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Analysis of the Water Supply and Demand Balance at the Mua Hills Settlement, Machakos County, Kenya.

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Abstract

Over the years, population growth has surged, putting increased pressure on the already limited water resources. This study focused on assessing whether the current water supply in Mua Hill Settlement, located in Machakos County, Kenya, is sufficient to meet the demand. The research aimed to suggest methods for evaluating the adequacy and efficiency of the water infrastructure in place. It was grounded in theories related to evaporation and transpiration, as well as natural resource management. Additionally, it examined two key concepts: sustainability in rural water supply and the Internet of Water Things. The study utilized social and descriptive survey designs, incorporating both qualitative and quantitative approaches through purposive, stratified, cluster, and random sampling techniques. The study findings revealed that as of 2024, the water demand in Mua Hills exceeded the available supply of 8.7 m^3/day. This aligns with the postulations of Sophocleous (2004) and An et al. (2021), that factors such as population growth, economic development, technological progress, land use changes, urbanization, environmental degradation, government policies, and climate change all influence local water demand. The research highlighted that Mua's rapidly growing population has resulted in significant conversion of agricultural land into residential areas, deforestation that is occasioned by the demand for construction materials, and a lack of government initiatives to maintain or upgrade the existing water system. The study recommended conducting regular mapping, monitoring, and evaluation of water projects in relation to population dynamics and land use every 3 to 5 years, to inform desirable remedial interventions.

Keywords: Water demand/supply, natural resource management, environmental degradation.

1. Introduction

1.1 Study Background

Over the years, there has been a rapid population growth thus exerting more pressure on the limited available water resources. This has resulted in instances of water rationing for the consumers. Consequently, professionals concerned with water resources such as planners need to produce innovative ways of diversifying water sources so as to meet the ever-increasing water demand. One of the major sources of water worldwide is rainfall or precipitation which feeds into surface water sources such as rivers, lakes, and pods and into groundwater sources such as wells, and boreholes.

Water, which is essential for all forms of life, covers 71% of the Earth's surface. On Earth, 96.5% of the planet's water is found in oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0.001% in the air as vapor, clouds and precipitation. Only 2.5% of the Earth's water is freshwater, and 98.8% of that water is in ice and groundwater. Less than 0.3% of all freshwaters is in rivers, lakes, and the atmosphere, and an even smaller amount of the Earth's freshwater (0.003%) is contained within biological bodies and manufactured products. Water on Earth moves continually through the hydrological cycle of evaporation and transpiration (evapotranspiration), condensation, precipitation, and runoff, usually reaching the sea. Harvesting the runoff water through the construction of dams, pods, and water pans offers alternative water sources of water for domestic use. Evaporation and transpiration contribute to the precipitation over land. Water is becoming scarce due to an increase in population, industries, and agricultural activities and due to poor rainfall, which is an implication of climate change.

Among various continents, Asia has 36% of the available freshwater reserves, with over 60% of the world's population where water is a scarce commodity. Compared to Asia, Africa is in a better situation, where 13% of the population has access to 11% of the freshwater reserves. Australia and Oceana have plenty of water with 1% population owning 5% of the freshwater reserves, followed by North and Central America, with 8% population and 15% water reserves, and South America with 6% global population and 26% freshwater reserves. More than 2.2 million people die each year from diseases related to contaminated drinking water and poor sanitation. By the year 2050, water scarcity will affect between two to seven billion people out of the projected total population of 9.3 billion.

The drivers of this water resource challenge are fundamentally tied to economic growth and development. Agriculture accounts for approximately 3,100 billion m^3 or 71% of global water withdrawals today, and without efficiency gains will increase to 4,500 billion m^3. The water challenge is therefore closely tied to food provision and trade. Centers of agricultural demand, also where some of the poorest subsistence farmers live, are primarily in India, Sub-Saharan Africa, and China. Industrial withdrawals account for 16% of today’s global demand, growing to a projected 22% in 2030. These two land uses could be supplied with water from alternative water sources such as harvesting runoff water and extraction and treatment of sea and ocean water.

With increasing climate variability, rainfall seasons across the world are becoming less predictable and reliable. The frequency of extreme weather events, such as floods and droughts, has increased over the past decade, causing supplies to diminish. Thus, there is a need to develop infrastructure to help harvest the flood water and store it for use during the dry seasons. In the majority of river basins, present utilization is significantly high and is in the range of 50 percent to 95 percent of utilizable surface resources.

1.2 Problem statement

The water supply is rapidly dwindling due to mismanagement of water resources, over-pumping, and pollution. Climate change has added to the problem by causing erratic and unpredictable weather, which has drastically diminished the supply of water coming from rainfall and glaciers. In India, the requirement of water for various sectors was assessed by the National Commission on Integrated Water Resources Development (NCIWRD) in the year 2010. It was found that major components of demand in India were agricultural use (irrigation), industrial use, and domestic use. Around 65% of India’s total water demand is for groundwater, which plays an important role in shaping the nation’s economic and social development. Therefore, with the growing demand for water and depletion of the available water sources, an assured supply of good quality water is becoming a growing concern. Such is also the case in Kenya.

The rapid increase in population, urbanization, and industrialization has led to a significant increase in water requirements. In the next decade, the demand for water is expected to grow by 20% fueled primarily by industrial requirements, domestic demand which is expected to grow by 40%, and irrigation requirements.

Groundwater is the major source of drinking water in urban and rural Kenya. It is also an important source of water for the agricultural and industrial sectors. Groundwater increasingly is pumped from lower and lower levels, and much faster than rainfall can replenish it. As a result of increasing uncontrolled agricultural activities upstream, the quality and quantity of water in some rivers are at a threateningly low level. As a result, the water demand for the environment could increase rapidly. The water demand is increasing day by day; on the other side supply of water either remains constant or decreases due to global warming. The adjustment of the demand and supply of water could cause a water crisis which is already happening in Kenya, like in other countries in the world. The resultant cause would be inadequate access to safe drinking water, inadequate access to water for sanitation and waste disposal, groundwater over-drafting (excessive use) leading to diminished agricultural yields, overuse and pollution of water resources harming biodiversity, and regional conflicts over scarce water resources. Kenya is facing water stress. Therefore, there is an urgent need to utilize rainwater harvesting should be used to save water for the future.

1.2.1 Significance of the study

Currently, most major cities worldwide are suffering stress on their water supply systems due to increased urbanization rate, climate change, rainfall variability, and an increase in population (Sivakumar, 2011). On the other side of the story, the long-awaited and predicted El Nino rains are occurring worldwide. More closely here in Kenya, they are specifically evidenced at the Mua Hills rural settlements. This then is a timely study to equip communities and governments with knowledge on water sufficiency. Such information ably anchors thought on possible supplementary water supply from alternative sources. This would include harvesting, storing, treating, and distributing storm water for later days when the rains fade. The study will add impetus to embrace the body of knowledge on available alternative water sources such stormwater harvesting as a sustainable method of augmenting rural water supply. In so doing, it helps alleviate the water shortage problem, especially in ASAL, like the study area. This will entail conserving green spaces and wetlands, stormwater Swales, rain barrels and cisterns, and stream restoration.

Up until now, dialogue about stormwater harvesting has, by and large, been high level. It has lacked the in-depth investigation required to conclusively determine its strengths and weakness. Its niche within the sustainable rural drainage and integrated rural water management toolkit has lacked articulation (Mitchell et al., 2007). Stormwater harvesting has multifunctional benefits, including the potential to enhance rural stream health through improvements to the flow regime. It also provides an alternative valuable water supply source. This study anticipates the placement of stormwater harvesting at the forefront as a reliable way of harvesting rainwater. Such a supply is then made valid through the integrated system of the collection, treatment, storage, flood protection, and distribution components. The environmental flow benefits of rural stormwater harvesting accompany all this.

Mua Hill settlement qualifies as a classical area for the study due to its challenges in the water supply. In addition, its hilly topography gives a good potential for stormwater harvesting and conservation of the hill as an ecologically sensitive area. The settlement is located in Machakos county, 18 kilometers from Machakos town and 58 kilometers from Nairobi CBD. The study area is also 53 kilometers from the upcoming Konza Technopolis city. Thus, the hill has experienced and is still experiencing tremendous urbanization to accommodate the spillover population of Machakos and the city of Nairobi. As a result, deforestation has been dramatically experienced in the area to pave the way for settling the rapidly increasing population. This has increased water demand while depleting the water sources.

Initially, there were permanent rivers and dams within the settlement, but as of now, in 2023, all the surface water sources have dried up, with only a few seasonal rivers available. Organizations such as the World Bank have put effort into drilling boreholes in the area, but these water systems have also failed due to poor institutional management. The study’s interest to identify water supply deficits and therefore support mitigation measures from diverse water sources can be used to augment rural water supply in order to spur sustainable development in Mua Hill settlement is therefore urgent, meaningful, and timely, and it affects a specific critical local population but with a broader reach to a nearby town and city. The findings will influence the broader issues of urban settlement and water sufficiency in society while building

1.2.2 Study objectives

The general objective of this study was to determine whether the existing water supply meets the water demand using a case study of the Mua Hills settlement, In Machakos County, Kenya. The associated secondary objectives then assumed the following form:
1. To determine the existing water supply sources and volume.
2. To delineate the prevailing water demand types and levels.

1.2.3 Study Hypotheses.

Null H_0 hypothesis: Existing water supply sources and volume do not match the prevailing water demand types and levels.
Alternate H_1 hypothesis: Existing water supply sources and volume are a match the prevailing water demand types and levels.

1.2.4 Research questions

In the Mua Hills settlement:
1. What sources provided water to the settlement?
2. What sources of water could potentially supply water to the settlement?
3. What water supply levels prevailed in the settlement?
4. What were the ultimate water supply levels possible for the settlement?
5. What were the prevailing forms of water demand in the settlement?
6. What were the levels of water demand in the settlement?

1.3 Relevant Scholarship

1.3.1 Theoretical Framework.

1.3.1.1 Theory of natural resource economics

The field of natural resource economics delves into efficiently utilizing society's limited natural resources, encompassing non-renewable resources like minerals and fossil fuels and renewable resources such as fisheries and forests (Harding, T., et.al., 2020. Toews, G. & Vezina, P.L. 2022; Toews, 2006). Theoretical frameworks and empirical research explore diverse models detailing supply behaviour and therefore the efficiencies of how individuals and societies extract, utilize and manage these finite resources. Of value here is the manner of using resources to meet current needs without compromising opportunity for future generations (Gray, 1913; Hanley, Shogren & White, 1997; and Hotelling, 1931). In the context of renewable resources, like water, which is the focal point of this study, the theory suggests that an optimal harvest should strike a balance between the marginal benefits achievable in other sectors of the economy, the additional growth of the resource, and the cost savings derived from delaying the harvest or conversely the additional cost of extracting a resource today when it cannot be accessed and extracted in future. This concept of stock externality highlights that having a greater quantity of the resource available at the time of harvest leads to lower per-unit harvest costs. Regulatory measures to address property rights failures include allocating rights, imposing use fees, implementing liability rules, and establishing tradable quotas.

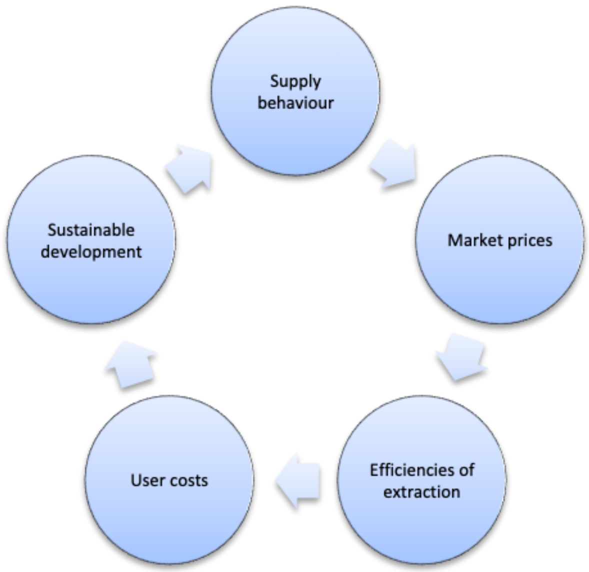

Figure 1: Principal elements of the theory of natural resource economics. Source: Author, 2024, abstracted from Gray, 1914; Hotelling, 1931; & Shogren 1997.

Moreover, natural resource economics investigates how societies can conserve their biological diversity more cost-effectively by considering fundamental economic principles such as relative economic circumstances, opportunity cost, and incentive design (Gray, 1913; Hanley, Shogren & White, 1997; and Hotelling, 1931). Additionally, there is a need to explore and devise cost-effective strategies to mitigate risks associated with stock pollutants, exemplified by phenomena like deforestation, which adversely affect water resources.

1.3.1.2 Evaporation and Transpiration (ET) Control Theory

Evaporation and Transpiration (ET) describe water movement from the Earth's surface to the atmosphere (Makanda, K., et.al., 2022., Dirwai, T. L., et., al., 2021., Jinxia et al., 2012). ET helps illustrate the continuous circulation of water within the Earth and atmosphere—a complex system involving various processes. Initially, water in surface sources like lakes, rivers, and dams evaporates into water vapor, condenses to form clouds, and precipitates as rain (Barry, R., et.al., 2024; Anna Pazola, et.al., 2024; Seiler & Gat, 2007). Rainwater, upon reaching the land, creates runoff, which can either infiltrate the ground and contribute to groundwater or flow to surface sources through natural channels or stormwater drains into rivers, lakes, or dams. This represents the natural water cycle.

However, urbanization and changes in land cover, coupled with increased deforestation for development, have disrupted this natural cycle in many parts of the world. This disruption leads to heightened runoff during rainfall, reduced groundwater infiltration, groundwater depletion over time, and pollution of surface water sources, resulting in water-related challenges. Interfering with one aspect of the water cycle affects the entire system (Barry, R., et.al., 2024; Anna Pazola, et.al., 2024; Seiler & Gat, 2007).

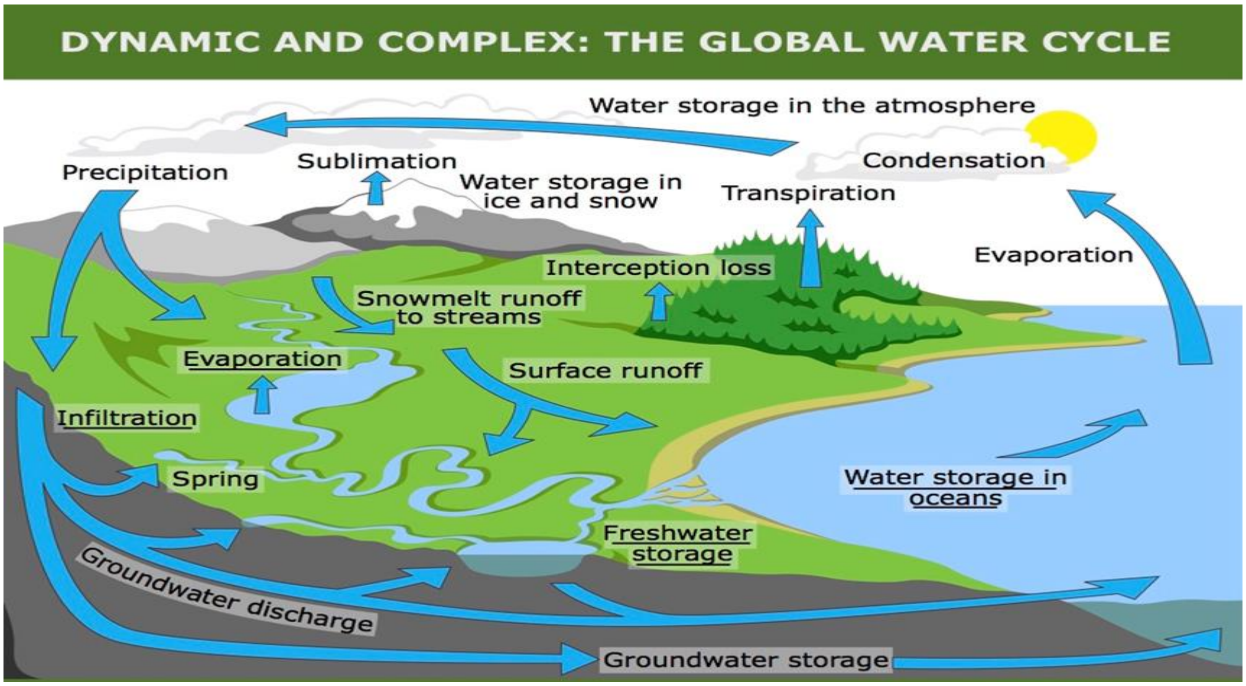

Figure 2: Water cycle. Source: https://www.sciencelearn.org.nz/resources/721-the-water-cycle, June 2009.

The ET control theory involves comparing the target ET with the current ET. The target ET typically equals the average precipitation (Makanda, K., et.al., 2022., Dirwai, T. L., et., al., 2021., Jinxia et al., 2012). When the current ET exceeds the target ET, the water supply surpasses demand (Makanda, K., et.al., 2022., Dirwai, T. L., et., al., 2021., Jinxia et al., 2012). The study observed a rapid increase in the population over the last two centuries, leading to the overexploitation of natural ecosystems in the quest for water. This societal behavior has created an imbalanced natural environment and challenges such as water shortages (Makanda, K., et.al., 2022., Dirwai, T. L., et., al., 2021., Jinxia et al., 2012). Planning interventions, such as stormwater harvesting with proper treatment and distribution, can enhance rural water supply. Engineering mechanisms can also be implemented to ensure that some runoff water infiltrates groundwater sources for future use. Remote sensing techniques are crucial in monitoring the entire water cycle (Makanda, K., et.al., 2022., Dirwai, T. L., et., al., 2021., Jinxia et al., 2012).

1.3.2 Conceptual framework.

1.3.2.1 The concept of sustainability in rural water supply

Sustainable development is about meeting present needs without compromising the ability of future generations to meet their own (The United Nations Economic Commission for Africa (ECA), African Union Commission (AUC), United Nations Development Programme (UNDP), and African Development Bank (AfDB), 2024., Mensah J., 2019; Knaap J., & Knaap M., Beckerman (2017. This concept is the foundation of the United Nations Agenda for the 17 Sustainable Development Goals (SDGs), which encompasses four interconnected dimensions: Society, environment, culture, and economy (UNESCO, 2021). It represents a paradigm that seeks a balanced approach to environmental, societal, and economic considerations, aiming for an enhanced quality of life. In the context of rural water supply, sustainability refers to the ability to provide reliable and safe water services to rural communities over the long term while considering environmental, social, and economic factors (Mohtar, R., 2024; Moriarty et al., 2008, 2024). Sustainable rural water supply systems aim to ensure that communities have continuous access to clean water and that the infrastructure, management practices, and community engagement are designed to endure and adapt to changing conditions.

The role of local communities in the sustainability of water supply systems is paramount. Sustainable water supply infrastructure should be designed to withstand environmental conditions and be easily maintained by local communities, using appropriate technologies and materials. The involvement of local communities in decision-making, planning, and managing water supply systems is not just beneficial, but essential for sustainability. This ensures that systems meet local needs and that there is community ownership and responsibility. Building the capacity of local institutions, water committees, and individuals to manage and maintain water supply systems is crucial to this empowerment. This approach empowers communities to take ownership, address challenges independently, and foster a sense of responsibility and commitment. Lastly, sustainability involves considering the environmental impact of water supply systems, including water source protection, watershed management, and minimizing energy-intensive technologies. Ensuring the financial sustainability of rural water supply systems is also critical. This can be achieved through cost recovery mechanisms, tariff structures, and exploring alternative funding sources.

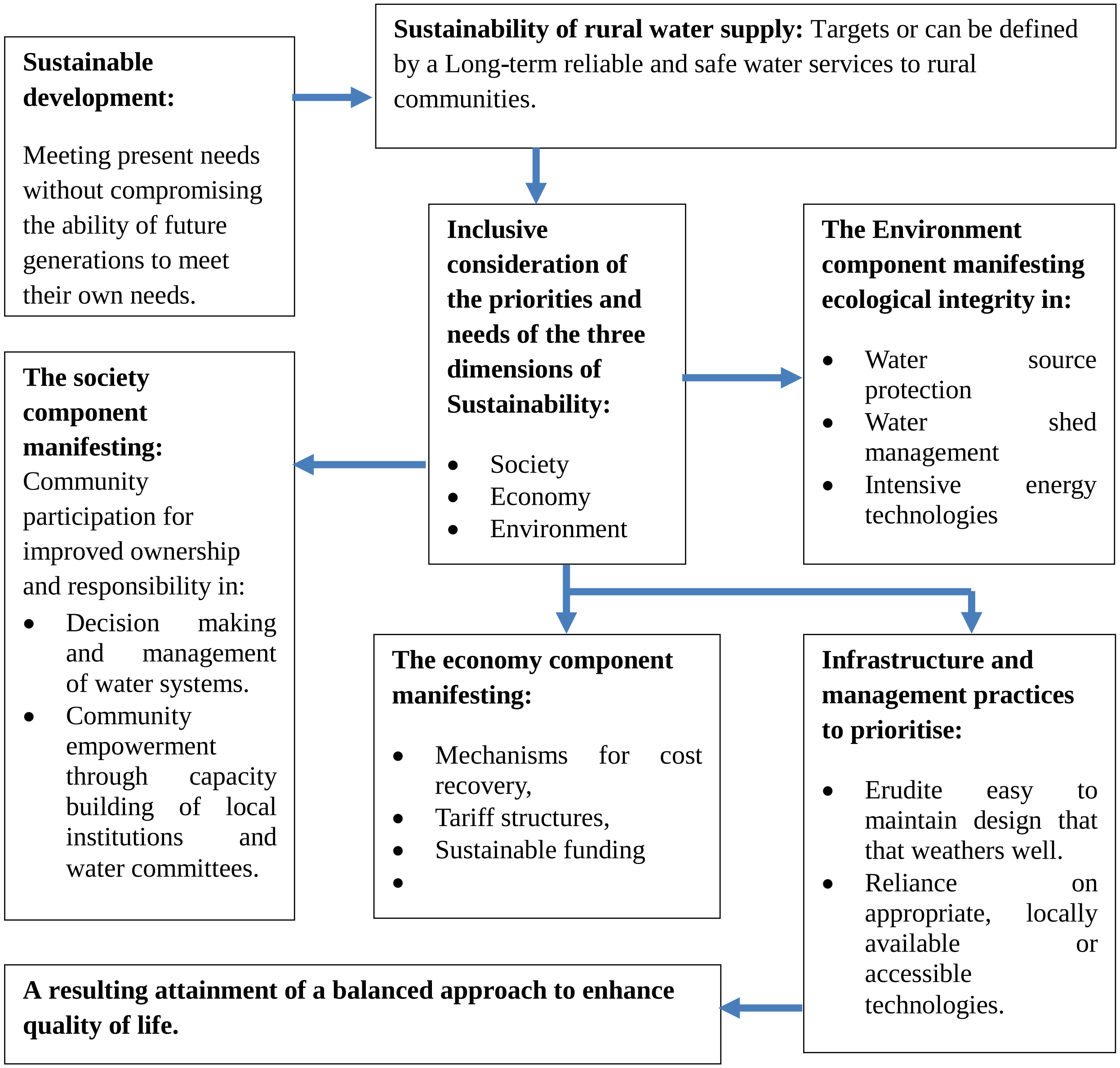

Figure 3: Concept of sustainability in rural water supply. Source: Author[1], 2024.

1.3.2.2 Concept of internet of water things

The Internet of Water Things (IoWT) concept involves the application of the Internet and technology in addressing water challenges (Lowe Qin & Mao, 2024; Chandra Prabha, & Navneet Munoth. 2023; Robles et al., 2014). This concept is crucial in monitoring the whole water supply system from collection at the water sources to transmission to the treatment and purification chambers, to the storage tanks, and finally, how it is distributed to the end users. It enables the formation of a control tower probably up the hill from where the whole system is monitored. Monitoring the quality and quantity of water in the water system is crucial. Through IoWT, it is possible to monitor the quality of water, thus safeguarding the wellbeing of the end users, ensure all households have access, and also monitor and protect the water sources to avoid over-exploitation of some water sources and reduce negative environmental implications such as climate change (Lowe Qin & Mao, 2024; Chandra Prabha, & Navneet Munoth. 2023; Robles et al., 2014).

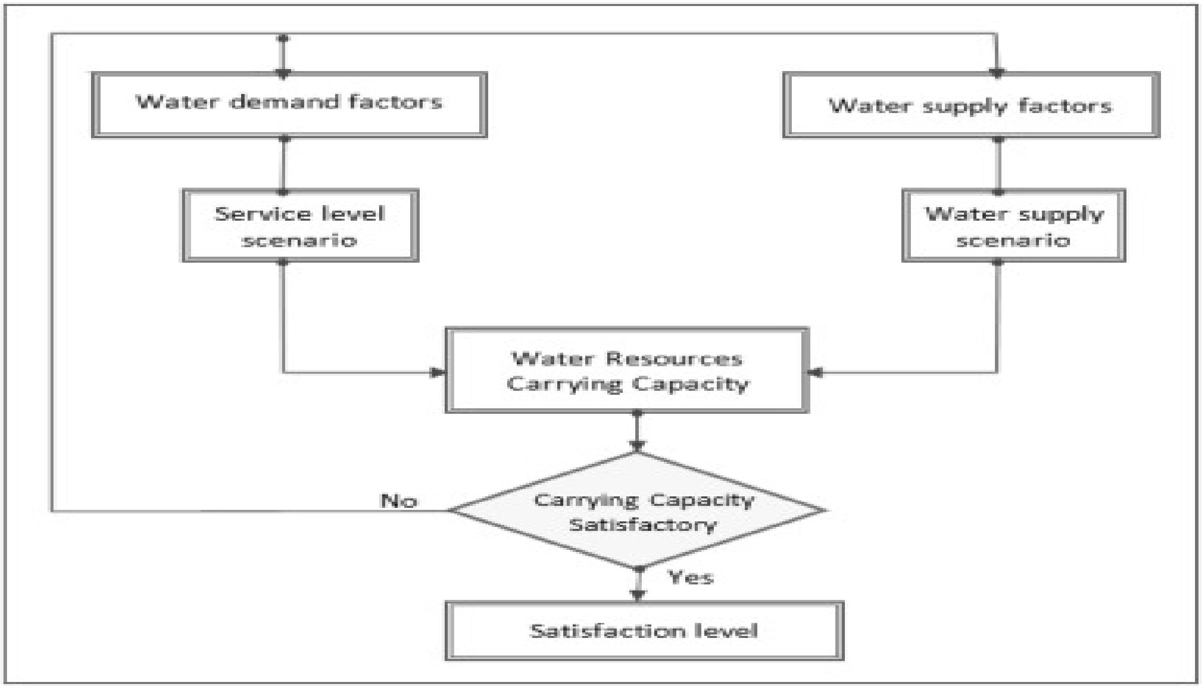

Figure 4: Conceptual framework. Source: Author[1], 2024.

1.3.2.3 Operational definition of terms

Water is the liquid that falls as rain and of which seas, lakes, and oceans are composed of (Lycan, 2006).
Water demand refers to the volume of water needed by users to satisfy their needs (Merrett, 2004).
Water resources are natural water reservoirs that have the potential to be useful for humans, serving as sources for drinking water supply or for irrigation (Shiklomanov, I. A. , 2020; Shiklomanov, I. A., & Rodda, J. C., 2021; Shiklomanov, 1991).
Water supply involves the delivery of water through public utilities, commercial entities, community initiatives, or individual efforts, typically facilitated by a network of pumps and pipes (The Aquaya Institute and REAL-Water Consortium. 2022; REAL-Water Initiative. 2021; Wagner, & Organization, 1959).

2. Research Methodology

2.1 Research design.

Research design essentially spells out articulately, the procedures to be followed in carrying out an ascertained scientific inquiry. It first assembles together complementary research designs by appreciating aspects of the impeding inquiry with respect to its purpose, analytical basis, environment, and methods (Maringa 2014, 2005; Maringa, & Ochieng, 2006; Mugenda and Mugenda, 2003). To this extent, a social survey descriptive research type (a fact-finding venture that seeks to determine and report on the current status of study subjects) that blends both the qualitative and quantitative research forms was selected for use here. It aided in the choice of the overall research methodology applied including sampling design, research methods, techniques, field tools, and subsequent analysis in the study. Several factors were considered when determining the type of research design to be used: the availability of resources, the type of information desired, the ability to manipulate the independent variables, and the degree of control the researcher had.

2.2 Target population

2.2.1 Inclusion criteria

The study encompassed all residents of the Mua Hills settlement, ensuring a comprehensive representation of the community. Additionally, relevant critical informants at the sub-county and county levels were included. This approach was chosen as the study was focused solely on the Mua Hills settlement, which spans three sub-locations: Kyaani, Kyanda, and Mua Hills. The respective population of each sub-location, as per the 2019 Kenya population census reports, is detailed in Table 1 here below:

Table 1: Population data according to 2019 National Census data.

Mua Hills Settlement population					
Sub-Location	**Male**	**%**	**Female**	**%**	**Total**
Kyaani	906	51.59	850	48.41	1,756
Kyanda	1,491	50.08	1,486	49.92	2,977
Mua Hills	2,110	51.83	1,961	48.17	4,071
TOTAL	4,507	100.0	4,297	100.0	**8,804**

Source: Author[1] 2024.

2.2.2 Exclusion criteria

The study excluded anyone outside the area except the vital administrative or technical informants at the sub-county and county levels.

2.3 Sampling

The sampling method used in this study offered two significant advantages: it expedited the data collection process and reduced costs (Simon, D., & Burnett, J., 2024; Şanlı, S. 2023; Baza. D., 2022; Naing, L., et. al., 2021; Casella et al., 2004; Kish, 1965). Key informants were identified using purposive sampling. The study area was divided into three groups based on the three sub-locations which engendered cluster sampling that was complemented with a measure of stratified sampling that recognized various hierarchies of social status in the study area. The choice of respondents was guided by the use of simple random sampling as prescribed by the Tippett's table of random numbers. This then is how samples for household questionnaires, business questionnaires, and focus group discussions within each subgroup were selected and this ensured the representativeness of data. It enabled subsequent generalization in the findings and conclusions.

2.3.1 Sampling plan and sample size

Sample size was determined based on the five parameters: desired statistical power, effect size, significance criterion, estimated measurement variability, and whether a one - or two-tailed statistical analysis was planned. Miaoulis and Michener (1976, 2020) and Singh, A. S., et al., 2021, stated that three criteria are usually needed to determine the appropriate sample size: the level of confidence or risk, the level of precision, and the degree of variability in the measured attributes.

The central limit theorem guided the determination of the household and business questionnaire sample sizes. The theory generally states that the central limit theorem "starts" at an N of about 30. Thus, this research worked with a sample size of 33 (just to be in the safe zone, in terms of meeting the threshold of the central limit) per subgroup, making the overall sample size 99 for both the household and business questionnaires.

Using purposive sampling, the following key informants were identified: Machakos Town sub-county physical planner, Machakos Town sub-county surveyor, Machakos Water and Sewerage Company (MACHWASCO) manager, and the environment expert at the Machakos Town sub-county. Focus Group Discussions (FGDs) were used to identify issues and interpretations from homogenous groups with similar characteristics (Maringa 2014 a & b; Maringa, 2005; Maringa, & Ochieng, 2006; Mugenda & Mugenda, 2003). This study considered three (3) FGDs: Men, women, and youth. Mugenda & Mugenda (2003) also noted that FGDs typically consisted of 8 – 10 members and discussions here would take 2-3 hours. Thus, for this study, three members were picked for each cluster (men, women & youth) in each sub-location to form FGDs of 9 members each. Each sub-location provided nine members for FGDs: 3 men, three women, and three youths. These were picked using simple random sampling.

2.4 Methods of Data Collection

2.4.1 Primary data collection

The first mode of data collection was an examination of existing documents, where Registry Index Maps (RIM) were acquired from the Survey of Kenya and digitized. More primary data for GIS analysis was acquired from Google Earth and satellite data. Secondly, survey instruments were appropriately administered for household and business questionnaires. Both these types of questionnaires were prepared and fed into Kobo Collect, which was used for data collection and analysis. Interviews were carried out for the identified key informants. The key informants for this case were the Machakos Town sub-county physical planner, the Machakos Town sub-county surveyor, the MACHWASCO manager, and the environment expert at the Machakos Town sub-county. In addition, the study also collected data from old members of the society through oral histories. Documenting how water scarcity had come up in the area was of great necessity. The observation method aided in filling in the mapping and taking photos of all existing water resources within the study area. Lastly, the study conducted focus group discussions.

2.4.2 Secondary data collection

Secondary data collection included a review of related literature, past research and reading journals, magazines, and articles and government archives. This research also referenced secondary data from acts, the constitution, government policies and archives.

2.4.3 Research instruments.

Structured interview schedules for use with key informants were prepared for the Machakos Town sub-county physical planner, Machakos Town sub-county surveyor, MACHWASCO manager, and the environment expert at the Machakos Town sub-county. Household and business questionnaires were also prepared and fed into the Kobo Collect online application. Additionally, structured interview schedules were prepared to guide the FGDs. Lastly, observation matrices were assembled together in order to guide the mapping and taking of photographs of all existing water resources within the study area.

2.5 Data Analysis Methods

The data collected was analyzed using Kobo Collect. Further descriptive data analysis was done through Microsoft Excel and Statistical Packages for Social Sciences (SPSS), while the GIS data analysis and modelling tools were put to use for location and mapping.

2.6 Data Presentation Methods

The analyzed data was presented in different forms; the qualitative data was presented in the form of descriptive-analytical reports. Data presentation forms such as maps, analytical lines, bar graphs, pie charts, measures of the central location, photographs, figures, and tables were also used.

3. Results and discussions

3.1 Findings on analysis of existing water supply vis-a-vis water demand in Mua Hill settlement.

3.1.1 Residents perspectives on water shortages and their adopted options for remedy

In addition to the preceding discussion on observed structural and institutional failures that resulted in water deficiency, the residents provided alternative insights to this challenge. They volunteered several reasons which in their understanding caused the water shortages that they experienced. These are listed in the table here below:

Table 2: Reasons for water shortages & available mitigation measures

Reasons for water shortages	**Number of affirmative responses**	**surviving water shortages**	**Number of affirmative responses**
Dry seasons	5	Alternating with dam water	1
Dry seasons	1	Buy tanks	1
Drying up of the waters	1	Buy water from clean waters	1
Drying up of Wells	1	Buying	1
Due to dry seasons	1	Buying tanks	1
Lack of a good source of water	1	Buying the water	1
Lack of good sources of water	1	Buying water	1
Lack of good supply	1	Buying water tanks	6
Lack of rain and water shortage in boreholes	1	By use of pipe	1
Lack of rainfall	33	Go for it wherever it's found	1
Lack of rains	1	Minimize usage of the available water	1
Lack of water sources	3	Minimize water usage	9
Lack of where to get water	1	No	1
Lack where one can access water	1	Purchase	1
Low rainfall	1	Purchase the water	1
Low rainfall amounts	6	Purchase water	8
No	1	Purchasing	1
Poor access	5	Purchasing	29
Poor supply	1	Purchasing water	1
Shortage of water in the sources	1	Rain	1
Shortages in the water sources	1	Usually buy water from clean waters	1

Reasons for water shortages	**Number of affirmative responses**	**surviving water shortages**	**Number of affirmative responses**
Tank	2	Waiting until night so as to have water from the well	1
Total responses	**22**	**Total responses**	**22**

Source: Author[1] 2024

Table 3: Basic statistics of what residents think causes water shortages & alternative sources of water that residents pursue when confronted by water shortages.

Statistics		RFWS	ASW
Valid	22	22	
Missing	0	0	
Mode		1.00	1.00
Range		32.00	28.00
Minimum		1.00	1.00
Maximum		33.00	29.00

Source: Author[1] 2024

Table 4: What residents think causes water shortages.

Reasons for Water Shortages (RFWS) in the opinion of residents					
		Frequency	**Percent**	**Valid Percent**	**Cumulative Percent**
Valid	1.00	16	72.7	72.7	72.7
	2.00	1	4.5	4.5	77.3
	3.00	1	4.5	4.5	81.8
	5.00	2	9.1	9.1	90.9
	6.00	1	4.5	4.5	95.5
	33.00	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Source: Author[1] 2024

The dominant reason for water shortage though representing only 4.5% of the options available, is lack of rainfall with 47% of the residents affirming it as a cause of the low of water supply. Other reasons even though together constituting 95.5% of the options mentioned, basically only resonate mainly with 1% and on three occasions by 4%, 7% and 8% of the residents.

Table 5: Alternative sources that residents pursue when confronted by water shortages.

Alternative Sources of Water (ASW) Sought by residents when faced with water shortages					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	18	81.8	81.8	81.8
	6.00	1	4.5	4.5	86.4
	8.00	1	4.5	4.5	90.9
	9.00	1	4.5	4.5	95.5
	29.00	1	4.5	4.5	100.0
	Total	22	100.0	100.0	

Source: Author[1] 2024

On the other hand, the dominant survival strategy adopted by residents to assuage water shortages was purchasing of water. This was popular with 41% of the residents even though constituting a meagre 4.5% of the options on hand. Other approaches constituting 95.5% of the options, were practiced on most occasions by 1% of the residents and in two instances by 8% and 13% of the residents.

Table 6: Correlation between reasons for water shortage and alternative water sources.

Power Analysis Table					
	Power[b]	Test Assumptions			
		N	Null	Alternative	Sig.
Pearson Correlation[a]	1.000	22	0	1	.01
a. Two-sided test.					
b. Based on Fisher's z-transformation and normal approximation with bias adjustment.					

Source: Author[1] 2024

There is a perfect positive correlation at an alpha error level of 0.01, between residents choices of reasons that explain water shortages and the alternative sources they choose thereafter. This suggests that perception of causes of water shortage and the search for most available alternative sources emerge from a common knowledge pool and that one informs the other. Residents in the community tend to think together or influence each other considerably.

3.1.2 Water supply

The field data collected showed that the majority of the residents relied on harvesting rainwater and storing it in plastic or concrete tanks. During dry seasons, they supplemented that with borehole water and also drew water from the river. Only nine respondents had piped water; the connection was from the available boreholes.

Table 7: Water supply in Mua

Primary water source	Number of respondents relying on each type of primary water source	Percentage distribution
Borehole	37	**36%**
Piped water	9	**9%**
Rainwater harvesting	71	**70%**
River	20	**20%**
Grand Total	**102**	

Source: Author[1] 2024

Although the rivers in the study area were sources of water supply, most were seasonal and thus unreliable throughout the year. They failed to supplement of rain water harvesting. This lead to waters shortages in the dry spells.

Figure 5: Seasonal River in Mua hill settlement. Source: Author[1] 2024.

The field observation showed three boreholes in the Kyanda sub-location and 2 in the Kyaani sub-location. During the colonial era, a well-established water supply system comprised boreholes, water UPVC rising mains, storage tanks, and distribution pipes. The storage tanks at the Mua Hill sub-location were constructed up the hill. Thus, water from the boreholes would be pumped up the hill to the storage tanks and distributed to residents via gravity.

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Figure 6: Water storage tank at Mua Hills. Source: Author[1] 2024.

However, the water system had been vandalized, leading to water shortage in the area. This occurred due to a lack of proper management of the water sources. The water pipes were vandalized too around 2013 when roads were being expanded. One of the colonial boreholes at Makyau was still non-functional, though there still was water in it. The county government refurbished the other boreholes, but connections to the storage tanks and distribution lines had not been laid. Financially able residents nevertheless had made connections to their homesteads.

Figure 7: A vandalized water pipe in a Mua Hill settlement. Source: Author[1] 2024.

Two dams were dug during the colonial era at Makyau, but only one was renovated by the County government, and solar panels installed to pump the water. Plans were still underway to connect the water to the storage tanks and distribute it to the locals.

Figure 8: Borehole at Makyau, Mua hill settlement. Source: Author[1] 2024.

Figure 9: The non-functional colonial era borehole at Makyau, Mua hill settlement. Source: Author[1] 202.4

In addition to the two dams, the Athi Waterworks Development Agency drilled another borehole, but this turned out to be salty. A water distribution point was constructed since no connections were provided to the neighbouring homes. From the interview with the MACHWASCO manager, the data for the capacity of the colonial boreholes was missing, but for the Tanathi,. He shared that the borehole was equipped with a moderately low flow pump set of an 8.0m^3/hr capacity with the following pumping head components:-

- Dynamic Head – 77.62m
- Static Lift - 10.0m
- Tank elevation - 15.0m
- Friction head loss - 12.38m

Assuming the borehole worked 12 hours a day, it supplied 60m^3/day. Considering the renovated colonial borehole worked at the same rate, the supply from the two boreholes was 120 m^3/day. This fell short of the declared daily water demand or need level.

Figure 10: Borehole by Athi Waterworks Development Agency at Makyau. Source: Author[1] 2024.

The county government renovated the colonial dam at the Kyaani sub-location. In addition, the County government of Machakos drilled an additional borehole in 2021. Some residents had managed to have connections to their homesteads, while the majority continued to suffer shortages as they were still waiting for the County government to provide water connections. The MACHWASCO manager shared the following details about the Miwongoni dam constructed in 2021 by the County government: The borehole was equipped with a moderately low flow pump set of an 8.0m^3/hr capacity with the following pumping head components:-

- Dynamic Head – 92.51m
- Static Lift - 7.0m
- Tank elevation - 15.0m
- Friction head loss - 10.0m

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Thus, these two boreholes, like the other two at Makyau, could also supply 120m^3/day (120,000 Litres/day). The supply was therefore still deficient when matched with the daily water demand level.

Figure 11: Borehole by County Government at Kyaani sub-location. Source: Author[1] 2024.

During the field survey, it was also noted that there were a number of private boreholes within the Mua Hill settlement. This was a common trend among current immigrants, who preferred to drill their own boreholes for construction purposes. The larger public still remained unsupported in this regard. In conclusion, only four public boreholes were functional within the Mua Hill settlement. The total water supply from all the public boreholes within the area came to an insufficient 240m^3/day (240,000 Litres/day), assuming they functioned 12 hours a day. Twenty-six respondents indicated they travelled 2km to access water sources, and while 13 obtained water 5km away from their homes. The average distance walked in search of water was 7.2km.

This showed that the available water resources were not evenly distributed, affirming the existing profile of water scarcity or deficiency. A water supply system needed to be established to cater for those who are far away from the water sources.

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Table 8: Distance to water sources.

Distance to the water source in KM	Number of respondents at set distances to the water source	Percentage distribution
0.1	4	4%
0.2	1	1%
0.5	6	6%
1	17	17%
1.5	4	4%
2	26	26%
2.5	1	1%
3	10	10%
3.5	1	1%
4	2	2%
5	13	13%
6	1	1%
Grand Total	**101**	100%

Source: Author[1] 2024

Despite the effort to supply water in the area, 69% of the respondents indicated that they experienced a water shortage. It was clear that the water supply was already below the demand level.

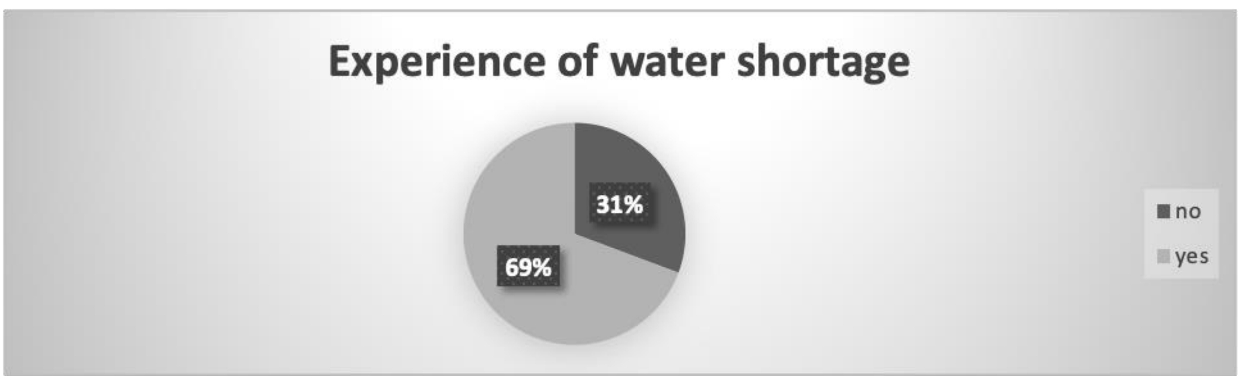

Figure 12: Water shortage in Mua. Source: Author[1] 2024.

Apart from water shortage and long distances to the water sources, 37% of the respondents indicated that the water sources were unreliable, attributing this to a failure of water resource management. The issues of hard water were specifically related to the Tanathi borehole at Makyau in the Kyanda sub-location. Such water needed to be treated. These challenges reinforced the prevailing status of water deficiency.

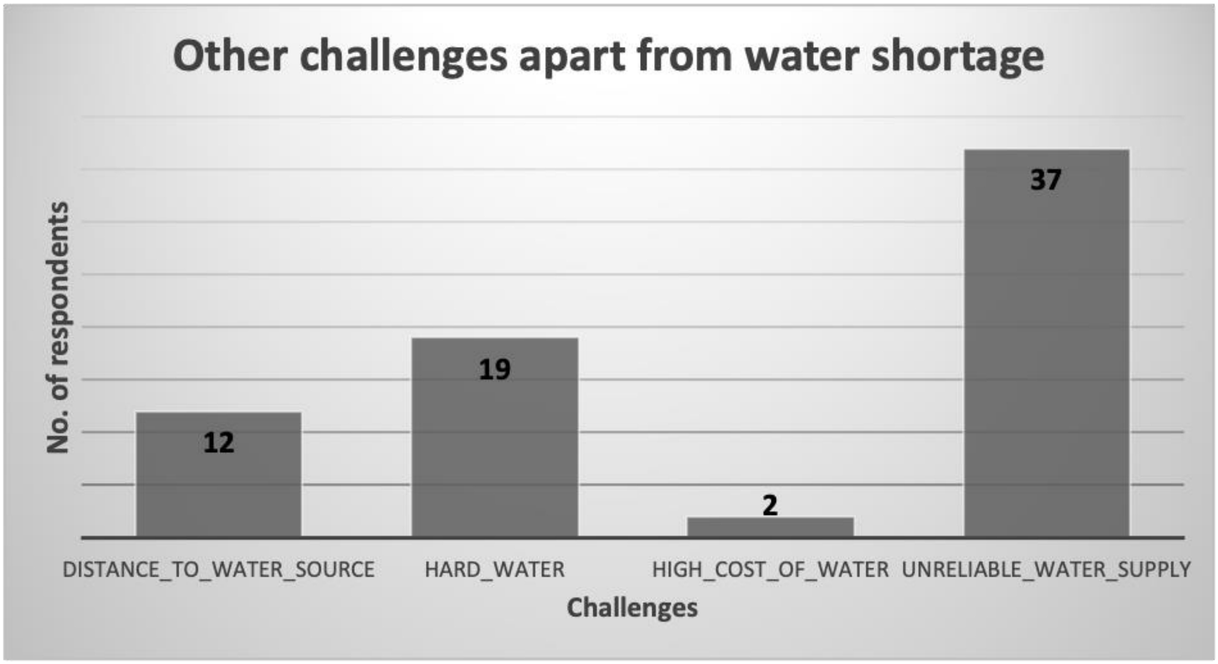

Figure 13: Analysis of challenges. Source: Author[1] 2024.

On a positive note, 87% of the respondents shared that the water was safe for human consumption. The 13% negated that because of the salty borehole at Makyau. Thus, there was a need to tap into the available water sources when and where it was safe.

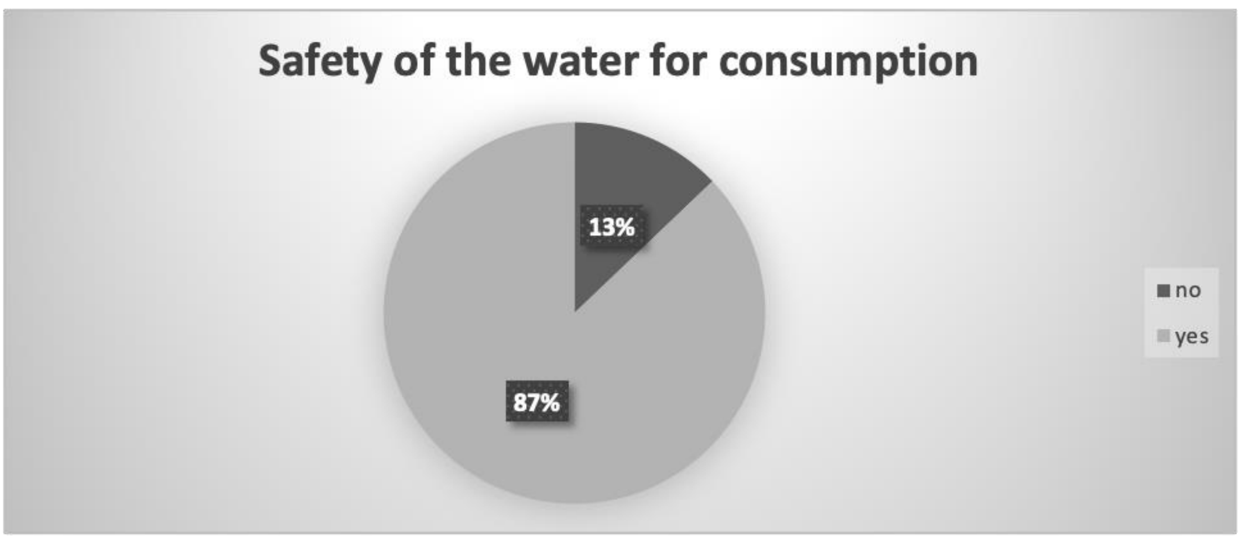

Figure 14: Safety of the water for consumption. Source: Author[1] 2024.

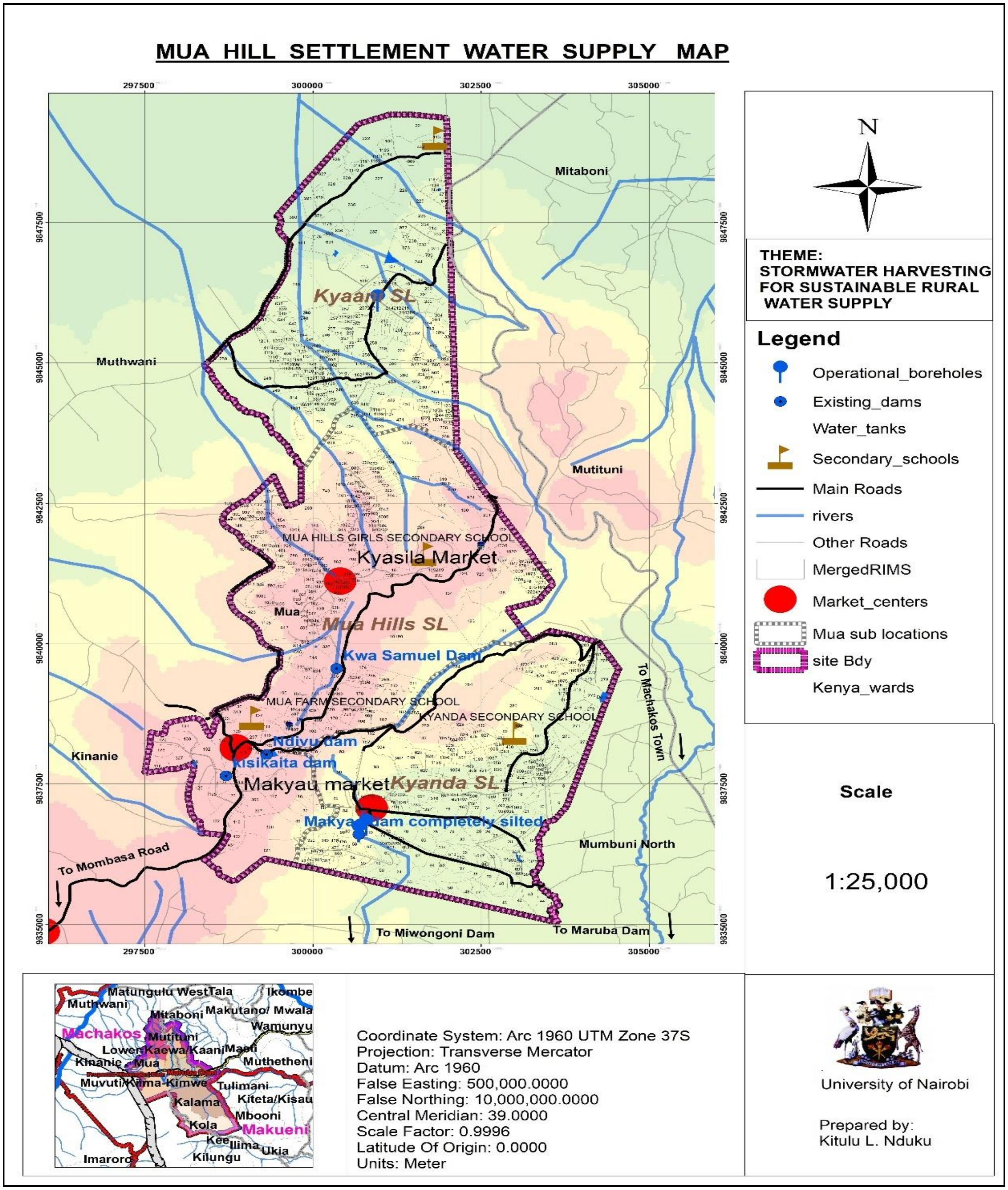

Figure 15: Water supply map. Source: Author[1] 2024.

3.1.3 Water demand

The field survey revealed that water was commonly soled at a cost of 10 shillings for every 20 liters. Further, 45% of the households indicated using 51 – 100 liters a day.

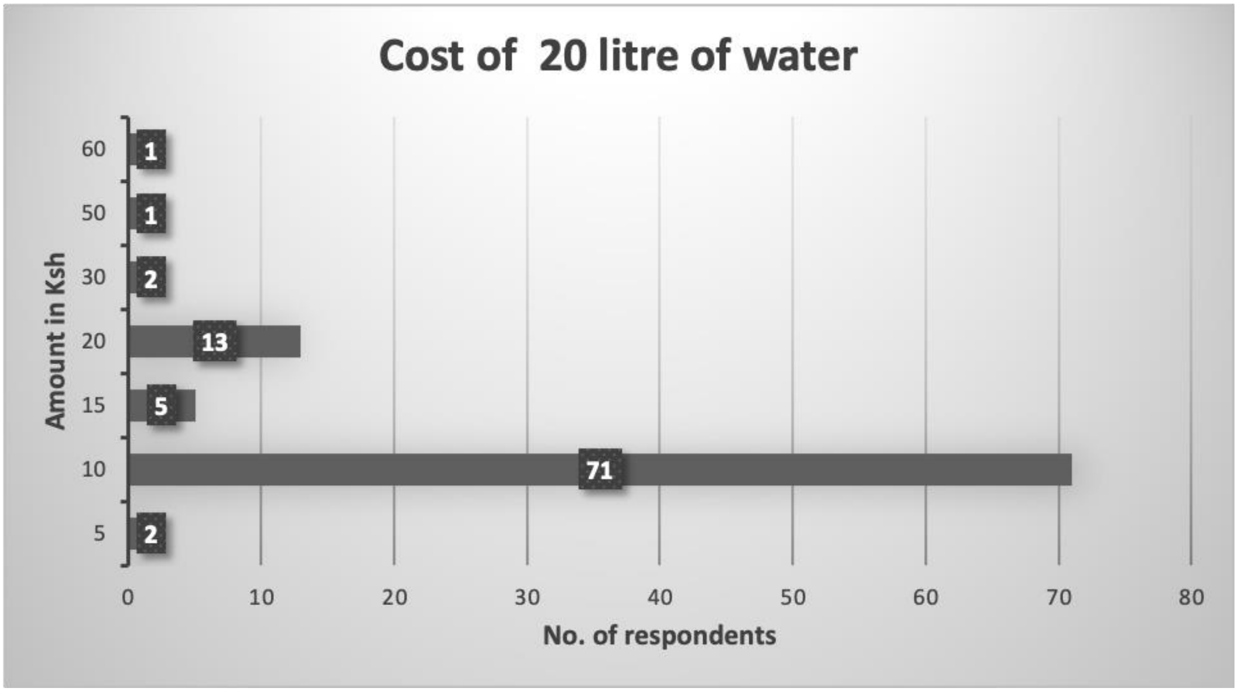

Figure 16: Cost of 20 liters of water in Mua Hill settlement. Source: Author[1] 2024.

Table 9: Amount of water used per day.

Amount of water used per day	Number of households using a set amount of water per day	Percentage distribution
Less than 50 litres	26	26%
51 – 100 litres	45	45%
101 – 150 litres	11	11%
151 – 200 litres	11	11%
201 – 250 litres	2	2%
251 – 300 litres	5	5%
Over 300 litres	1	1%
Grand Total	**101**	100%

Source: Author[1] 2024.

Taking the range 51 – 100 liters a day mode as a mean value, it can be derived that the average consumption level was 75 liters a day per household. The national census report of 2019

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indicated that the average household size is 3. Thus, water demand for the Mua Hills Settlement that included the three locations of Kyaani, Kyanda and Mua Hills, can be projected as follows:

Table 10: 2019 water demand.

Sub-Location	Year 2019 Ppln	Number of households	Daily water demand in litres	Average daily household demand in litres
Kyaani	1,756	586	43,950	75
Kyanda	2,977	993	74,475	75
Mua Hills	4,072	1358	101,850	75
Total	**8,805**	**2937**	220,275	75

Source: Author[1] 2024

Table 11: 2024 water demand.

Sub-Location	Year 2024 Ppln	Number of households	Daily water demand in litres	Average daily household demand in litres
Kyaani	1,983	661	49,575	75
Kyanda	3,363	1121	84,075	75
Mua Hills	4,600	1534	115,050	75
Total	**9,946**	**3316**	**248,700**	75

Source: Author[1] 2024

Table 12: 2029 projected water demand

Sub-Location	Year 2029 Ppln	Number of households	Daily water demand in litres	Average daily household demand in litres
Kyaani	2,241	747	56,025	75
Kyanda	3,800	1267	95,025	75
Mua Hills	5,197	1733	129,975	75
Total	**11,238**	**3,747**	**281,025**	75

Source: Author[1] 2024

Table 13: 2034 Water demand projection.

Sub-Location	Year 2034 Ppln	Number of households	Daily water demand in litres	Average daily household demand in litres
Kyaani	2597	866	64,950	75
Kyanda	4405	1468	110,100	75
Mua Hills	6024	2008	150,600	75
Total	**13,026**	**4,342**	**325,650**	75

Source: Author[1] 2024

In addition to these water demand levels of the population at the Mua hill settlement is the population of Machakos town. This is because Mua Hill is the catchment of the new dam, Miwongoni Dam, which was under construction to supply water to Machakos town. Initially, the Maruba dam, constructed in the 1950s, provided adequate water to Machakos town. The catchment for the Maruba dam is Iveti Hills, a gazetted forest. However, activities upstream, such as uncontrolled agricultural practices, had led to the siltation of the Maruba dam. Thus, it is gratifying that the National government rehabilitated the Maruba dam in 2010. This still is a temporary solution as the land used upstream in the catchment area still needs redress.

After rehabilitation in 2010, the Maruba dam was able to meet the water demand for the town. However, this was short-lived, given the rapid population growth in the city. Therefore, the County government of Machakos resolved to have a second rehabilitation and augmentation project from 2019 to December 2024. The second rehabilitation project entailed the construction of another dam, the Miwongoni Dam because desilting the initial dam was found to be more expensive than the construction of a new dam. It was expected to raise the water supply to 17,500m^3/day. The MACHWASCO technical manager indicated that the total water demand for the town as of January 2024 was 25,000m^3/day. This water demand can be projected as follows:

Table 14: Projected water demand and population growth trends for Machakos town.

Machakos town population	
Year	2024
Total Population	220, 061
Water demand	25,000 m^3/day
Year	2029
Population	255,111
Water demand	28,982 m^3/day
Year	2034
Population	295,743
Water demand	33,598 m^3/day

Source: Author[1] 2024

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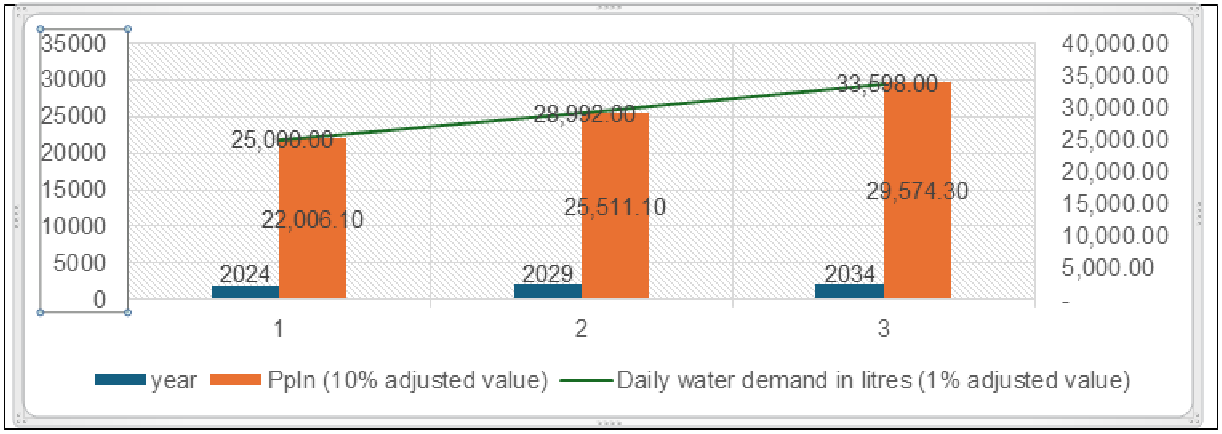

Figure17: Projected water demand and population growth trends for Machakos town.

The is corresponding total water demand is as calculated here below:

Table 15: Projected Water demand and population growth for Machakos town.

Year	Mua Hill settlement Population	Mua Hill settlement water demand	Machakos town Population	Machakos town water demand	Total water demand
2024	9,946	248.7 m^3/day	220, 061	25,000 m^3/day	25, 249.7 m^3/day
2029	11,238	281.025 m^3/day	255,111	28,982 m^3/day	29,263 m^3/day
2034	13,026	325.65 m^3/day	295,743	33,598 m^3/day	33,923.7 m^3/day

Source: Author[1] 2024.

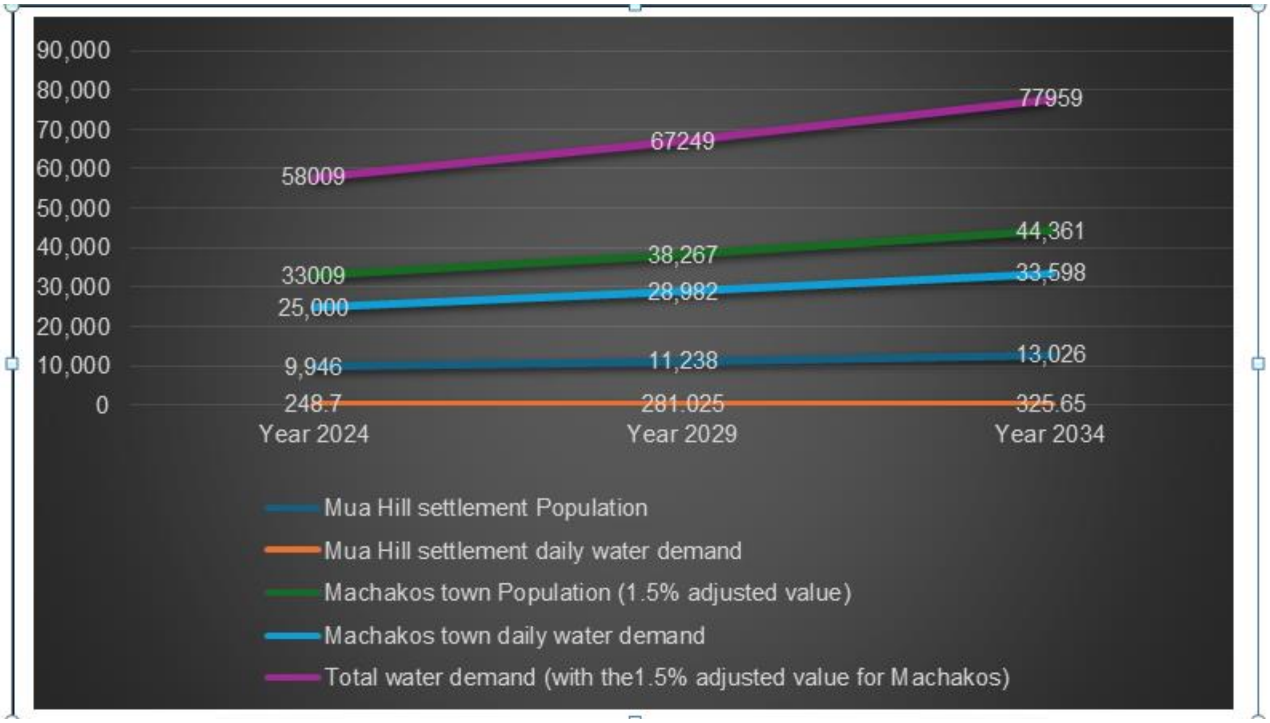

Figure 18: Projected Water demand and population growth for Machakos town. Source: Author[1] 2024

The waters supply deficit at the Mua Hills settlement alone assumes the following form:

Table 16: Changing water deficit levels at the Mua Hills settlement (water demand and supply balance).

Year	**Water demand**	**Water supply**	**Deficit**
2024	248.7 m^3/day	240m^3/day	**8.7m^3/day**
2029	281.025 m^3/day	240m^3/day	**41.025 m^3/day**
2034	325.65 m^3/day	240m^3/day	**85.65 m^3/day**

Source: Author[1] 2024.

Even with the construction of the new dam, Machakos town would still have a deficit because the expected water supply by the end of 2024 will be 17,500m^3//day as opposed to a water demand level of 25,000m^3//day.

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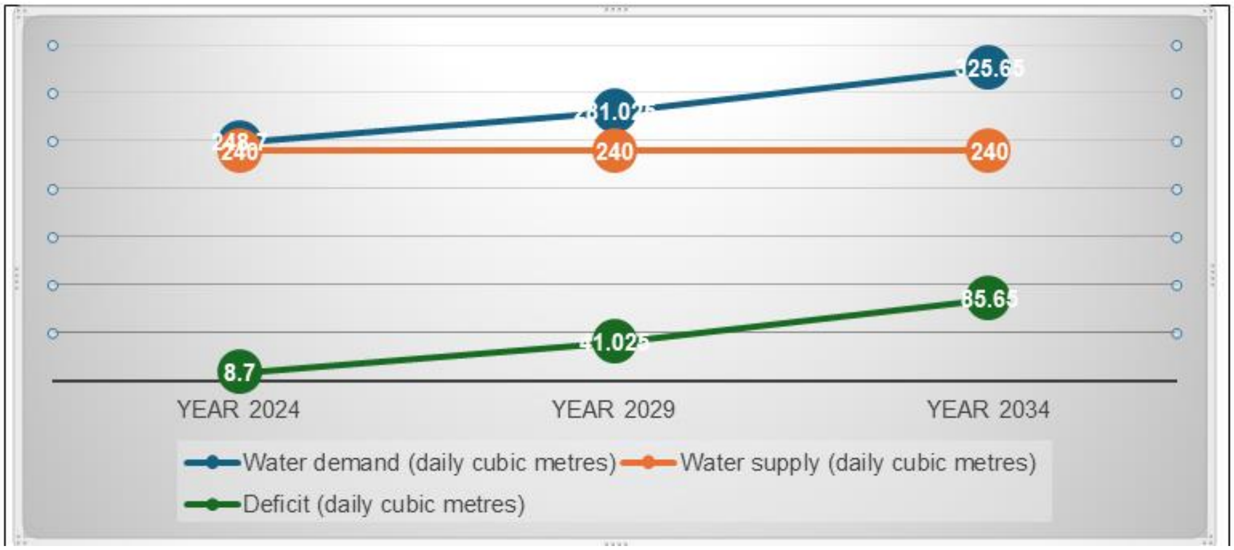

Figure 19: Projected water deficit levels at the Mua Hills Settlement (water demand and supply balance). Source: Author[1] 2024.

In conclusion, the study agrees with Water for Prosperity and Peace, 2024; Future Global Urban Water Scarcity and Potential Solutions, 2021; Sophocleous (2004) and An et al. (2021). These studies aver that population growth, economic expansion, technological advancements, land use and urbanization, environmental degradation rates, government initiatives, and climate change affect water demand in an area. As shown in the calculations, the population of the Mua Hills settlement has been growing rapidly. This has led to a lot of conversion of agricultural lands to residential use. It has also resulted in the cutting down of trees to provide timber for construction. The the lack of government initiatives to implement or repair the initial water system treat water has further exacerbated the challenge of water shortfalls. It has failed to improve pumping capacity and provide sufficient water reticulation, leaving a majority of residents with no water connect residents. Residents continue to travel long distances in search of water.

Conservation and restoration of the Mua hills will be critical for the people within it and Machakos town. There were untapped stormwater harvesting mechanisms that could be used to increase water supply in the area, especially for other uses such as agricultural livestock and construction. These though were not considered during the calculation of the water deficit. There is a compelling need to tap into the available water resources, maximize their use, and conserve the hill. This would maximise water is harnessing at the Miwongoni dam for supply to the Machakos town and even the lower parts of the Mua ward.

4. Conclusions

Like other rural and urban areas, the Mua Hills settlement had a water demand that surpassed the water supply. This state manifested itself increasingly over time when the population kept growing while no specific measures were taken to ensure the available resources like water were still sufficient. In most societies, the supply of such utilities remains constant, while the sources get polluted, thus leading to a deficiency. For any rural area, just as in urban areas, it is necessary to take note of the implications of economic expansion, technological advancements, land use and urbanization, environmental degradation rates, government initiatives, and climate change on water demand and supply in an area.

5. Recommendations

The study recommended that periodic mapping, monitoring and evaluation of water projects in relation to population, land use, water regimes dynamics be done after every 3 – 5 years. This would help to ensure that water supply was upgraded to match increasing water demand. Where need be, proper management and conservation of catchment areas for water sources would need to be done well.

5.1 Implications to planning theory.

The water supply deficit in the Mua Hills settlement impacts planning theory decisively. It calls for well thought out sustainable resource management that is informed by integrated urban planning of the catchment area. This management must necessarily be anchored in the participatory inclusion of the community. It must promote a balanced view of the tripolar elements, society, economy and environment, of sustainability and contemporary practices of climate action.

5.2 Implications to practice/ additional knowledge to the discipline

Water supply deficits can lead to considerable social challenges of health and sanitation. It hampers productive activity of a society. This results in weakening economies, and eroded self-reliance of communities. In such a setting rising poverty, lack of food sufficiency and social strife on account of scarcity of resources and unequal access to opportunities are real possibilities. The ensuing desperation will easily compromise conservation in land use practices in exchange for overuse of any resources available. In such circumstances, sustainable use of the environmental comes under considerable risk.

5.3 Implications to policy

All policy that seeks to address the observed water supply deficit must necessarily be geared towards remedy of the primary challenges of a rapid population growth that consistently increases demand. Aging infrastructure, that results in rising inefficiencies and reducing capacities as well as performance also needs attention. Finally, there is the compromised water quality that is occasioned by water catchment areas being encroached by agriculture and other forms of human settlements. . Such inimical land use developments result in the inevitable siltation and pollution of water flows. This should also be addressed.

A thorough upgrade of requisite water supply and storage infrastructure is urgently essential. Further, it is necessary to adopt policies that promote sustainable water management practices such as rainwater harvesting. Rehabilitation of water catchments is another front worth attention. Adoption of agricultural practices that contain soil erosion and siltation would also add much value. Community empowerment is also of value. It takes the form of awareness promotion, effective accountable delegation, inclusion in decision making and participation in regulatory matters of development. This provides a favourable premises for responsible settlement patterns and water management. Education on conservation and sensitive, sustainable land use creates more resilience in the water catchments. It carries a potential to stabilize supply levels. There is therefore a need to come up with a policy on water catchment management and a rural land use policy to guide and regulate land uses in the catchment area of Mua hills.

5.4 Implication to academia/ suggestions for future research

Issues related to water resource management, environmental sustainability, and public health come into sharp focus here as being needy of more inquiry. Accordingly, the prevailing water sources, and infrastructure for water treatment, storage and conveyancing invite a closer examination of their resilience, capacities and performance. This is particularly important in the face of growing populations, transforming settlement patterns and therefore land uses as well as climate change. A deep dive into the broader consequences of water scarcity on the health and sanitation of resident populations, future land use patterns, and sustained economic activity, is also necessary. Social organisation, internal consultative mechanisms and inclinations for self-management as a critical pillar for effective catchment use is another area requiring to be probed further.

In summary, then, there is need for further research to be done on water catchment management and its general implication on rural and urban water supply systems. Analysis of human activities on water catchments and the role of governance and institutions in the conservation of water catchment areas also needs examination. Lastly, studying people’s perspectives on traditional water supply systems such as stormwater harvesting as opposed to modern water systems does need to be inquired into.

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