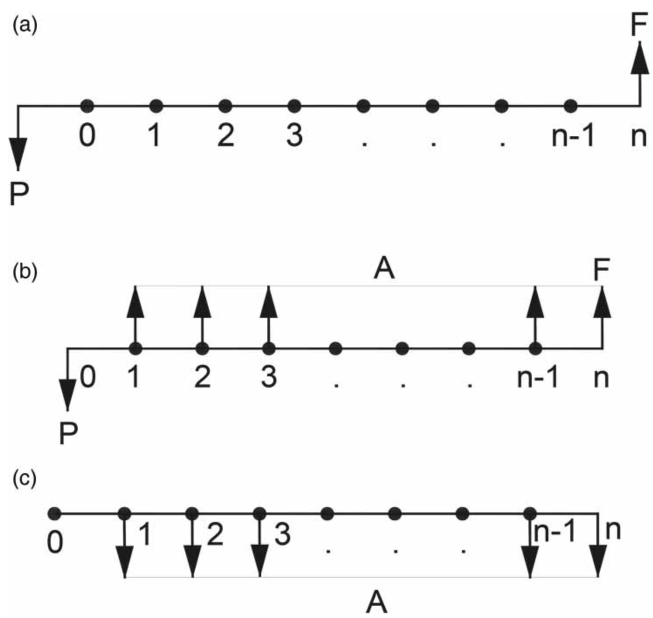


Figure 1 | Cash flow over time: (a) *P* and *F* relationships, (b) *P* and *A* relationships, and (c) *F* and *A* relationships.

and (ii) among others, the family may include different individuals with different characteristics: sex, age, location, and behavior. When categorized on sex, females are considered (sometimes) to consume more water than males (Hussien *et al.* 2016; Alharsha *et al.* 2019).

While factors related to personal hygiene have been addressed in the literature (Hussien *et al*. 2016; Alharsha *et al*. 2019), including aspects of washing, the frequency of water availability is another critical issue that needs to be considered. It is accounted for in a situation where water is reliable, one may take and use it any time (WHO 1997), and a person/use is comfortable because water is always available for drinking, cooking, washing, and other domestic means (URT 2002).

The water quality represents the water in which necessary treatments have been made to ensure it is not harmful to the user (WHO 1997). It is also called 'potable water', which is safe to drink, pleasant to taste and usable for domestic purposes.

Additionally, for water to be used for drinking purposes, some aspects must be monitored for pollutants such as heavy metals, pesticides, and organic compounds due to their potential toxicity and harmful effects on human health and the environment (Omer 2019; Gunnarsdottir *et al.* 2020). Moreover, microbiological tests for coliform bacteria and pathogens like *E. coli* serving as key markers for fecal contamination and the risk of waterborne diseases should also be done for making water safe (Gunnarsdottir *et al.* 2020; Wen *et al.* 2020). Additionally, surveillance for emerging contaminants, disinfection byproducts resulting from water treatment processes, and the presence of harmful algal blooms aids in identifying evolving threats to water quality (Omer 2019; Zhao 2020). Continuous monitoring and rigorous analysis of these indicators are indispensable for upholding water quality standards and safeguarding public health, necessitating a proactive approach to water management and regulation. The indicators advocate for the water in this context to be collected from improved sources (WHO & UNICEF 2014).

Affordability (from Oxford Dictionary) refers to being cheap enough for people to buy. It is also measured by its cost relative to the amount the purchaser can buy. In water's context, the term affordability relates to when a household thinks of its earning from which a portion must be set for water consumption.

Water need also relates to the extent to which a quantity or amount required is necessary. The household considers water needs per capita per day which determines the amount for one person in a day which forms the basis for the number of households and durations required. Various factors for the amount of water needed may include (Russell & Fielding 2010) climatic conditions and individual psychological features, among others. The World Health Organization (WHO) estimated a water requirement of about 20–40 liters per capita per day, while the European Environmental Agency estimated a minimum of 80 liters per day (Russell & Fielding 2010). It means that the amount of water required depends on its need characteristics. Regarding the amount of water needed, the household may intend to move a distance not exceeding 400 m to obtain the required water (Ministry of Water 2020).

In summary, for a household to be able to know its water needs, they may assess the water availability (frequencies); the quality, extent to which water is safe for own use; affordable, how much 1 liter or unit is sold for own ability to afford; quantity, how much water they need daily and distance, that is how long it will take in fetching water.

5. WATER SOURCES AND ELEMENTS OF PRINCIPAL AND ANNUITY

Water sources include a supply through taps, wells, rain harvest, and gravity, among others.

5.1. Water supply through pipes/taps system

The public authority is responsible for planning and managing piped water supply. For this system to function, the household is responsible for filling in the application form in the initial stages of water connection; after that, a survey is conducted by the public authority. After that approval, the water supply through a controlled meter is established. The authority can only make the water connection if the site area is already developed to connect the community. Otherwise, connectivity would be charged to a far distance that is likely costly, or no connection will be made; this makes a household think of another source.

When a type of water source is identified and known in terms of its operation modality, the next step is to identify and describe the attributes of EEE that guide prioritizing respective source(s). The attributes of EEE for tapped water supply systems are identified and briefly described.

(i) Principal/capital: For piped water connection, five components that form a capital are established, and cost estimates identified: (i) preferably, a pipe of a specified length depending on where the endpoint (marked by the public authority) is located, preferably, proximity to the existing household's property; (ii) a meter, offered by the water authority; (iii) present cost value for excavation of maximum depth of 45 and 60 cm wide, lay the pipe and backfilling; water tap(s) connectivity cost; (iv) storage tank estimated 3,000 liters and its support structure, plumbing fitments, and labor costs; and (v) motor cost – to help pump the water to the storage tank. The cost sum for these components gives a principal amount for the investment of piped water system (Table 1).

(ii) Annuity: The annual value involves three types of costs: (i) water consumption: accounted per day and accumulates on a weekly/monthly and up to annum periods; this is paid by the user to the water public authority; (ii) estimated electricity charges incurred during pumping of water to storage tank. Alternatively, petrol or diesel may be used instead of electricity if a motor pump system is used; (iii) maintenance activity costs, e.g. cocks' replacements. The costs, when summed up, give annuity cost.

Table 1 | Breakdown of capital investment costs for the alternative water supply projects

No	Description of work	Qty	Unit	Rate	Amount – Tshs (usd)
Alternative one – Direct supply through taps					
i	Excavate, supply PVC pipe, lay pipe, fill and compact at a distance 150 m	150	m	10,000	1,500,000 (578)
ii	3-horsepower motor	1	No	750,000	750,000 (289)
iii	Supply and fix 3,000 L Simtank complete with fittings and steel stands and all other fittings	1	No	3,000,000	3,000,000 (1,156)
	Total of alternative no. 1			**Tshs (usd)**	**5,250,000 (2,023)**
Alternative two – Rainwater gutter to harvest rainwater from the building					
i	Supply and install 100 mm UPVC gutter	33	m	25,000	825,000
ii	75 mm downpipe socketed	9	m	6,000	54,000
iii	Gutter angle	5	No	15,000	75,000
iv	Gutter external angle	10	No	15,000	150,000
v	75 mm bend	14	No	6,000	84,000
vi	Fascia bracket	100	No	5,000	500,000
vii	75 mm down clip	18	No	10,000	180,000
viii	Gutter union clip	8	No	10,000	80,000
ix	100 mm outlet drop	5	No	10,000	50,000
x	Alco flex white 280 ml	1	No	35,000	35,000
xi	50 mm diameter overhanging pipes to reserve simtank + all fixtures and fittings	5	m	50,000	250,000
xii	Supply and fix 3,000 L simtank complete with fittings and steel stands and all other fittings	1	No	3,000,000	3,000,000
xiii	Construction of 6,000 L concrete cold water storage tank (constructed with burnt bricks header walling with braced with heavy BRC wire meshes)	1	No	5,000,000	5,000,000
	Total of alternative 2			**Tshs (usd)**	**10,283,000 (3,963)**
Alternative three – Drilled well 50 m deep					
i	Survey of the water in the area	1	Sum	450,000	450,000
ii	Drilling and tube installations	50	m	115,000	5,750,000
iii	Pump machine	1	No	2,300,000	2,300,000
iv	Supply and fix 3,000 L simtank complete with fittings and steel stands and all other fittings	1	No	3,000,000	3,000,000
	Total of alternative 3				**11,500,000 (4,432)**

Note: (i) Maintenance costs apply to all alternatives but were not factored in, and (ii) salvage value was not included in the analysis.

5.2. Water supply through drilled wells

It involves the water supply system that draws water from the drilled well(s).

5.2.1. Principal/capital

Four categories of components include: (i) cost for surveying the area where drilling work is conducted, (ii) drilling and piping system and installations, (iii) storage tank of estimated 3,000 liters and its support structure, plumbing fitments and labor, and (iv) motor – initial cost is used, depending on the output rate and life span (Table 1).

5.2.2. Annuity

Two categories of components that include: (i) electricity charges – incurred during the pumping of water from a source to the storage tank where alternatively petrol or diesel may be used if the motor pump system is deployed; (ii) any maintenance charge, e.g. upon wearing out of the items.

5.3. Water supply through harvesting from rooftops

It is a type of water supply in which water is harvested from corrugated iron sheets (CIS) rooftops through a gutter system and rainwater pipes to the storage tank.

5.3.1. Principal/capital

Four categories of components: (i) storage tank constructed, covered on top, complete with supply water taps, and a washing tap outlet; (ii) good gutters and pipe works connected to the tank; (iii) storage tank of 3,000 liters and its support structure, plumbing fitments and labor; and (iv) motor – initial cost is used, depending on the output rate and life span (Table 1).

5.3.2. Annuity

Two categories of components: (i) electricity charges – estimated use during pumping water from a source to the storage tank. Alternatively, petrol or diesel may be used; (ii) any maintenance charge, e.g. on a wear-out item of the system.

5.4. Water supply through gravity

It is the type of water supply in which water is tapped from the hilly ground. A good reservoir needs to be constructed at that highest point level so that water would flow by gravity to the point of service.

5.4.1. Principal/capital

Four categories of components: (i) reservoir constructed complete with its structures; (ii) piping systems from a reservoir to the service point; (iii) storage tank estimated one of 3,000 liters and its support structure, plumbing fitments and labor; and (iv) motor – initial cost is used, depending on the output rate and life span.

5.4.2. Annuity

Two categories of components: (i) electricity charges – estimate of use during pumping water from a source to the storage tank. Alternatively, petrol or diesel may be used; (ii) any maintenance charge, e.g. on a wear-out item of the system.

5.5. Future value, duration, and interest rates

The principal and annuity components were identified and described for each of the four water investment sources (tapping, rainwater harvesting, wells, and gravity-fed systems). The other three components used on each water source include future value, interest rate, and duration.

5.5.1. Future value

The future value arises when capital is invested and continues to be used over a period, influenced by the specified interest rate. This value represents the amount when the item reaches the stage of being salvaged.

5.5.2. Interest rate

The interest rate is determined by the amount of capital invested. For the water projects, this rate may be applied on a quarterly, semiannual, or annual basis. It is denoted by i and expressed as a percentage.

5.5.3. Duration

The duration of a tapped water project covers the entire period from initiation to final implementation and completion, measured in days, months, or years. This timeframe includes several key phases: the planning stage, where project objectives, resources, and strategies are defined; the execution phase, during which construction and installation are carried out; and the monitoring phase, where progress is assessed and adjustments are made as needed. Each phase is crucial for ensuring the project is completed efficiently and effectively, with all resources, effort, and investments to achieve the intended outcomes.

5.6. Water source investment for households

Figure 2 outlines three dimensions of water source investment for households. They include water accessibility indicators, water source types, and facets of engineering economics to enhance water source prioritization.

5.7. Use of engineering equivalence to prioritize water investment project

Data based on the current market value (2019) were used to provide cost estimates for comparing three water sources: tapped water systems, rainwater harvesting systems, and drilled wells. These cost estimate values are used to highlight the computation of principal/capital and annuity values. Such values are derived using other parameters (duration, interest, and future values) to help identify a present worth for prioritizing alternatives. The data from three individual households based on their projects are used. Data for making components of principal and annuity values are summarized in Table 2. When used for computations, a summary is outlined in Table 2. As described in the methodology section, each investment was considered to last for 75 years using an interest rate of 15% per year.

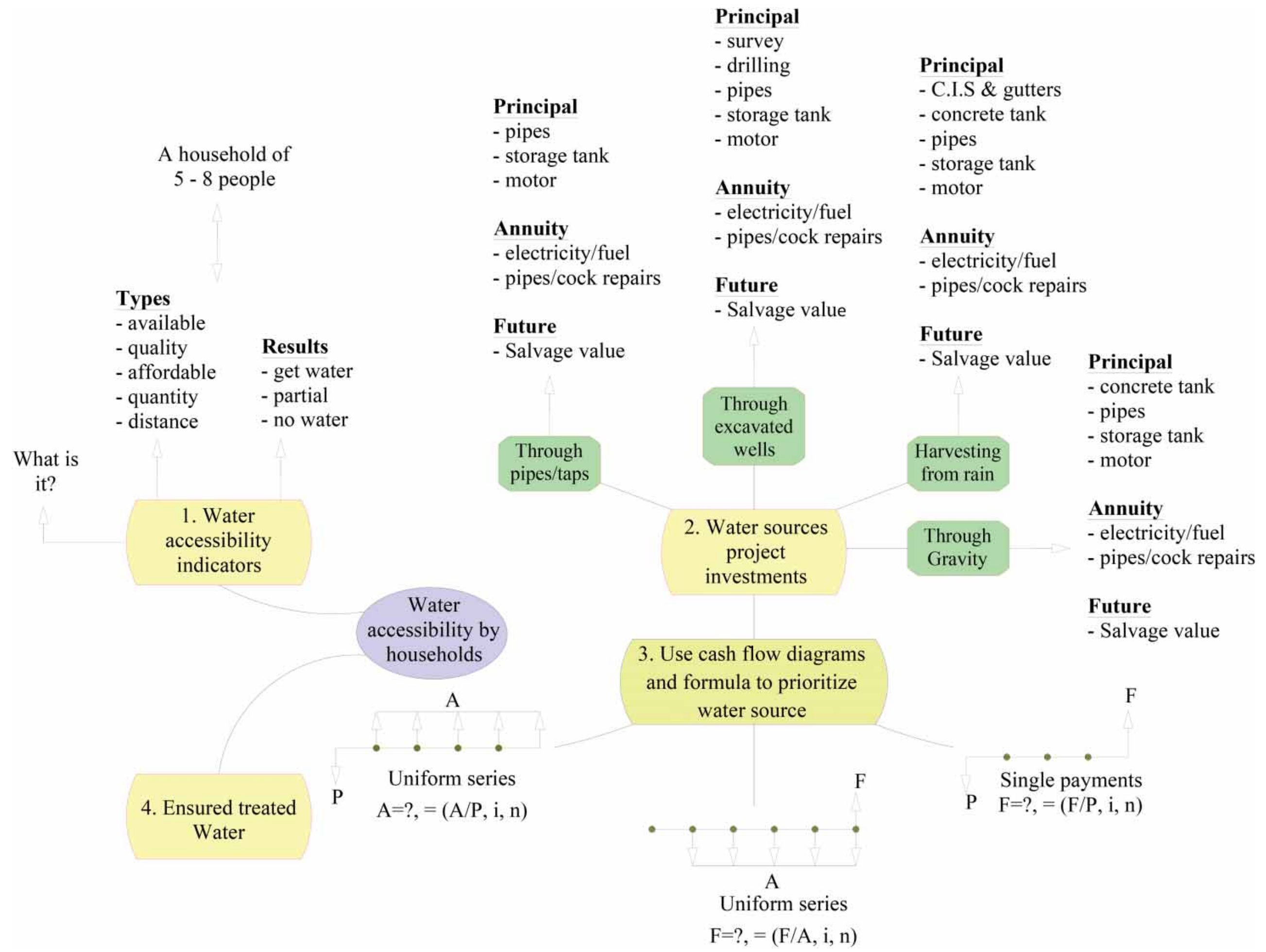


Figure 2 | A framework to prioritize water sources for households.

Table 2 | Water sources components computed for prioritization

Water source	Costing variables	Formula	Present worth (Tshs)
Supply through taps	(i) $P = 5{,}250{,}000$/-; (ii) $A = ?$ $i = 15\%$; $n = 75$ years $A = 360 \times 2{,}400 = 864{,}000$/- (Assumed that eight households pay 2,400/- per day) to water authority and consumed for 360 days	(i) 5,250,000/-; (ii) $P = A(P/A)$, i, n=864,000(P/A), 15%, 75 $864{,}000 \times 6.666 = 5{,}759{,}424$	5,250,000 + 5,759,424 = **11,009,424/-**
Supply through rainwater harvest	$P = 10{,}283{,}000$/-; $i = 15\%$; $n = 75$	No bill is paid When water is stored for a long time, it may not be good for drinking purposes	**10,283,000/-**
Supply through drilled well	(i) $P = 11{,}500{,}000$/- (ii) If water is pumped daily, the assumption is that the charge will be 250/- per day, giving a total of $A = 90{,}000$/- $i = 15\%$; $n = 75$ years	(i) $P = 11{,}500{,}000$/-; (ii) $P = A(P/A)$, i, n=90,000 (P/A), 15%, 75 $90{,}000 \times 6.666 = 599{,}940$	11,500,000/- + 99,940/- =**12,099,940/-**

From Table 2, the alternative one, tapped water, gives a present worth of Tshs (usd) 11,009,424/- (4,242), rain harvest Tshs (usd) 10,283,000/- (3,962), and drilled water Tshs (usd) 12,099,940/- (4,662). When looking at these values, an alternative investment would be rainwater harvest because it has minimal value.

However, with further observation, one may note that water obtained from this source is stored for a long time; thus, it may be used for other purposes, such as washing and gardening, since it may not be fit for drinking. The other option may be the 'tapped system' if this conclusion is drawn. However, it incurs a daily bill of Tshs 2,400/= for every 1,000 liters, which equates to a rate of Tshs 2.40/= per liter, paid to the water authority. This rate may change at any time as the external party regulates it. Therefore, the option 'drilled water system' may be prioritized. Generally, when we note these justifications, it can be said that the choice depends on individual uses. For example, if the specific case requires washing or gardening or water for feeding cattle, the rainwater harvesting option would be appropriate. It is further suggested that essential aspects in this paper are for users to consider their own specific needs and focus more on the procedures (not on the used values) since the application and the prevailing situation characteristics differ.

On the other hand, when the conjunctive use of two different water sources is feasible, the best option with the lowest present worth value is the tapped water and rainwater harvesting systems (Table 2). However, based on the present worth value, the ranking of water supply systems starting from the best to the worst combination of two systems follows the following trend: rainwater harvesting and tapped water systems > drilled well and rainwater harvesting > drilled well and tapped water (Table 2).

6. CONCLUSIONS

The Tanzania population who live in both urban and rural areas lack access to good water. This problem is contrary to the nation's strategic plan to ensure all Tanzanians have access to good water by 2002 (MWLD 2002). Most citizens obtain water that is supplied through taps, which sometimes goes for ration, water might be dirty, or such water may not be affordable, especially for low-earning individuals. The indicators for water assessment were evaluated to help households determine their measures for domestic water needs. They include water availability, quality, quantity, affordability, distance to be fetched, and time to take. Four types of water sources were also evaluated, and the components of costs used in the EEE were identified to help prioritize a water source. Sources include a supply through taps, drilled well, rain harvest, and gravity. Components identified from these water sources were defined regarding water project investment, addressing such components as a principal, annuity, and future value.

Data obtained from individuals in Mbeya City for the tapped system, rain harvest, and drilled well gave the present worth of Tshs 11,009,424/-, rain harvest Tshs 10,283,000/-, and drilled water Tshs 12,099,940/-. It was concluded that although supply through rain harvest is favorable, this water is stored for a long time; thus, it may not be good for drinking purposes. In that way, a 'tapped' system would be appropriate, although, also, in this system, a rate of Tshs 2,400/- daily payment bill to the water authority is likely to change at any time as the external party regulates it. Therefore, the option 'drilled water system' may be prioritized. Generally, the choice of alternative depends on individual uses.

It is recommended that households may prioritize the use of drilled water. It is further suggested that users should consider their own specific needs and focus more on the procedures for computational alternatives rather than on the used values since the application and the characteristics differ.

DATA SENSITIVITY

Data collected from three clients regarding the specified water supply sources (tapped water, drilled wells, and rainwater harvesting systems) were used in the research as-is. Information about their names, contracts, and other details remains confidential.

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AUTHOR CONTRIBUTIONS

Conceptualization: Y.H.B.M.; methodology: Y.H.B.M. and O.B.S.; writing original draft: Y.H.B.M. and O.B.S.; writing review and editing: Y.H.B.M. and O.B.S. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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