Water Sensitive Approach for a Resilient Urban Neighborhood:

The Case of Kotari Condominium.

By

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This is to certify that the thesis prepared by Feyisa Nebiyu Doboch entitled: Water sensitive approach for a Resilient Urban Neighborhood: The Case of Kotari Condominium and submitted in fulfillment of the requirement for the Degree of Master of Science in Architectural Engineering complies with the regulations of the university and meets the accepted standards for originality and quality.

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Declaration

I the undersigned, declare that this thesis is my original work and has not been presented for any degree or diploma in other institution or university and that all sources of material used for the thesis have been duly acknowledged, following the scientific guidelines of the Institute.

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Confirmation

I state that, Feyisa Nebiyu has carried out this research work on the topic "Water sensitive approach for a resilient urban neighborhood: The case of Kotari condominium" under my supervision, and it is sufficient for submission for the partial fulfillment for the degree of Master of Science in Architectural Engineering.

Supervisor: Tesfaye Hailu Bekele
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Abstract

This thesis addresses the critical issue of water shortages in rapidly urbanizing areas, specifically focusing on the Kotari Condominium in Addis Ababa Ethiopia, where residents face recurrent water supply challenges despite the area's ample surface and groundwater resources. The general objective of the research is to develop architectural and engineering solutions to enhance water resilience in urban neighborhoods. The methods involved a comprehensive analysis of water demand and supply chain infrastructure, assessment of current water resilience strategies, and identification of suitable approaches for both internal and external building spaces. The study also entailed designing a context-specific solution tailored to the unique needs of the Kotari Condominium neighborhood. Key findings from the research highlighted that significant deficiencies in the existing water supply system, including inadequate infrastructure, poor coordination among stakeholders, and the lack of effective water management practices. These issues resulted in persistent water shortages and heightened vulnerability to water-related risks. The proposed solutions focus on improving infrastructure through the adoption of advanced water-saving technologies, enhancing stakeholder coordination, and implementing integrated water management strategies that are both sustainable and resilient. Specific recommendations include upgrading the water supply network, incorporating rainwater harvesting systems, ground water extraction systems, and promoting water-efficient appliances and fixtures within buildings. The conclusions drawn from this study underscore the vital importance of sustainable and resilient water management practices in addressing urban water shortages. The research provides a model that can be adapted to similar contexts in other developing nations facing comparable challenges. By emphasizing the necessity of architectural and engineering interventions, the study offers valuable insights for policymakers, urban planners, and other stakeholders involved in urban water management. These findings contribute to the broader discourse on water resilience, highlighting the need for innovative solutions to ensure equitable access to safe and secure water and sanitation services in rapidly growing urban areas.

Keywords: *Water Resilience, Urban Water Management, Water Shortages, Sustainable Infrastructure, Architectural Engineering Solutions*

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List of Abbreviations and Acronyms

AAHDPO	Addis Ababa Housing Development Office
AAWSA	Addis Ababa Water and Sewerage Authority
CWRA	City Water Resilience Approach
GDP	Gross Domestic Product
MCM	Million Cubic Meters
SDG	Sustainable Development Goal
WASH	Water, Sanitation, and Hygiene
WC	Water closet
WR	Water Resilience
WHO	World Health Organization
UNICEF	United Nations International Children Emergency Fund
UN	United Nation
UNEP	United Nations Environment Program

Local names

- Kotaro Condominum, Hayile Garment Area, Nifas Silk Lafto SubCity, Addis Ababa.

Figure 0.1 : Google map Image, showing the Site Location and Local Names.

Chapter One: Introduction

1.1. Background of the Study

Easy access to clean water is fundamental for health, playing a vital role in everything from household activities like cooking and drinking to recreational activities. As per a World Health Organization news release dated July 12, 2017, more than 2.1 billion people worldwide lack access to clean and safe drinking water. Each year, 3.4 million individuals succumb to illnesses caused by inadequate and contaminated water sources. Many women and children dedicate 3-6 hours daily to fetching water from polluted and distant locations. This considerable time spent walking an average of 3.7 miles for clean water detracts from opportunities to earn income, fulfill familial responsibilities, or attend school. Notably, half of the world's hospital beds are typically occupied by patients afflicted with diseases linked to the absence of clean water access. (Mission – WHO Lives, July 12, 2017, news release).

Climate change and environmental shifts are increasingly influencing water resources and global water supply systems (Steffen et al., 2011; Ferguson et al., 2013; Rockström et al., 2014). Communities worldwide are encountering growing water security challenges, including more frequent floods and heightened pressure on eco-hydrological systems like rivers, wetlands, and groundwater. There is ample evidence indicating that traditional approaches to water resource management are inadequate in addressing unexpected events or uncertainties in the hydrological cycle (Huitema et al., 2009; Wong & Brown, 2009; Huntjens et al., 2012; Bell, 2015).

The majority of water systems globally lack resilience to increasing risks, particularly in the southern regions, resulting in the inability to provide essential services in many areas. Urban areas face significant challenges in achieving water resilience. Therefore, innovative approaches are necessary for urban water management. Developing water resilience is critical for addressing water-related issues and ensuring equitable access to safe and secure water and sanitation services for all. Additionally, it plays a crucial role in safeguarding communities from water-related risks. Decision-makers and stakeholders require the knowledge and capacity to make informed decisions and investments in their city's water sector (UN World Water, 2015).

Addis Ababa is currently undergoing significant social, ecological, and demographic shifts due to rapid urbanization, presenting numerous complexities and challenges. As the capital city of

Ethiopia, Addis Ababa attracts substantial migration from rural areas, resulting in a considerable increase in population. According to the 2013 national census, the city's population stood at 3,384,569, projected to reach 9.8 million by 2037, with an annual growth rate of 3.8% (CSA, 2013). This population surge creates pressing demands for employment, food security, potable water shortage, housing, and environmental protection. Housing, in particular, poses a longstanding challenge, requiring a substantial number of units to accommodate the growing population. In response, the Ethiopian government initiated a condominium-housing program in 2005, offering subsidized loans for the purchase of housing units to alleviate the housing shortage (AAHDPO, 2015).

Condominium housing refers to multistory mass housing tenure, where each household owns an individual unit but shares ownership and responsibility for communal open spaces and facilities. However, there is no individual ownership of the surrounding neighborhood land. A condominium association, comprising representatives from the residents, oversees the management of these communal areas (UN-HABITAT, 2011). The primary objective of the program was to construct cost- and time-efficient housing units for the urban poor. The program has made considerable progress in addressing the housing demand gap (AAHDPO, 2015). Over the past 19 years, numerous condominium neighborhoods have been developed across the city, with plans for further expansion in the future. However, the planning and design of indoor spaces and outdoor spaces of the condominium building lack the consideration of the Shortage of potable Water Supply the city is suffering from the program at the current time and needs more thoughtful strategies.

1.2. Problem Statement

Water scarcity is a prevalent issue in developing nations, often stemming from a confluence of factors such as drought, economic constraints, and social unrest. These factors significantly impede household access to adequate and dependable water supplies.

According to UNICEF (2022) reports a dire situation in Eastern Africa due to a combination of drought, instability, economic hardship, and conflict. Over 20 million people across Djibouti, Eritrea, Ethiopia, Kenya, and Somalia require urgent water and food assistance, including a staggering 10 million children. This represents a significant increase from 2021, with a 38% rise in the total number of people in need and an 88% jump in households facing water insecurity. The situation is particularly alarming for children. Compared to 2021, the first quarter of 2022 saw a concerning 37% increase in admissions for severely malnourished children in Ethiopia, Kenya, and Somalia. Furthermore, Ethiopia faces a distinct challenge due to its status as one of the African nations with the poorest access to clean water, sanitation, and hygiene facilities.

Despite Ethiopia having plenty of surface and groundwater resources, there are still shortages. Ethiopia has been experiencing rapid urbanization demanding the construction of apartments to create better living spaces. In this area, water demand has increased dramatically, however, like every building and service, the condominium houses are getting water supply from AAWSA. However, the inhabitants were facing a shortage of pure water redundantly. Thus, architectural Intervention is needed to make a deeper investigation and give the inhabitants the best-researched solution.

However, it requires context tailored ways of Engineering and architectural integration prototypes based on a genuine understanding of WR. Therefore, the aim of this research is to investigate sustainable infrastructure knowledge from the perspectives of both architecture and engineering. This study seeks to utilize this knowledge to devise architecturally integrated solutions tailored for condominium housing neighborhoods. And prepare an alternative solution for the selected case (Kotari Condominium Neighborhood) through the interplay between the theoretical, technical, and contextual perspectives which focused on neighborhood Water resilience through balancing the programmatic demands of the inhabitants. The water shortage was the major problem of the inhabitants which needs a solution immediately to ensure world SDG plans.

1.3. Objectives

2.3.1. General Objective

The general objective of this research is to identify Architectural and engineering solutions for water-resilient urban neighborhoods in Kotari Condominium.

2.3.2. Specific Objectives

1. To identify water demand and supply infrastructure around Kotari Condominium.
2. To evaluate appropriate water resilience approaches in and around the buildings
3. To develop a context-tailored water resilent strategies for the Kotari Condominium neighborhood.

1.4. Research Question

1. What are problems related to water demand and supply infrastructure around Kotari Condominium?
2. How is the water resilience approaches in and around the buildings Kotari Condominium?
3. How can technical and spatial strategies adopted into the Kotari condominium neighborhood?

1.5. Scope of the study

Thematically, the research centered on the resilience of urban water systems, especially at a neighborhood level using a tailor-made approach. Spatially the research was limited to the current jurisdiction boundary of Addis Ababa city Hailegarment Kotari Condominium. Moreover, temporally the research was conducted for 10 months from July 2023 to April 2024. Furthermore, the study spanned a duration of 10 months, commencing in July 2023 and concluding in April 2024.

1.6. Significance of the Study

This study played a significant role in resolving issues and optimizing the quality and quantity of resilient water management strategies within the selected case study.

1.7. Limitation of the Study

Lack of Accurate Hydro-logical Data: The absence of precise hydro-logical data for the Kotari condominium hindered the comprehensive analysis of water resources.Constraints on Underground Water and Rainwater Harvesting Integration Technical and financial limitations prevented the full integration and utilization of underground water and rainwater harvesting systems.Insufficient Historical Data: A lack of comprehensive and reliable historical hydro-logical data for the Kotari condominium limited the ability to establish long-term trends and patterns in water consumption, runoff, and infiltration.

Limited Access to Infrastructure: Restricted access to the condominium's infrastructure, including pipes, tanks, and meters, hindered detailed investigations and monitoring.

Transient Residency: The high turnover rate of tenants in the condominium limited the ability to establish long-term relationships with residents and obtain consistent information about water usage patterns and preferences. Limited Resident Availability: The unavailability of many residents during daytime hours hindered the conduct of in-depth interviews and on-site investigations, restricting the collection of firsthand information.

Chapter Two: Literature Review

2.1. Resilience

Before the 19th century, resilience was a natural part of traditional construction methods, shown through practices like making components bigger, having backups, and keeping parts separate, all of which made buildings stronger.(Hassler & Kohler, 2014).

Resilience can be understood in various ways, but fundamentally, it means being able to handle and bounce back from challenges and risks by responding, adapting, and growing.

Resilience has experienced significant growth in recent years, emerging as a central concept in international policy and academic dialogues concerning civil contingencies and crisis management. With governments and institutions facing a range of challenges including environmental hazards, technological accidents, climate change, and terrorist attacks, there's a growing acknowledgment of resilience as a critical policy approach. (Coaffee et al., 2018)

Research and literature pertaining to resilience in planning frequently concentrate on environmental mitigation and adaptation, with a particular emphasis on managing land use. This approach aims to alleviate present stressors and mitigate the likelihood of future disturbances. The concept of resilience has also been helpful in bringing disaster preparedness and climate change adaptation together. It focuses on making systems stronger in the face of dangers, instead of trying to stop the dangers from happening altogether. (Pilar Avello et al., 2019). Resilience has become a big deal in the last 40 years, popping up in discussions about sustainable development, climate change, and governance. It's all about building systems that can handle unexpected challenges and keep going strong. Whether it's in making policies or dealing with climate issues, resilience reminds us to plan for the unexpected and adapt to change. (Siavash, 2017).

A resilient city withstands shocks and adapts to change while maintaining its core functions and identity. To achieve resilience, cities must assess risks, reduce vulnerability, and enhance readiness for emergencies.

2.2. Water Resilience

Resilience, a concept spanning various disciplines, is particularly relevant in the context of water systems. Water resilience refers to a system's capacity to navigate and respond to stress, shocks, and unpredictable future conditions. (Ciprian et al., 2019)

According to the Stockholm International Water Institute, building water resilience is essential for solving local water challenges and ensuring safe, reliable water and sanitation services for everyone. It also helps protect communities and infrastructure from water-related risks.

To make water systems stronger, new efforts should fix any overlaps or gaps among stakeholders. This means working together across different areas and being ready for different problems. It also involves dealing with issues like unclear policies, coordination problems, and funding shortages that can affect how water resources are managed. (Pilar Avello et al., 2019)

2.3. Water Source

Water covers about two-thirds of the Earth's surface. It's crucial for agriculture, industry, homes, recreation, and the environment. Most of Earth's water—over 97%—is salty, leaving only 3% as freshwater. Of that, around two-thirds is frozen in glaciers and polar ice caps. The rest of the freshwater is mainly underground, with only a tiny bit above ground or in the air. (Tortajada & Araral, 2021)

In Ethiopia, rivers, streams, lakes, and ponds serve as crucial water sources, particularly in rural regions. The quantity of surface water accessible greatly relies on rainfall. During periods of low rainfall, the availability of surface water fluctuates significantly between wet and dry seasons, as well as from year to year.

When considering the total water on Earth, it amounts to roughly 1400 million km3. Out of this, approximately 97.5% by volume exists in the oceans as saltwater. Only about 2.5%, which equates to around 35 million km3, is freshwater.. (UNEP, 2002). We can see the hydrology water cycle in Figure 1 below.

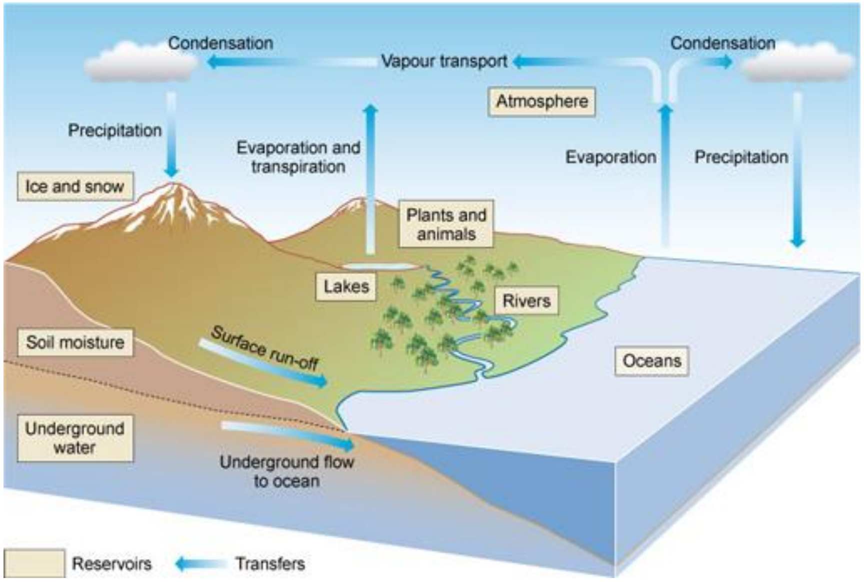


Figure 0.2 Hydrological water cycle source: www.open.edu

2.3.1. Underground Water Source

Groundwater, the second-largest freshwater source, primarily resides in underground pore spaces and defined channels, such as those found in karst formations resulting from the dissolution of rocks like limestone (Li, 2016).

The latest UN World Water Development Report focused on groundwater this year. It revealed that merely 3% of agricultural land in sub-Saharan Africa is outfitted for irrigation, with only 5% of that utilizing groundwater, despite its often plentiful presence in the region. (UN World Water Development Report, 2022).

Two significant studies have highlighted that groundwater, present underground in aquifers, rocks, and soils, constitutes approximately 99% of all liquid freshwater on Earth and is plentiful across much of Africa. However, a lack of investment has led to its underutilization or inadequate management. These reserves hold the potential for irrigation and providing clean and safe water. Yet, there's also a risk of rapid depletion or pollution if they're exploited unsustainably.

Experts from the British Geological Survey and University College London (UCL) have conducted comprehensive mapping to assess the quantity and potential yield of groundwater resources throughout the African continent.(referred to in Figure 2 below).

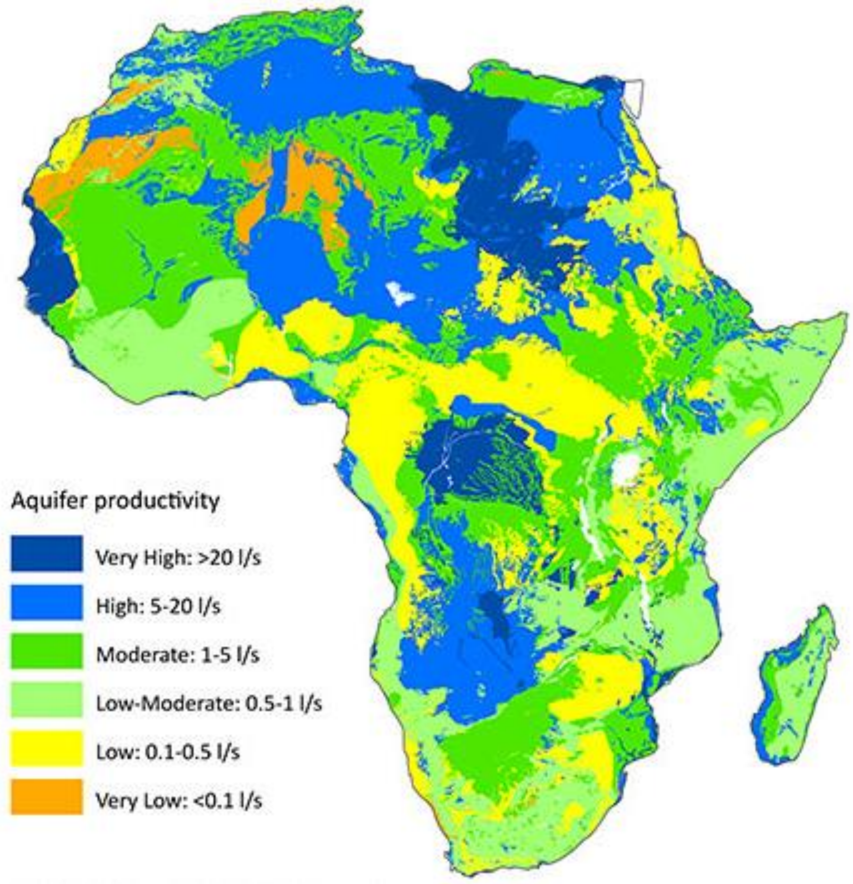


Figure 0.3: Illustrates the potential groundwater yield across Africa, sourced from Environmental Research Letters.

As shown in figure 2.2. Ethiopia has a moderate underwater productivity rate generating up to 5 liters per second in most areas, especially following the Great Rift Valley basin. Ethiopian groundwater potential ranges from 2.6 to 1000 billion cubic meters. (Berhanu et al., 2014). Ethiopian groundwater potential can be seen in Figure 3 below

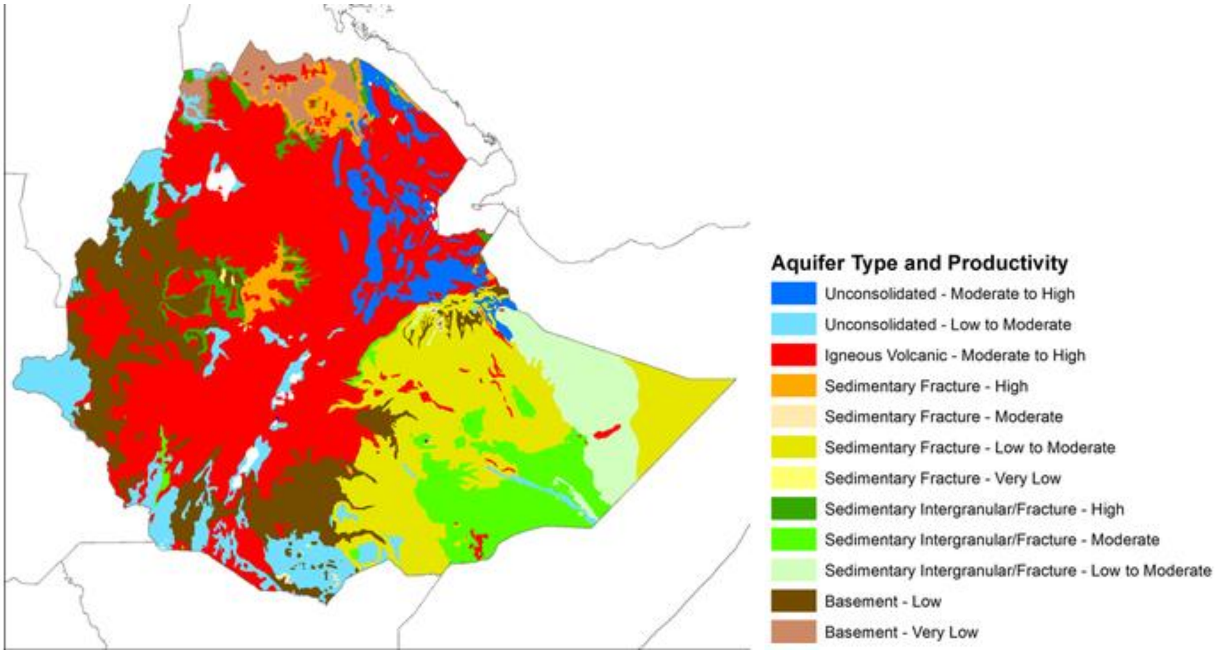


Figure 0.4: Ethiopian Hydrology map, Source: British Geological Survey

2.3.2. Rainwater Harvesting

Water harvesting is a widely recognized practice globally, especially on large institutional plots, primarily for two key benefits. Firstly, it helps bridge the gap in water demand caused by scarcity, covering outdoor water needs and reducing costs associated with municipal water supply. Secondly, by capturing rainwater on-site, it mitigates runoff generated by development. Germany, Singapore, and Japan are noted for their exemplary implementation of large-scale institutional plot rainwater harvesting.

Table 0.1 Rainwater harvest practice in Germany, Singapore, and Tokyo-Japan

No	Country	Type Of Institutional	Type Of Rain Water Harvest S	Catchment Area In M^2	Harvest In M^3/ Yr.	Use of Water Harvest	Source
1	Frankfurt	Airport	Active	26,800	100, 000	• Cleaning The Air Conditioning	(Un-Habitat, 2011).
2	German	University Of Darmstadt	Active Rainwater Harvest S	-	80,000	• Toilets Flushing • Cooking And Cleaning In Laboratories	(Un-Habitat, 2011).
3.	Berlin	Daimlerchrysler Potsdamer Platz	Arain Water Harvest S	32,000	3500	• Toilet Flushing, • Garden Watering	(Un-Habitat, 2011).

						• Recharging Of Ponds	
4	German (Berlin)	Belss-Luedecke-Strasse Building	Arain Water Harvest S Prain Water Harvest S	7,000 4,200	2,430	• Toilet Flushing • Garden Watering	(Un-Habitat, 2011).
5	Singapore	High Rise Buildings	Arain Water Harvest S			• Toilets Flushing, • Watering The Plants	(Unep, 2017)
6	Changi	Changi Airport	Prain Water Harvest S	8,400 M	28-33% Its Demand	• Fire-Fighting Drills • Toilet Flushing	(Unep, 2017)
7.	Tokyo, Japan	Sumo-Wrestling Arena And Sumida City Hall	Arws	8,400	1,000	• Toilet Flushing And Air Conditioning System.	(Unep, 2017)

2.3.3. Piped Municipal Water Supply

The conveyance of water from its source to the point of use with minimal losses is termed as water supply. A functional water supply system ensures a consistent, understandable, safe, and dependable provision of water. The delivered water must adhere to predetermined standards of quality and quantity. Therefore, an effective water supply system should possess the following attributes: it must fulfill various demands such as domestic, industrial, commercial, and public needs; it should maintain adequate pressure during continuous usage; it ought to transport treated water to consumers with a specified level of purity; it must be capable of providing sufficient water for emergencies like firefighting; it should prioritize reliability and safeguard against potential contamination; and the system should operate efficiently with minimal losses (Vargas & Alexander, 2011).

2.4. Urban Water Supply

Urban water supply systems face mounting challenges due to population growth, economic development, shifts in lifestyle, and urbanization. Climate change exacerbates these challenges by worsening water scarcity and deteriorating water quality. Developing and underdeveloped countries are particularly disadvantaged, grappling with limited resources, rapid population expansion, low GDP, polluting industries, inadequate institutional response, and flawed planning and management practices.

The water supply system plays a crucial role in delivering safe drinking water for consumption, aiming to provide the necessary quantity and quality. Water quality primarily hinges on how water is treated during distribution, as illustrated in Figure 4 below. The most pressing concerns regarding water distribution include assessing public health risks stemming from poor water quality and gauging the effectiveness of existing technologies and policies. Therefore, traditional methods of water conservation and restoration represent a collective body of information, knowledge, practices, and symbols passed down and developed by societies with long-standing histories of sustainable interaction with the natural environment.

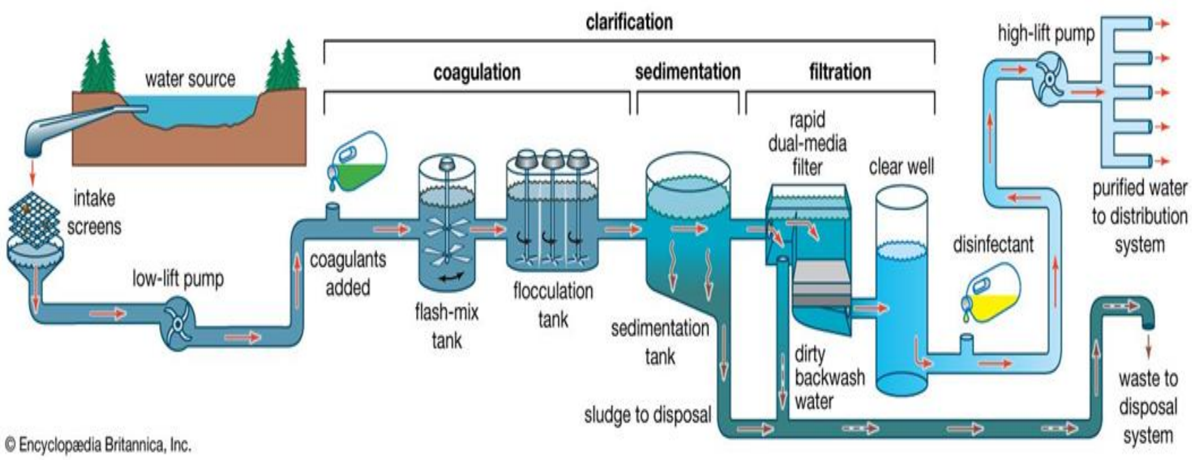


Figure 0.5: Water treatment process Source: Encyclopedia Britanie. Inc.

2.5. Gray water treatment method

Grey water comprises wastewater from sources such as bathtubs, showers, hand basins, kitchen sinks, dishwashers, and laundry machines, while black water originates from toilets (Eriksson et al., 2002). However, wastewater from kitchen sinks is often categorized as black water. The separation of grey water and black water, along with on-site treatment of grey water for potential reuse in toilet flushing or garden irrigation, presents an appealing option, particularly in regions facing water scarcity. Various studies have explored alternative greywater treatment systems, including physical, chemical, and biological methods (Prathapar et al., 2006; Pidou et al., 2008).

2.6. Approaches for a water-resilient urban neighborhood

2.6.1. Water Accounting

Water accounting refers to the examination of the current state and patterns in water availability and usage. Water accounting entails the systematic collection, analysis, and communication of current information regarding the stocks, flows, and fluxes of water (from source to sinks) in natural, disturbed, or heavily engineered environments (FAO, 2016).

Water resources necessitate a standardized framework for description, employing precise terminology and a uniform data collection system adhering to recognized quality standards. Understanding and enhancing these services are imperative for sustaining current per capita water availabilities and managing water footprints. Regulation of water consumption and pollution is essential. Audited Water Accounts serve as the foundation for evidence-based decision-making and the establishment of agreements with riparian partners, including those spanning international borders.

Water accounting is a method that tracks water movement through hydrological processes, considering land use, how water is managed, and the benefits it provides. It aims to ensure fair and transparent water management for all users, ultimately achieving a sustainable balance between water use and availability. (Seyoum, 2020)

2.6.2. Corporate Water Stewardship

The concept of water stewardship encompasses a range of practices that various stakeholders, including businesses, utilities, and communities, can adopt to promote the sustainable and equitable management of freshwater resources. These practices go beyond simply reducing water use within an organization. Water stewardship encourages a holistic approach, encompassing measures like improving water use efficiency at operational levels, engaging with suppliers to promote responsible water management throughout the supply chain, and participating in long-term, collaborative projects focused on sustainable water management in river basins. Ultimately, water stewardship fosters a dual focus: ensuring long-term water security for all while also enabling individual entities to manage risks and capitalize on opportunities related to water use. (Jones et al., 2015)

2.6.3. City Infrastructure Design

According to Water infrastructure resilience, 2019 report,Water infrastructure stands out from other infrastructure systems due to its dual functionality. Not only does it deliver essential water services to communities, but it also acts as a protective shield, mitigating risks posed by natural disasters like floods and droughts to other critical services. This report equips water system managers with the knowledge and tools necessary to enhance the resilience of water service delivery in the face of these natural hazards and the evolving threats of climate change.

The report outlines six key principles that water system managers should consider when implementing resilience measures. These principles are crucial for effective decision-making, especially under conditions of high uncertainty:

1. System Awareness: Conducting comprehensive network analyses and criticality assessments to gain a deep understanding of the water system's strengths and vulnerabilities.
2. Proactive Maintenance: Prioritizing maintenance activities to minimize vulnerability and improve the system's capacity to withstand disruptions.
3. User Collaboration: Encouraging active participation from water users to implement effective demand management practices.
4. Nature-Based Solutions: Leveraging natural processes to manage and respond to the risks associated with natural hazards.
5. Contingency Plan Development: Developing and continuously refining plans to effectively address emergencies and disruptions to water service.
6. Embracing Innovation: Seeking and implementing innovative solutions where appropriate to enhance resilience.

Beyond Water Delivery, the Value of Safeguard Services the report highlights the broader societal benefits associated with water infrastructure. By safeguarding against natural hazards, water systems indirectly protect other vital services like electricity, transportation, and even water itself. This safeguard function should be a major consideration when advocating for investments in building resilience within water systems.

2.7. Resilient strategy

Choosing a resilience strategy isn't always straightforward. While a system might be functionally strong, stakeholders may advocate for a transformation approach to enhance its inclusivity, potentially creating friction. In such scenarios, a combined strategy that balances various stakeholder priorities might be more practical. Businesses should also consider readily implementable solutions with potentially significant long-term benefits, even if the immediate returns are modest. Transparency regarding past, present, and future expectations based on available information is crucial. An overly optimistic strategy might prioritize short-term resource allocation at the cost of long-term resilience. Below are various resilient strategies According to (Feliming et. al., 2024 and Barid, et al., 2021)

2.7.1. Persistence

The concept of persistence revolves around the ability to restore stability following a disruption or shock. It pertains to the ongoing operation and functionality of an organization or system, either remaining unaffected or experiencing only temporary disruptions. Achieving success through a persistence strategy entails swiftly reverting to the conditions that existed before the disturbance. Many current resilience strategies prioritize persistence, which is also a primary aim of the majority of sustainability initiatives, whether stated outright or implied.

2.7.2. Adaptation

Adaptation fundamentally diverges from persistence by recognizing that future conditions will likely differ from the present, with changes unfolding gradually and predictably within defined parameters. Successful adaptation involves continual monitoring of gradual shifts over time and proactive responses to both current and anticipated changes. Long-term alterations such as population growth, rising sea levels, precipitation variability, and urbanization exemplify shocks and stresses that necessitate adaptation strategies.

Practically, an adaptation strategy entails addressing immediate scalability concerns while also anticipating future thresholds that could trigger significant transformations. This might involve adjusting supply chains, implementing backup systems, or relocating operations to less vulnerable areas.

2.7.3. Transformation

Transformation strategy arises from a profound shift within a system, whether due to extreme environmental conditions (e.g., prolonged drought) or substantial changes in system requirements (e.g., transitioning from surface water to groundwater usage). While many regions worldwide are currently focused on persistence or adaptation. Implementing a transformation strategy typically entails reevaluating core aspects of an institution, including its operations, organizational relationships, and geographical distribution of functions. This may involve assessing supply chain vulnerabilities and developing alternative strategies. Understanding system vulnerabilities and opportunities is crucial, as disruptions in one part of the system can propagate and magnify across other areas.

2.8. Contextual review

2.8.1. History of Distribution of water in Addis Ababa

Ethiopia boasts 12 river basins, with Addis Ababa, the capital, adorned with numerous rivers that feed into the main Akaki River. Among these tributaries are the Kebena, Banche Yeketu, Kortame, Bulbula, LequSoramba, Kotebe, and Fincha Rivers. The Akaki River itself is comprised of two primary branches, meeting at the Aba-Samuel reservoir. Little Akaki meanders through the city's western expanse, originating northwest of Addis Ababa near Wechacha Mountain, while Big Akaki courses through the eastern region, sourced from the northeast near Entoto Kidane Miheret. Folws into Aba-Samuel reservoir after 53km.

Addis Ababa relies on man-made water reservoirs in the Awash basin for its main water resources, notably Legedadi, Gefersa, Dire, and Aba Samuel. With the exception of Aba Samuel, which was initially constructed for electricity generation in the late 1930s, all these reservoirs cater to domestic and industrial water needs. While the Aba Samuel Reservoir now serves as a receptacle for some municipal and industrial effluents, it remains a crucial component of the city's water supply system.

Approximately 80% of Addis Ababa's water supply is sourced from these reservoirs, supplemented by a well system contributing the remaining 20%. This combined system yields a total volume of 210,000 m3 per day or 77 million cubic meters (MCM) annually. (Yohannes and Elias 2017)

A previous study led by Alemayehu Et al. underscored the significance of the Akaki well field, which furnishes 30% of Addis Ababa's water supply. Effective aquifer management is essential to sustain this vital water source. Ethiopia has robust national water supply and sanitation policies, with key agencies delineating clear roles and strategies adhering to established with the following service standards:

Table 0.2: Service standards for water consumption

Setting for	Consumption: Per capita	Service: In radius of
Rural	15 liter/capita/day	1.5 Km
Urban	20 liter/capita/day	0.5 KM

In 2001, the government's National Water Strategy encompassed various components, including a water resources strategy, a hydropower development strategy, a water supply and sanitation strategy, and an irrigation strategy.

The water supply and sanitation strategy aimed at achieving several objectives:

Facilitating decentralized decision-making processes.

Encouraging the involvement of all stakeholders, including the private sector.

Enhancing levels of cost recovery.

Integrating water supply, sanitation, and hygiene promotion activities.

By 2014, water tariffs in Addis Ababa followed an increasing block structure. For instance, the initial 15m3 of water consumption per month incurred a charge of approximately 0.14 USD per m3, which then escalated to 0.21 USD per m3 for usage up to 50m3, and further increased to 0.24 USD per m3 for consumption exceeding 50m3.

However, the overall level of cost recovery remains insufficient to cover operating expenses, let alone ensure adequate maintenance of facilities. Recurrent expenditures, estimated at USD 29 million in 2001–02, were primarily financed through user charges (64%), alongside subsidies from regional governments (31%) and the federal government (5%). Nonetheless, a handful of service providers manage to recover all operating costs and even generate a modest surplus.

2.8.2. Major water reservoirs in the city

In Ethiopia, there exist 12 primary river basins/valleys, along with 11 lakes, 9 saline lakes, 4 crater lakes, and over 12 swamps. The combined yearly water flow from these 12 rivers is estimated at

123.25 billion m3. Some of these rivers extend into neighboring countries, with approximately 95% of Ethiopia's runoff exiting through these international rivers. Additionally, there is an estimated groundwater potential ranging from 2.6 to 6.5 billion m3, translating to an average of 1,575 m3 of available water per person annually, a substantial amount. However, due to significant variations in rainfall and limited storage capacity, water availability often doesn't align with demand.

Presently, only about 3% of Ethiopia's water resources are utilized, with a mere 11% allocated for domestic water supply, representing only 0.3% of the total. Addis Ababa, the capital city, primarily relies on the Gafersara dam, initially constructed during the Italian colonial period and renovated in 2009, for its drinking water supply. Other water sources such as wells and additional dams contribute to supplementing the city's water needs.

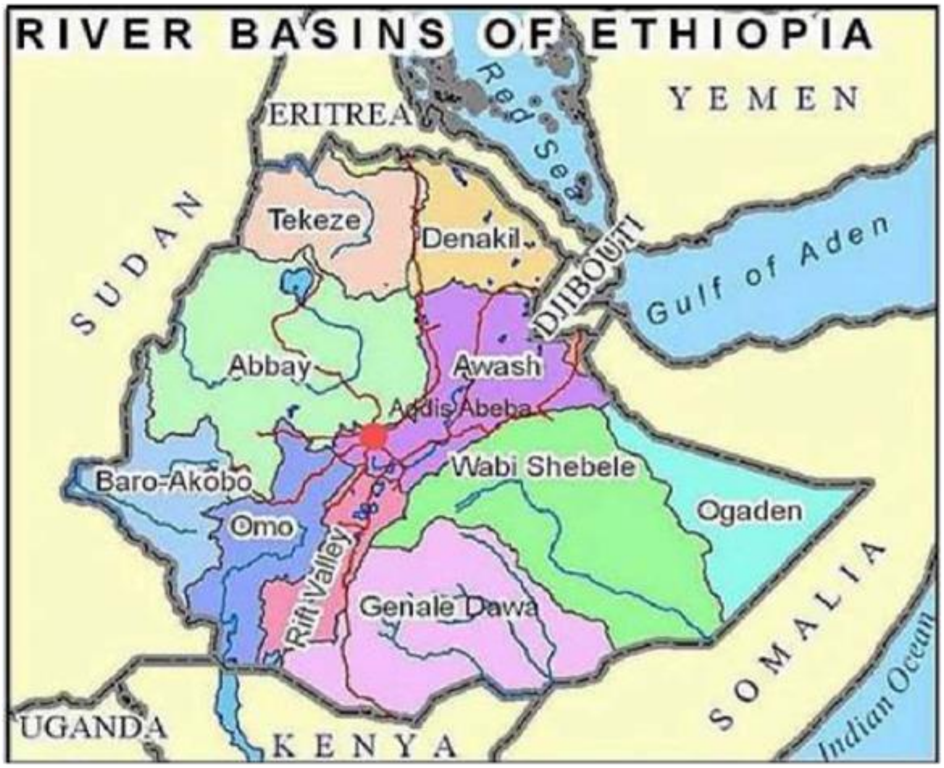


Figure 0.6: Map of Ethiopia Sowing River Basins

2.8.3. Water supply and distribution system

The city commenced its water supply in 1901. From 1942 to 2001, numerous water supply projects were undertaken, encompassing initiatives such as the construction and enhancement of the Legadadi dam, improvements to treatment plants, distribution systems, groundwater utilization, and spring development.(AAWSA in 2004).

According to Nigusse Desalegn, spokesman for the Addis Ababa Water and Sewerage Authority (AAWSA), as stated by Terefe, D. (2019), At present, the dams, reservoirs, and wells comprising Addis Ababa's water supply system cater to less than two-thirds of the required 930,000 cubic meters of potable water per day, as reported by AAWSA.

Over the past five years, the city's water demands have nearly doubled, a trend that continues to escalate daily due to urban expansion, characterized by both outward and upward growth, marked by a surge in the construction of apartment complexes and office buildings. This information was highlighted in a Reuters article titled "Faced with climate change and growth, Ethiopia's capital shores up its water supply. "

2.8.4. Climatic factors affecting water supply

The city is situated in a region characterized by high annual rainfall, typically exceeding 1,000 mm. This rainfall occurs within a condensed timeframe during the three to four months of the rainy seasons, resulting in the accumulation of a substantial water volume. This stored water serves as a crucial resource for the city's water supply throughout the remainder of the year. This insight is derived from the study titled "Climate change impact on surface water sources of Addis Ababa: a case study in Legedadi-Dire-Gefersa catchments and reservoirs." Available on dspacedirect.org

2.8.5. Rainwater harvesting potential of the city

Rooftop rainwater harvesting has the potential to alleviate water supply shortages in Addis Ababa, especially considering the vulnerability of existing water sources to prolonged dry periods and the impacts of climate change, as evidenced by the events in 2015. Kuczera's findings suggest that rainwater harvesting can help mitigate water supply vulnerabilities in urban areas. Furthermore, rainwater harvesting reduces reliance on groundwater resources, as a significant amount of rainwater can be collected from rooftops, leading to savings in potable water.

Groundwater reserves can be augmented through increased rainwater harvesting, providing a vital supply during the dry season, accounting for 51% of the potable water supply. It's estimated that rooftop rainwater harvesting could replace up to 2.3% of the city's potable water supply, particularly through large public institutions. The study reveals that these institutions could replace varying proportions of their water supply, ranging from a maximum of 64.9% in July to a minimum of 0.9% in December and January.

The recommendation is to integrate rooftop rainwater harvesting into Addis Ababa's water supply system as an alternative source, especially with the support of initiatives like the Ethiopian Rainwater Harvesting Association, which can help address the city's water supply shortages.

2.8.6. Underground water resource

An aquifer comprises underground layers of permeable rock capable of holding water. Groundwater, which resides within aquifers, is replenished by precipitation that seeps through soil to the water table and by water seeping from surface water sources like streams, lakes, and wetlands

In Addis Ababa, the groundwater characteristics are as follows: The predominant groundwater flow direction within the city is from north to south. Transmissivity, borehole yield, groundwater depth, and total dissolved solids increase in the north-south direction, with exceptions in certain areas where intensive fracturing and thermal effects cause high yield and total dissolved solids. Borehole log analysis indicates that the central part of the city, including areas like Filwoha, Llideta, and Kality, exhibits confined groundwater conditions elongated in the north-south direction.

Groundwater in Addis Ababa, which is unconfined and has a depth of less than 80 meters, is highly vulnerable to various pollutants, except those that are highly absorbed or readily transformed. Semi-confined aquifers in the area are considered to have low vulnerability due to the presence of semi-impermeable strata between the groundwater level and contaminant sources, prolonging the travel time for contaminants to reach the groundwater. Confined groundwater zones in Addis Ababa are deemed to have negligible vulnerability to pollution due to the high confinement provided by impermeable strata. (Ababa, 2001).

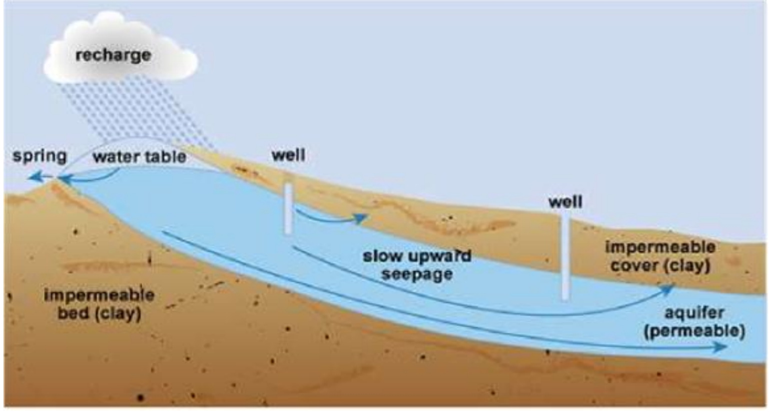


Figure 0.7: Groundwater recharg

Chapter Three: Methodology

3.1. Selection of Study Area

Figure 3.8 : Google map Image, showing the Site Location and Local Names.

The study focuses on the Kotari Condominium Neighborhood, also known as Haile Garment Condominium , located near Mekenisa in Addis Ababa's Lebu area. It is found near Mekenisa, Lebu area adjacent to the Haile garment factory. The project started in 1997 and was distributed to the winners in 2000 (AAHDPO, 2015). Now it has been inhabited for more than 15 years. This neighborhood, impacted by significant water scarcity, was selected due to its heightened vulnerability to water-related challenges. The Addis Ababa city administration has reported instability in the water demand and supply chain around Kotari Condominium, which makes it a suitable case study for examining urban water resilience.This research explores the water demand patterns and supply infrastructure surrounding the Kotari Condominium. Accordingly, Kotari Condominium was selected as case site-based studies conducted in other disciplines indicate that there was a prevalence existence of water-related problems in the neighborhood. Kotari Condominium is more affected by issues of water resilience in urban neighborhoods which are issues of study.

The case area was selected for the following reasons:

a. According to the Addis Ababa city administration and urban Sanitation and water department report water demand and supply chain around Kotari Condominium is more unstable.
b. Studies conducted in other disciplines indicate that there is a prevalence existences of water-resilient problems in the neighborhood.

All neighborhoods in Addis Ababa were surveyed for visual inspection of their prevalence of urban water-related issues.

3.2.Research Design

This study aimed to learn about and explain water resilience in an urban neighborhood of the selected case (Kotari Condominium). To ensure the credibility of the findings and gain insights into understanding water resilience in urban neighborhoods, a case study was chosen as the research method. This decision was based on the objectives, source of data, type of data, number of samples, and method of analysis used, as well as previous experience with the topic under study. A survey was conducted to select the case area from the target area and to measure the water-resilient urban neighborhood. The samples were selected in a way that allowed drawing conclusions that were valid for the study area.

A case study is defined by Merriam (1998) as a research method that emphasizes the definition of the focal point of investigation: the case. This case can take various forms, such as objects, units, entities, or phenomena, each with clearly defined boundaries. Additionally, a case can represent an individual, such as a student, a teacher, or a principal, or a collective entity like a group, a specific program, or a policy. Case study research aims to provide a comprehensive portrayal and understanding of the subject matter.

Yin (2003) clearly stated that case studies are appropriate under the following circumstances: when the study aims to address "what," "how," and "why" questions; when it is not feasible to control the behavior of the participants; when contextual factors are considered crucial to the phenomena being investigated; and when there is ambiguity in delineating the boundaries between the phenomena and its context.

3.3. Data type and source

To gain a comprehensive understanding of the research question, this study employed a variety of data sources, including both primary and secondary data.

3.3.1. Primary data

Primary data collection used a variety of methods. Field observations and site photography documented the situation firsthand. Additionally, in-depth interviews with residents, representatives from NGOs, and government officials provided valuable insights. Maps and satellite imagery further enriched the data set.

3.3.2. Secondary data

Secondary data was collected from manuals, previous studies, the Kotari condominium neighborhood, satellite images (Google map or Satellite map), and relevant books. Secondary data was collected from existing sources like manuals, books, and past studies, satellite images (Google map or Satellite map), and relevant books (Will Hillier, 2022). Literature helped the development of guidelines for the evaluation of the pre-selection of the site for the case study.

3.4. Sample Size and Sampling Technique

To gather data for this research, purposive sampling was employed to select case neighborhoods. This was to ensure that a certain number of sites were selected from the neighborhood. To select a specific sample from the case area pre-survey was conducted to select a site that met the study objective. Information from the Addis Ababa city administration water and sewerage department was utilized. Finally, previous studies in other disciplines were consulted to guide the purposive sampling process.

Sample selection criteria were based on the following three basic points to align with the reseach objectives.

a. The interplay between water availability(Supply) and human needs(Demand),
b. The presence of water resilience problem and attempts made to resolve the issue,

This study's interviews were conducted with the inhabitants of the Kotari condominium neighborhood. The focus group discussion involved a maximum of 15 in one group, comprising interviews and different households. To determine the sample size for the questionnaire, interview, and focus group discussion, the following techniques were employed. To determine the sample size for an interview in this research, the following formula was adopted from Louangrath, Paul (2017).

$$n = \frac{N}{1+N(e)^2} \quad => \quad n = \frac{100}{1+100(0.05)^2}$$

$$n = \frac{100}{1+100(0.0025)} \quad => \quad n = \frac{100}{1+0.5}$$

$$n = \frac{100}{1.25} \quad => \quad n = 80$$

Therefore, $\underline{n = 80}$, where questioner =41, interview =10, focus group =29 in 3 group of 10 participants maximum

Where: n= sample size

N= no of households in the study site

e= sampling error (level of precision=5%) i.e. (0.05)

3.5. Method of data Collection

3.5.1. Field Observation

For this study, therefore, observation of the Kotari condominium neighborhood were conducted repetitively, and pictures of the Kotari condominium neighborhood were taken. One of the most effective methods for acquiring data on the impact of water resilience within a neighborhood is through the implementation of site visits. Project for Public Space (2005) Therefore, this study employed field observation of the chosen case study area as a primary data collection method.

3.5.2. Interview

This study utilized interviews as a primary data collection method. Interviews provide researchers with a direct way to gather information from participants, as noted by (Abiy Zegeye, et .al, 2009) who categorized interviews as structured, semi-structured, and unstructured. Furthermore, Yin (1994) highlights the effectiveness of open-ended interviews within case studies, allowing for a deeper exploration of participants' experiences. This study used interviews with open-ended questions to understand things we could not learn just by visiting the neighborhood. Interviews are better than surveys for getting people's opinions and feelings about water challenges in the Kotari condominiums.

3.5.3. Focus group discussion

For this research, focus group discussions were used to gather information that cannot be obtained by observation and visitation. Consequently, the aforementioned techniques facilitated the measurement of attitudes, perceptions, and motivations regarding water resilience and associated problems within the Kotari neighborhoods. In this regard, an interview was conducted using semi-structured interview questions.

3.5.4. Map and satellite image

For this research, maps and satellite image were used. Data on the current conditions of the case area was analyzed by using satellite images and existing land use from the settlement land administration authority office. Google Earth and Arc Globe maps were also used for additional information. AutoCAD was used for map drawin. For this research, maps and satellite images were used. Google Earth and Arc Globe maps were also used for additional information.

3.6. Method of Data Analysis

The analysis primarily focused on addressing the research objectives and answering the research questions. Data collection and analysis were conducted using the Google Workspace online platform. Initially, the data underwent sorting, where all interview and observational data were categorized into themes aligned with the research objectives. These objectives were then refined based on the emerging themes and categories identified from the interviews and observations. A thorough literature review was carried out, with a focused reading approach to extract relevant information that aligned with the research objectives. Throughout this review process, it was crucial to consistently refer back to the objectives to maintain alignment and identify any themes that deviated from the research context. Finally, the analyzed data were presented using maps, tables, graphs, and pictures obtained during the field survey.

3.7. Method of Data presentations

Therefore, the analysis concentrated on the research objectives and sought to provide solutions to the research inquiries.

a. The first stage of data analysis involved the evaluation of the pre-selected site for the selection of the case area.
b. Then sorting of all interview and the next step involved organizing all the interview and observation findings into categories (themes) that matched the research focus.
c. Based on the themes and categories identified through interviews and observations, the research objectives were then further refined.
d. The research next analyzed satellite imagery and maps to identify spatial characteristics and assess their relevance to the research goals.

3.8. Validation

The primary aim of data collection is to comprehend the strategies and experiences of both planners and users within kotari condominum, with the intention of informing solutions based on the analysis results. Additionally, the objective is to explore any existing legal and institutional frameworks that govern and manage these water resilency.

The data collected were focused on the following key issues:

- To analyze the water demand and supply chain around Kotari Condominium.

- To understand appropriate building water resilience approaches.

- To design and propose a context-tailored design for the Kotari Condominium neighborhood.

3.9. Research framework

The research strategy offered a structured framework for devising a systematic study aimed at effectively tackling the objectives and questions of the research. The study employed exploratory and case study research methodologies to investigate water-resilient urban neighborhoods. The outlined study design illustrates a logical progression from the initial problem statement that sparked the research to the eventual conclusions and recommendations.

Framework

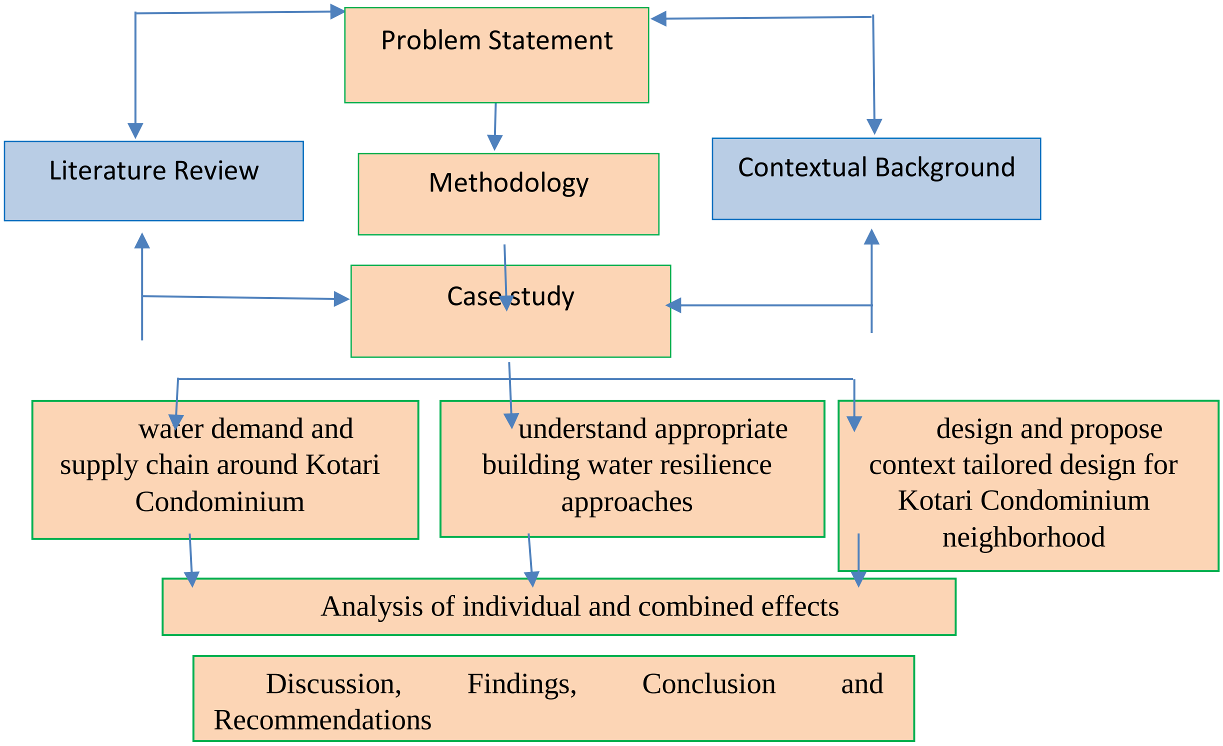


Figure 0.2: Research framework

Chapter Four: Result and Discussion

4.1. Water demand and supply infrastructure at Kotari Condominium

4.1.1. Water demand at Kotari Condominium

Addis Ababa relies on man-made water reservoirs in the Awash basin for its main water resources, notably Legedadi, Gefersa, Dire, and Aba Samuel. With the exception of Aba Samuel, which was initially constructed for electricity generation in the late 1930s, all these reservoirs cater to domestic and industrial water needs. While the Aba Samuel Reservoir now serves as a receptacle for some municipal and industrial effluents, it remains a crucial component of the city's water supply system.

Approximately 80% of Addis Ababa's water supply is sourced from these reservoirs, supplemented by a well system contributing the remaining 20%. This combined system yields a total volume of 210,000 m3 per day or 77 million cubic meters (MCM) annually. (Yohannes and Elias 2017)

A previous study led by Alemayehu Et al. underscored the significance of the Akaki well field, which furnishes 30% of Addis Ababa's water supply. Effective aquifer management is essential to sustain this vital water source.

Condominium Housing Practice is an Ethiopian national large-scale ongoing series housing development program. The data show that nations are rolling out extensive affordable housing initiatives. These efforts are part of a series crafted and overseen by the Housing Policy Section of UNHABITAT. This series aims to offer reliable and unbiased documentation of inventive affordable housing programs in developing countries.

The Housing Practices series offers practical guidance on housing programs, drawing upon successful real-world examples. Each volume serves as a detailed guide to a 'best-in-class' housing initiative that has demonstrably positive results.

Koari condominium is one of the housing programs found in the Nifassilk Lafto sub-city around the Mekannisa area. Kotari Condominium comprises more than 11 blocks of buildings in the neighborhood. From them, there are more than two types of building typology.

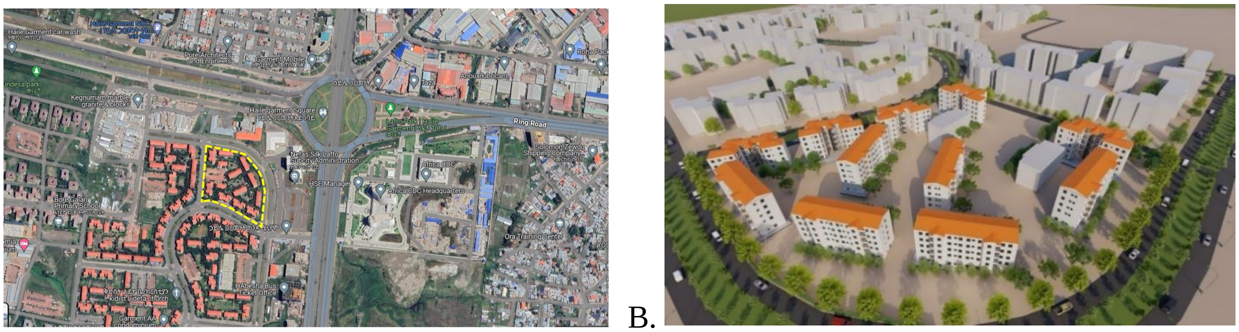
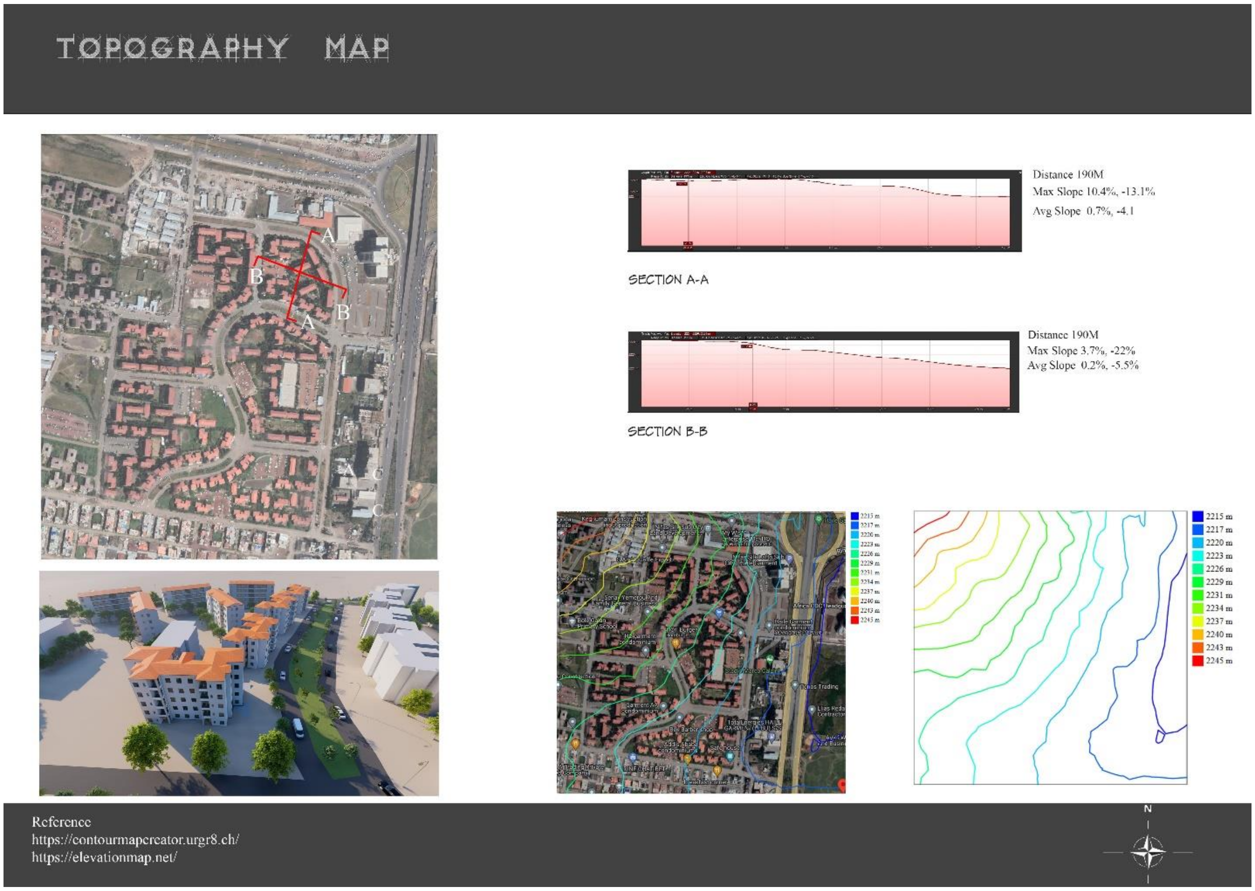


Figure 0.9: Kotari condominium Neighborhood Arieal view (source: a. google Mape & b. own)

According to the topography map, the site has a gentle slope which locates the housing at the lowest altitude.

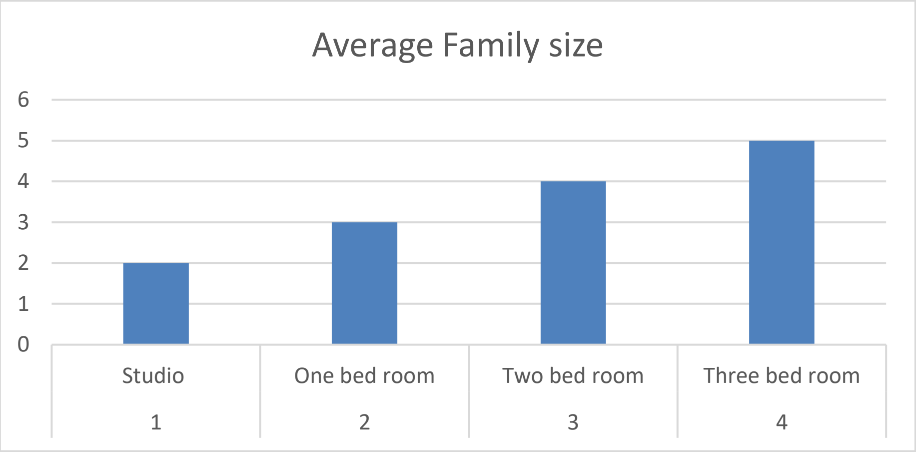


Reference
https://contourmapcreator.urgr8.ch/
https://elevationmap.net/

Figure 0.10: Topography map of Kotari condominium

Based on housing typology this neighborhood has 30 studios, 115 one-bedroom, 80 two-bedroom, and 80 three-bedroom types of residential units. The housing blocks account for residency for about a population of 950 people during the survey. This number varies due to the high mobilization of people.

Figure 0.11 : Family size and residential unit



No.	Typologies	Average Family size
1	Studio	2
2	One Bedroom	3
3	Two bedrooms	4
4	Three bedrooms	5

Table 0.3: Average family size in residential units

This indicates that the average family size increases as the number of bedrooms increases. On average one bedroom accommodates more than one person. Even if the number of persons with the number of bedrooms, the average number of people in a one-bedroom is more than one person.

4.1.1.1.Water demand

Water consumption in urban depends on the family size. When family size increases the water demand also increases. The individual demand for water in urban areas varies due to factors like household size, economic status, social dynamics, climate, and town infrastructure (MoWR, 2006). In East Wollega Zone, Oromia Region, Ethiopia, a study found that people used an average of 15.26 liters of water per day for tasks like laundry, drinking, cooking, dishwashing, bathing, cleaning, gardening, and sanitation. In contrast, another study in SNNP, Ethiopia, showed that households consumed an average of 53.8 liters of water per person per day, which was below the National Minimum Daily water requirement of 20 liters per person per day. This indicates that water consumption levels fell short of the recommended daily amount for household use.

Family size and daily water consumption of families from Kotari condominium indicate that the maximum consumption of a given family is below the minimum national and international standards. The water demand varies according to family size and building typology. The data indicate that small houses have small family size. The survey indicates that most residential units with more bedrooms accommodate large family sizes.

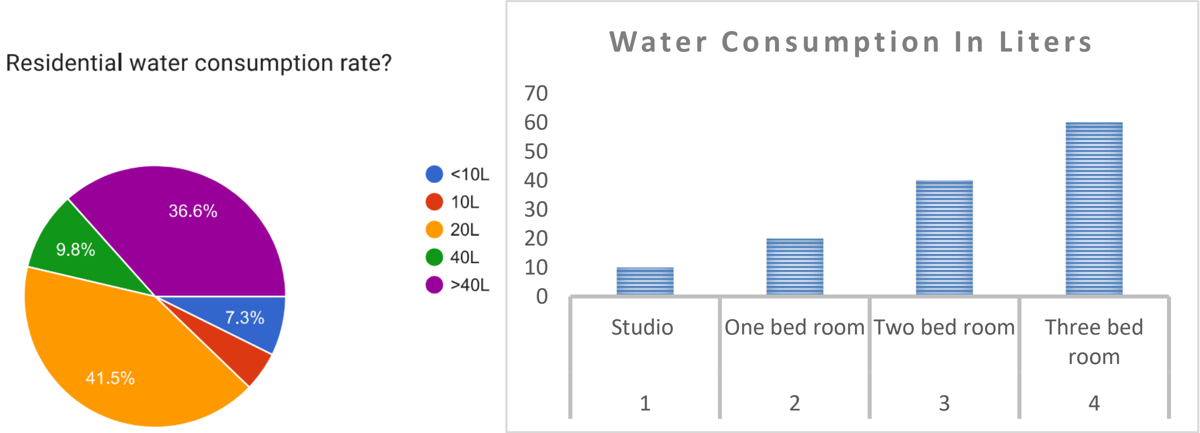


Figure 0.12: Water consumption

The data collected shows that the household may fetch water twice or three times a week and use it from storage. They store and use them in conservation. In each household, there is storage equipment to store water for two to three days. When water is available, it collects in different storage mechanisms in household equipment as much as possible.

To fulfill the demand and meet the national standard we need to produce 950*20=19,000 letters (19m3) of water. This indicates that on average units of studio housing consume 40 litters, one bedroom 60 litters, two bedrooms 80 litters, three bedrooms 100 litters of water per day.

4.1.2. Water supply infrastructural

The water source where the neighborhood residents get water is only a government source. Based on the assessment all the water supplied to the neighborhood is supplied by the Addis Ababa City Water and sanitation authority.

4.1.2.1. Municipal Tap Water

Municipal tap water, also referred to as running water, piped water, or municipal water, is water distributed through a tap or water dispenser valve. In numerous countries, tap water typically meets the standards for drinking water quality. It is frequently utilized for drinking, cooking, cleaning, and toilet flushing purposes.

The municipal tap water is delivery according to schedule. Most of the time they schedule twice or three times a week in Addis Ababa for most of the areas. Based on the Interview Collected anlysis Tap water is supplied in the Kotari condominium according to the following rate. Based on my physical door-to-door interviews, residents mostly report that the schedule for municipal tap water delivery occurs twice a week.

Figure 0.13: Tap Water supply rate (Own survey)

Indoor tap water is delivered through indoor plumbing, a system that has been in existence since ancient times but was accessible to only a limited number of individuals until the latter half of the 19th century when its popularity began to rise in what are now considered developed countries. Throughout the 20th century, tap water became commonplace in many regions and is now predominantly lacking only among impoverished populations, particularly in developing nations.

Governmental agencies typically oversee the regulation of tap water quality. Referring to a water supply as "tap water" distinguishes it from other primary sources of freshwater that may be available, such as water collected from rainwater cisterns, village or town pumps, wells, or water sourced from streams, rivers, or lakes (which may vary in terms of portability).

Most of the tap water is distributed to the customers by piped distribution where 7.5 % of water is distributed by point systems like Water Bono. The provided figure displays the analysis data gathered from the case area.

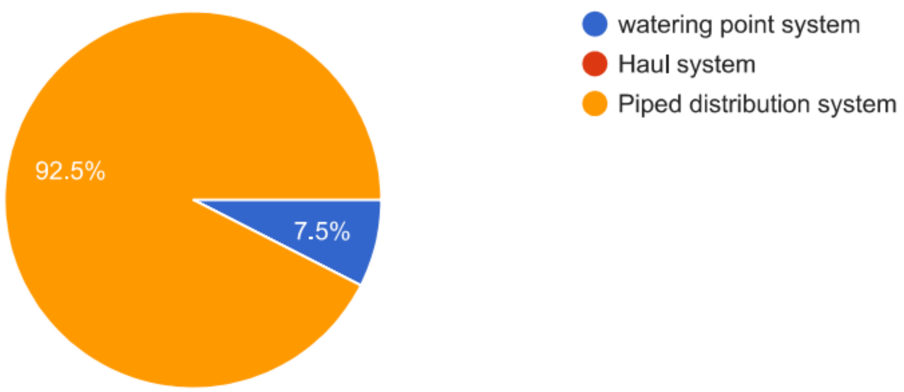


Figure 0.14: Tap water distribution system

4.1.2.2. Ground water sources

Groundwater sources refer to underground water aquifers accessed by drilling a hole down to the water table and then extracting the water as needed for irrigation or storing it in bore water tanks. Bore water is derived from groundwater, which originates from rainwater that naturally permeates into the ground and accumulates in spaces between soil and rocks. These underground spaces containing layers and bodies of water are termed aquifers.

The extraction of groundwater to the surface is achieved through a bore (well) or a network of bores. Utilizing bore water safely is essential. Water sourced from private bores represents a valuable resource capable of significantly fulfilling water requirements. Depending on local conditions, bore water may be suitable for various uses, including stock watering, irrigation, toilet flushing, and laundry or vehicle washing. It may also be deemed suitable for showering, food preparation, and consumption.

However, bore water is susceptible to contamination from both natural processes and human activities. Therefore, testing by an accredited laboratory is necessary to verify water quality, which may require treatment based on the intended usage.

Figure 0.15: Borehole (open source)

4.1.2.3. Rainwater harvesting

Rainwater harvesting, in its various forms, holds significant potential for domestic and multiple uses in rural areas worldwide. It encompasses practices ranging from household and roof water collection to active watershed management, promoting improved soil and water conservation. Rainwater harvesting serves as a proven method to enhance the resilience of households and communities against climate variability and is seen as a crucial component of climate change adaptation strategies.

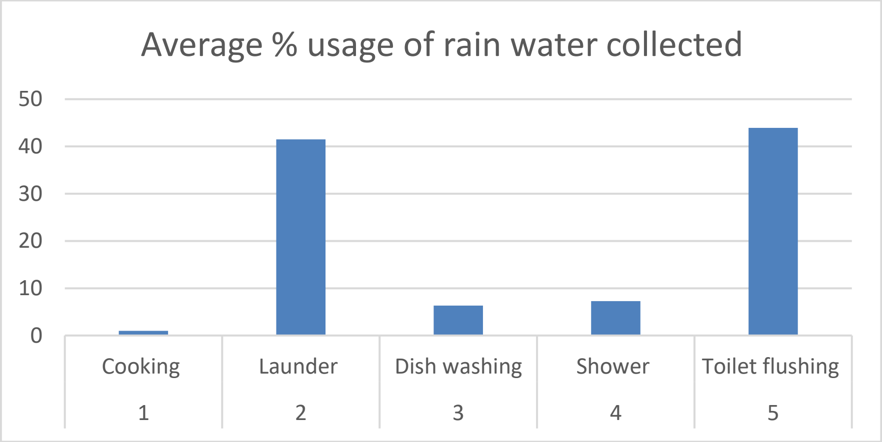
Rainwater sources include clean rainwater collected from rooftops and other surfaces into dedicated rainwater tanks, as well as excess water and runoff from paths, roads, and other surfaces channeled into storm water tanks.

Rainwater stands out as one of the purest and safest water sources, aside from mains water supply. Unlike other water sources, rainwater quality remains untainted by ground surface pollution (as in storm water), is free from salinity issues, contamination risks from animals and pesticides, and evaporation concerns (as with surface water sources). Furthermore, rainwater doesn't necessitate microbiological and chemical testing to ensure its suitability for use, unlike bore water.

Given its high quality and versatility, rainwater is arguably the optimal water source for farming. Therefore, dedicated stock water tanks for rainwater collection prove to be valuable additions. When combined with storm water tanks, additional harvesting opportunities for lesser needs are also provided.

By the end of the SDG period in 2030, the aim is to significantly increase the widespread adoption of rainwater harvesting practices across various scales. This effort is integral to achieving universal access to safe water and enhancing resilience to climate change.

Table 0.4: Average % usage of rainwater collected



The data reveals that the majority of harvested rainwater is utilized for various purposes, with a notable emphasis on toilet flushing and clothes washing. This trend can be attributed to the fact that the collected rainwater typically remains untreated. Additionally, external water sources, such as water piped in from a mains supply or an agreed remote source, or water transported via tanks, are commonly utilized and stored on the property. During the rainy season, residents on the ground floor often access rainwater harvesting through downpipes.

Figure 0.16: Rainwater harvesting during the rainy season (open source)

4.2. Appropriate building water resilient method and Practice

4.2.1. Storage of water

The questionnaire results indicate that the municipal water supply cycle of water supply by tap is on average twice a week. Availability of water is the basic problem but Different storage mechanism is used when the water is available. Most of the residents used to store water in the kitchen and bathrooms. This will minimize the space for kitchen activity. It disturbs architectural room space activity.

Figure 0.17: Indoor water storage mechanism

Some have private elevated water tankers. Some of the residents use this storage at the communal space like corridors which interrupt the movement of the residents.

Water is stored using various mechanisms to ensure availability for future use. Elevated water storage and underground tanks serve to store water for fire protection and potable drinking within a designated area or community. Elevated tanks leverage gravity to maintain consistent water pressure throughout the system. These tanks can be engineered in diverse shapes, sizes, and materials to suit the specific needs and intended applications of the distribution area.

Roof tanks, positioned atop high-rise buildings, are freshwater reservoirs primarily utilized in water supply systems, especially in areas with unreliable water mains and power supply. Water is supplied to roof tanks either via a transfer pump or directly from the mains water supply.

For most apartments, water is supplied by gravity, ensuring adequate pressure. However, apartments on the uppermost floors may experience insufficient pressure due to gravity limitations. In such cases, ground and underground tanks store water, and active pumping mechanisms are employed to elevate water to these higher locations, often necessitating the installation of pumps to address pressure issues.

Figure 0.18: Elevated water tanker (own survey)

Water storage options can be categorized into surface and subsurface storage facilities:

4.2.2.1. Surface storage

There are several methods of surface water storage, including open ponds or pans, naturally occurring pans, excavated ponds, cultivated reservoirs or tanks, sunken streambed structures, ponds for groundwater recharge, and surface dams. In Addis Ababa, the main surface water sources are Legedadi, Gefersa, and Dire reservoirs, while the primary groundwater sources come from the Akaki wellfields. The city administration utilizes water stored in these reservoirs during the rainy season to meet the demand during the dry season. Addis Ababa City has these reservoirs Legedadi, Gefersa, and Dire.

Figure 0.19: https://www.pietrangeli.com/legadadi-buttress-gravity-dam-ethiopia-africa/

4.2.2.2. Subsurface storage

Various methods, such as subsurface dams, sand dams, percolation dams, subsurface reservoirs, or cisterns, are employed for underground water storage. Addis Ababa has recently adopted the practice of subsurface reservoir storage.

Common underground water storage options include:

a. Poly Tanks: These tanks, made from polyethylene, are lightweight and durable, offering a cost-effective solution.
b. Fibreglass Tanks: Known for their durability and corrosion resistance, fibreglass tanks are lightweight and sturdy.
c. Steel Tanks: Constructed from steel sheets with a Zinc coating to prevent rust, steel tanks are robust and long-lasting, although heavier than other options. With proper maintenance, they can last for decades.

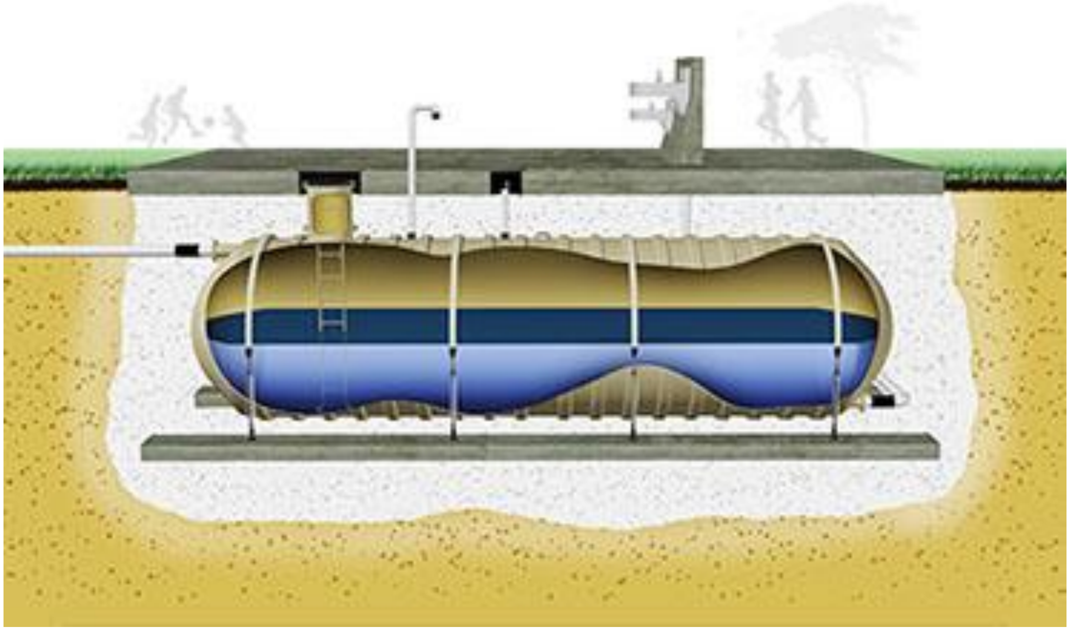


Figure 0.20 Fiberglass underground water storage reservoirs

4.2.2. Water conservation

Water conservation involves using water more efficiently, which can be achieved through technological upgrades and behavioral changes. Examples include installing high-efficiency appliances like clothes washers and low-flow fixtures, as well as adopting habits like turning off taps when not in use and fixing leaks promptly. Choosing efficient methods for tasks like dishwashing and laundry, such as using dishwashers and running full loads, also contributes to conservation efforts. Additionally, selecting foods with lower water footprints, such as eggs over beef, helps reduce overall water usage in daily life.

Figure 0.21: Water conservation mechanism, saving and reuse of dirty water for different purposes

Gardening can help save water in a few ways. If you live in a dry place, try growing plants that naturally handle drought and need less watering. Drip systems are great because they give plants just the right amount of water without wasting any.

In farming, we can use water more wisely by planting crops where they can get water from rainfall, using drip systems for irrigation, and not disturbing the soil too much. In some areas where water is scarce, people reuse water. For example, after doing laundry, they use the water to clean the floor. In the kitchen, water from washing dishes is used again before getting thrown away. And if there's leftover water, it's used for watering gardens or grass.

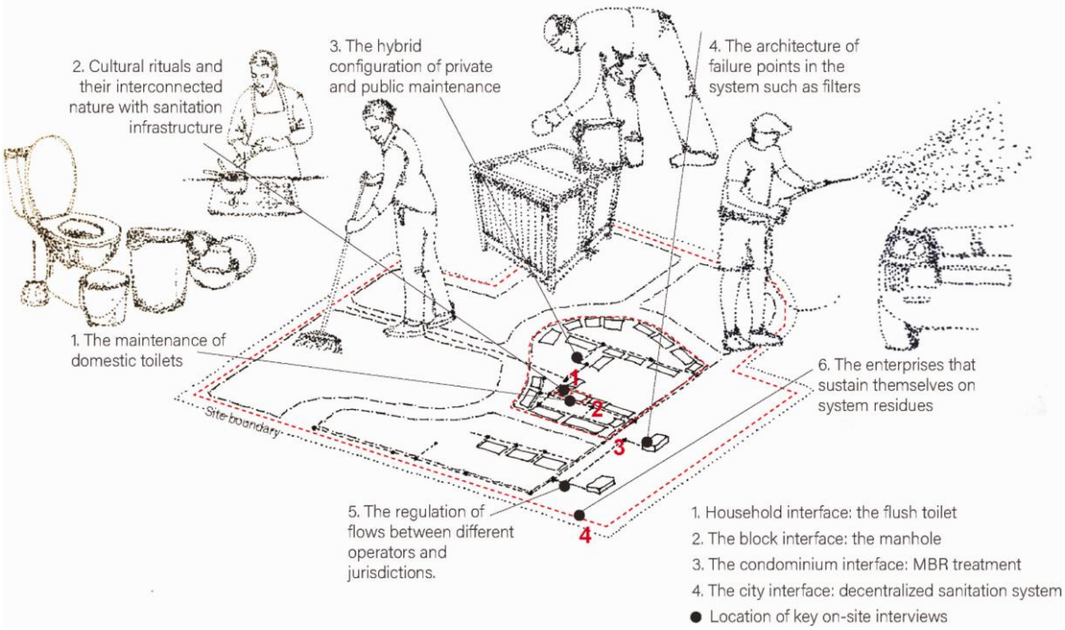


Figure 0.22: Water conservation mechanism Source (de Galiza Barbosa et al., 2022)

4.2.3. Water Treatment

Household water treatment is the process of treating water either at home or at the point where it is collected or used. This treatment aims to ensure that water is safe for use and can help reduce the risk of diseases transmitted through water, such as diarrhea. When deciding on water treatment methods for households or communities, it's important to consider factors like the current water and sanitation situation, water quality, the feasibility of installing water, sanitation, and hygiene (WASH) facilities, cultural acceptance, accessibility, available technology, the likelihood of consistent and long-term use, and local conditions.

There are various methods available to make water safe from harmful germs. Some of the most commonly used methods include boiling, chlorination, disinfection, and filtration.

4.2.3.1. Boiling

Boiling or heating water is widely recognized as one of the most commonly practiced and effective methods for eliminating disease-causing pathogens such as viruses, bacteria, and parasites. This approach is often implemented in households to ensure the safety of tap water for drinking purposes. However, most of the households use tap water directly for drinking.

It is important to use this treatment mechanism if we consider the water is infected with bacteria and infectious germs. By this mechanism, rainwater can be used for cooking and drinking after treatment in Kotari Condominium.

4.2.3.2. Chlorination

Chemical disinfection is another prevalent approach for ensuring water safety. Chlorination, a widely used chemical disinfection method, entails adding chlorine-based substances like sodium hypochlorite, calcium hypochlorite, or household bleach to water to eradicate bacteria and viruses. Additionally, other chemical disinfectants such as iodine and chlorine dioxide can also effectively disinfect water. At the municipal level, tap water undergoes chlorination treatment to eliminate bacteria and parasites before being supplied to households.

4.2.3.3. Flocculation-Disinfection (water agar)

Flocculation-disinfection is a water treatment method where a substance is added to water, causing solids to form larger clusters, or flocs, which can then be removed from the water. This process is commonly used for tap water, especially when there is residue present due to interruptions in the water supply schedule or broken lines, which may result in unclean tap water reaching households. The treatment product typically contains powdered ferric sulfate (a flocculant) and calcium hypochlorite (a disinfectant). After stirring, the solids settle to the bottom of the container, and the water is filtered through cloth into another container for safe storage and use.

Figure 0.23 : Wuha Agar

4.2.3.4. Slow Sand Filtration

Slow sand filtration is an efficient method for removing turbidity (cloudiness) and microorganisms from water through a combination of biological and physical processes in a single treatment stage. It typically involves vertically arranged layers of components, including a tank, a bed of fine sand, a layer of gravel for support, underdrains to collect filtered water, and a flow regulator to control filtration rate. Unlike other filtration methods, no chemicals are added during this process.

This equipment is commonly found in households and is used to treat tap water for drinking purposes.

Figure 0.24: Water purification for household used (own survey)

4.2.3.5. Gray water treatment

Gray water treatment isn't practiced in this area, but the Addis Ababa city administration has established two facilities dedicated to treating gray water originating from toilets and bathrooms. Akakai site which is the oldest water treatment plant in the city and Around Bole Lemi industry park which is AAWSA's illogical water treatment site. This treated water is used for gardening in the downstream and drinking for wild animals of downstream farmers.

Figure 0.25: Addis Ababa city admiration water treatment plant (google satellite image)

Small-scale wastewater treatment facilities utilize microfiltration and sludge activation techniques. This method converts sewage into clean water directly at the location, enabling its reuse for various purposes. Such an approach holds appeal for municipal authorities aiming to adopt green economy strategies. The subsequent section examines the infrastructure interfaces of Kotari's distinct sanitation setup, as illustrated in the accompanying figure below.

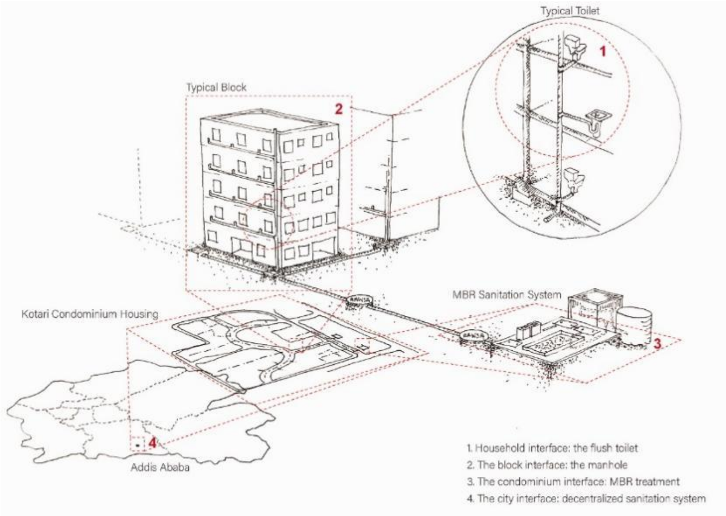


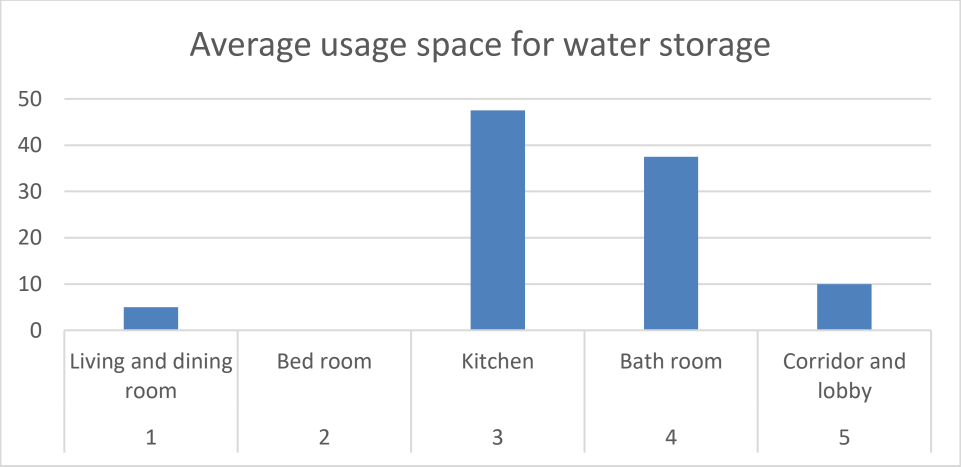
Figure 0.26: Gray water treatment for Kotari condominium Infrastructural configuration of Kotari's unique sanitation Source (de Galiza Barbosa et al., 2022)

4.3. Water resilient design and methods

4.3.1. Space planning and design

For water storage, all space in the residential unit can be used including the lobby and corridors. But mostly kitchens and bathrooms are most prevalent. According to the data collected they use all Spaces for storage of water. Open spaces in the compound are also used for stationing big groundwater tankers.

Figure 0.27: Average usage as water storage



Careful planning is important to store and get water easily in the right places for giving it to all blocks and buildings. Planning for resilience is really important to make sure water is strong. Kotari condominiums, which are big housing buildings, need quick solutions for their sanitation problems. They chose Min-dam, which is a high-tech way to handle this. Where we put storage places should be planned carefully, depending on how much they're used and how important they are.

4.3.2. Diversify water source

The idea of integration means a household uses more than one water source for drinking water. This can happen in a few ways. They might use different sources at the same time, or have backup options if their main one isn't enough. It could also mean they switch between sources depending on the season. For example, a household might mainly rely on one source, but switch to another at different times of the year, or use extra sources to add to their drinking water when needed.
Most of the residential unit owners were trying to use alternative water sources from storage tanks to withstand the water shortage they were facing.

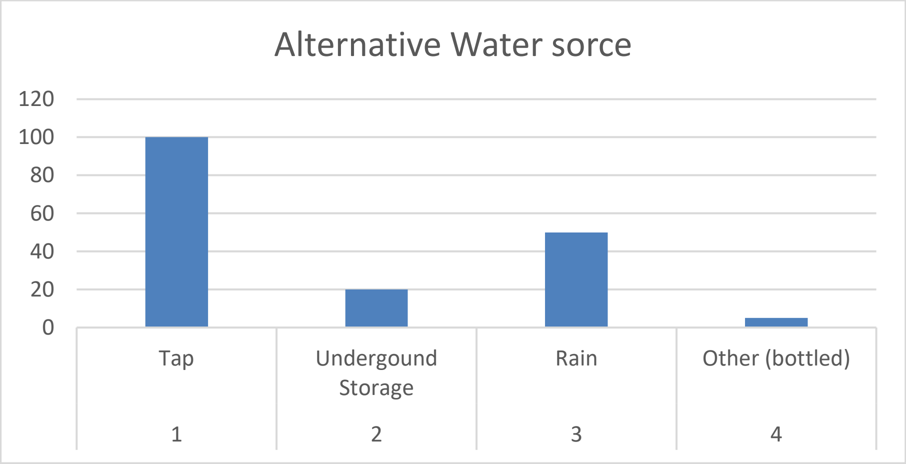


Figure 0.28: Alternative water source

4.3.3. Integrated design approaches

Supply, storage, and distribution systems have the potential to create resilient water systems through cycling components. Managing both grit and clean water, which could be reused, is crucial for water resilience. However, current capacity is limited due to technical and infrastructure deficiencies. Despite aspirations for using recycled water or grit, progress has been hindered by a lack of knowledge among involved parties and the absence of a formal management structure to drive innovation. Existing infrastructure is solely designed for municipal tap water.
Various water storage containers, including rainwater tanks, storm water tanks, bore water tanks, stock water tanks, and troughs, contribute to water storage. Additionally, private dams on land

capture and store rain and surface water. Water from property waterways like creeks can be pumped and stored in water storage tanks.

Utilizing water cyclically can be a viable approach amid resource scarcity. While drinking water treatment may not be feasible, gray water treatment offers opportunities for gardening and building cleaning.

4.4. Findings discussion

The need for conserving public potable water supplies continues to increase worldwide, and water resilience (WR) is a valuable strategy that may be used to overcome this increasing demand. Water resilience strategies such as internal space water storage preparation, reuse of water, usage of water-efficient plumbing material, and usage of Alternative water supply sources, such as rainwater harvesting, groundwater, and treated gray water have become the best solution to eliminate the water shortage. To keep the good health and well-being of the community providing clean water is the other major concern of our world at this current time (SDG-6). The challenge of water scarcity requires an alternative source to fill the gap between demand and supply urgently through water resilience. Water resilience is the simplest and the only option that gives a solution to the urban water crisis.

4.4.1. Water demand and infrastructure

The study shows that the majority of the water used in Kotari condominium comes from municipal tap water, sourced from surface reservoirs and groundwater. The surface reservoir is also a basic source of water at Kotari condominium through tap. Groundwater from boreholes of the municipality is also used as an alternative source of water at Kotari Condominium.

Rainwater harvesting is a common practice among residents, particularly those on the ground floor, in Kotari condominium. This activity involves collecting water during the rainy season. Individual households in Kotari condominium conducted rainwater harvesting privately, utilizing various methods and water containers. They typically collected water through downpipes, and the harvested water was then used for various household activities.

Based on the data, the current water demand and supply fall below the National standard of 20 liters of water per person/per day. To meet this demand, diversifying water sources is crucial. Three water sources have been chosen based on locational advantage: tap water supplied by the municipality, groundwater production from the site, and rainwater harvesting from building rooftops.

4.4.2. Appropriate building resielnt Approaches and Practices

Different adaptive methods are applied to the use of water at Kotari Condominium. The most important adaptive methods are; Storage of water for future use, conservation, water treatment, space planning, diversification of water resources, and an integrated approach. Commonly most of the Kotari residents used different storage mechanisms for storing water.

4.4.2.1.Space uses and planning mechanism

Space planning is a key issue that affects the diversity of water sources and the application of adaptive approaches. Storage, conservation, and diversification of water sources need efficient space planning and use.

4.4.2.2.Resilient and adaptive approach

Storage, conservation, and diversification of water sources need efficient space planning and use. Different methods and mechanisms are used for the adaptive use of water resources. The study indicates that different adaptive and resilient approaches are used separately but not integrated at Kotari Condominium

4.4.2.3.Integrated design

Integration of different sources and methods is one of the basic mechanisms used for the adaptive use of water resources. The study indicates that different adaptive and resilient approaches are used separately. Integration and use of an intelligent approach will further enhance water resiliency.

In Kotari Condominium Neighborhood, the current water supply from AAWSA only meets 30% of the water demand.

4.4.3. Technical and spatial recommendation to be adopted

4.4.3.1. Bathroom space planning and storage of water

Fiberglass water tanks are proposed for water storage, offering options for wall-mounted storage for toilets and handwashing, as well as ceiling-mounted storage. Residents will have the flexibility to choose the storage option that best suits their needs, with sizes tailored to family demand.

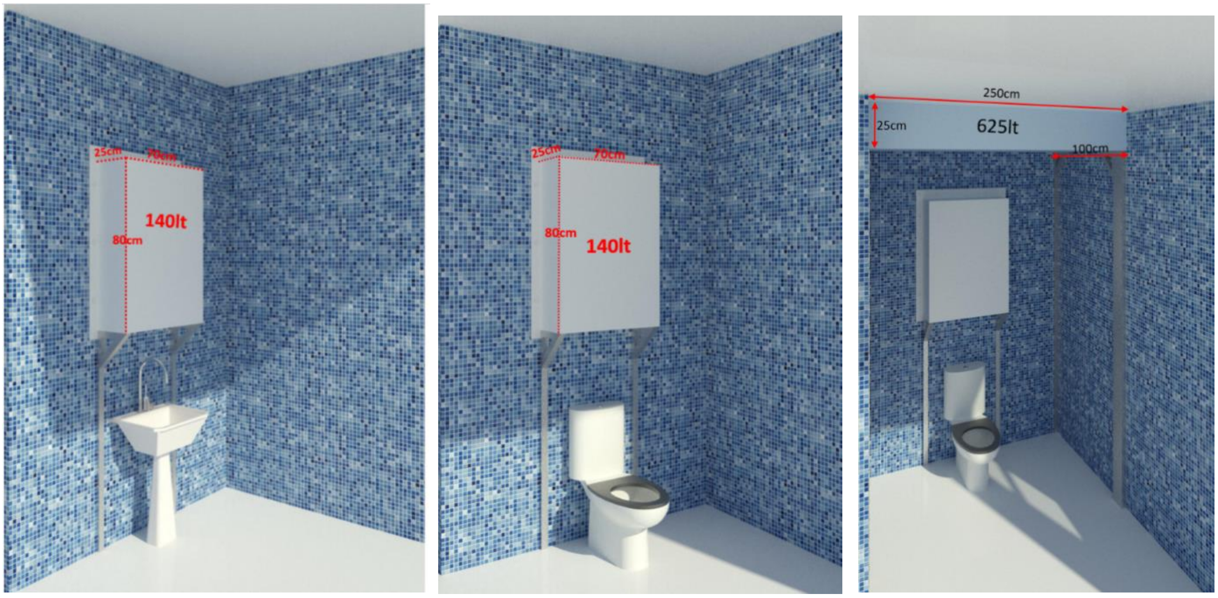


Figure 4.29: Bathroom Space Planning And Storage Of Water

4.4.3.2. Kitchen Space Planning and Storage of Water

Fiberglass water tanks are proposed for water storage, offering options for wall-mounted storage for dishwashing, as well as ceiling-mounted storage. Residents will have the flexibility to choose the storage option that best suits their needs, with sizes based to family demand.

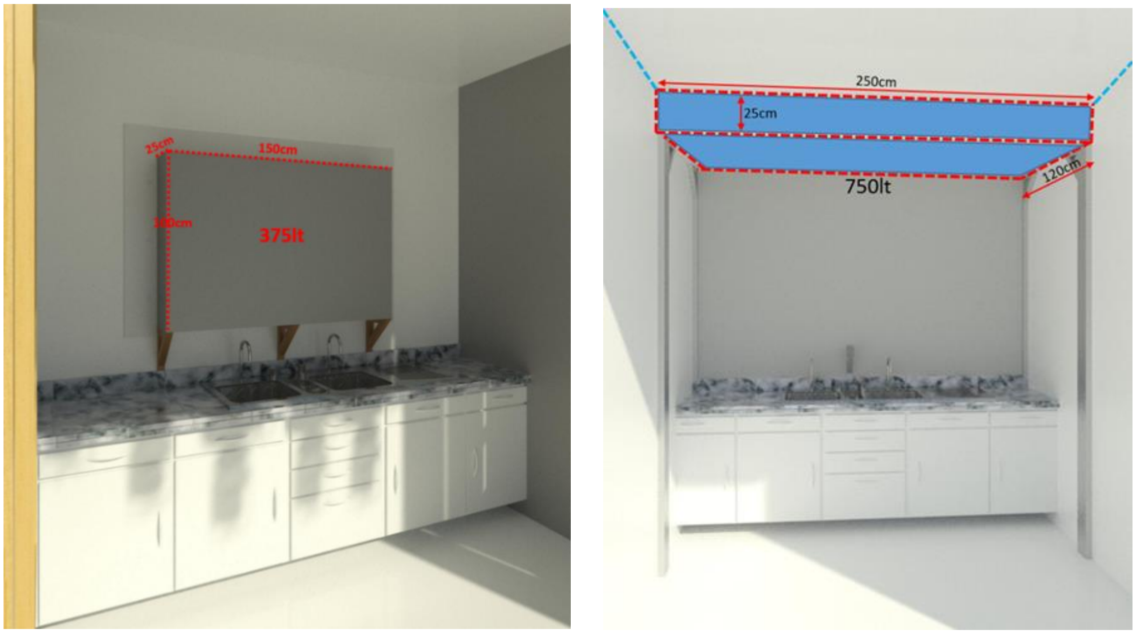


Figure 4.30: Kitchen Space Planning And Storage Of Water

4.4.3.3.Gray Water Re-Use

Poor quality gray water has no problem if it is used to flush the toilet because the water goes into the sewer or septic system where it would have gone had it not been reused gray water should be pumped into the toilet bowl for flushing

Figure 0.31: Gray Water Re-Use

4.4.3.4.Using Water efficient Plumbing appliances and fixtures

This study strongly recommends the use of important types of water-saving plumbing fixtures to ensure safe water usage and prevent wastage. Additionally, it advocates for the utilization of alternative water sources and water storage mechanisms to further enhance water conservation efforts.

Here are some of the recommended water-efficient plumbing fixtures: low-flow showerheads, low-flow toilets, water-saving faucets, smart faucets, pressure-reducing valves (PRVs), and low-flow showerheads.

Figure 0.32: Water-Efficient Plumbing Fixtures(Open source)

4.4.3.5. Diversification of Water Source

The study recommends utilizing additional alternative water sources alongside the current supply from AAWSA. Two alternative water sources are recommended for implementation and designed according to the landscape and topography of the site and managed and treated by AAWSA for drinking purposes. Rainwater harvesting and Ground Water.

After water treatment is completed, two additional sources, underground water and rainwater, will be incorporated into the piped water line from AAWSA. AAWSA will take ownership and responsibility for these additional water sources.

i. Municipal Tap Water

AAWSA takes ownership of the project, and the treated rainwater and groundwater to meet the pipeline currently supplied by AAWSA. According to this study, it is imperative to propose architectural and engineering solutions to make the neighborhood water-resilient and mitigate the water shortage faced by residents. To achieve 20 litter per day demand of water for 950 people the study suggests the following 50.6% to be covered by municipal tap line which is 3,515 m3 of water needed to cover 185 days of the year by tap water.

ii. Ground Water

According to the study, Groundwater is suggested to cover 120 days of year water consumption which is 32.87% of the water demand in the case area. This recommendation is based on the abundance of groundwater based on the collected data for the case area during the study. Since there is an abundant amount of ground water it is possible to supply more than this demand since groundwater is recharged frequently. This amount corresponds to 2,280 m3 of water needed for 4-month periods from the total year. To use water produced every week we need a surface water storage tanker of a capacity of 30 m3 or more to store water to be used daily.

Figure 0.33: Groundwater Harvesting

iii. Rain Water Harvesting

According to the study, rainwater is suggested to cover 16.5% of the water demand in the case area which accounts for 60 days or 2-month rainy season periods. This recommendation is based on the abundance of rainwater harvesting capability data collected around the case area from the rooftop. This amount of water could be stored in underground storage tanks. The rainwater harvested can be stored in 1,140 m3 to be used for 15 days only. So for 15-day use, we need 10 underground storage tanks of a capacity of 30m3.it is expected to be filled with rainwater 4 times a year in rainy seasons.

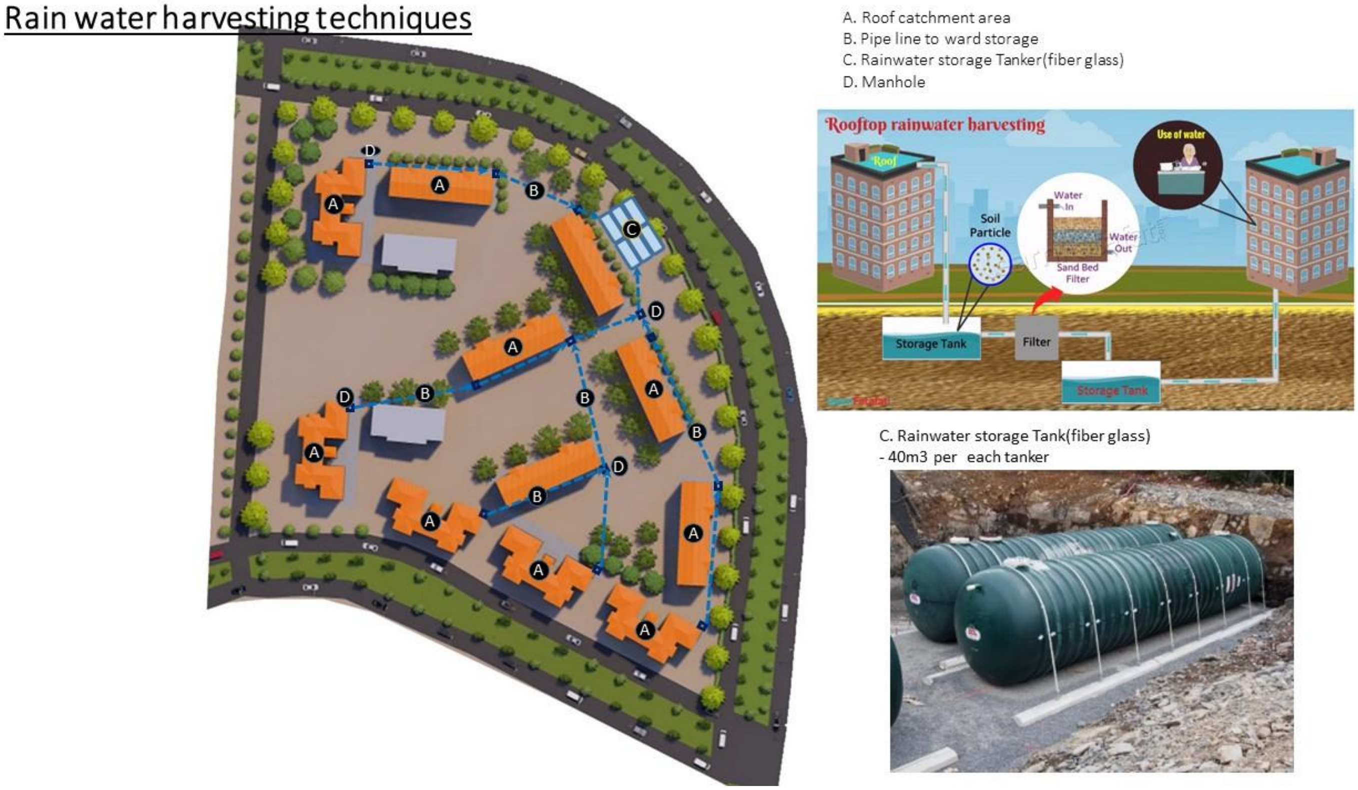


Figure 0.34; Rainwater Harvesting and Storage

4.4.3.6.Integration of the three Water Sources into One

Based on the map, it is advisable to construct both the rainwater and groundwater storage tanks at the lowest point of the site to maximize water accumulation. The stored water can then be pumped to the highest point of the site for easy distribution. After both rainwater and groundwater were treated, they were pumped to the highest point of the site to meet the pipe of AAWSA's water supply. This approach simplifies the process, reduces costs, and enhances manageability. AAWSA will take responsibility for treating the water and collecting bills from the residents, streamlining operations.

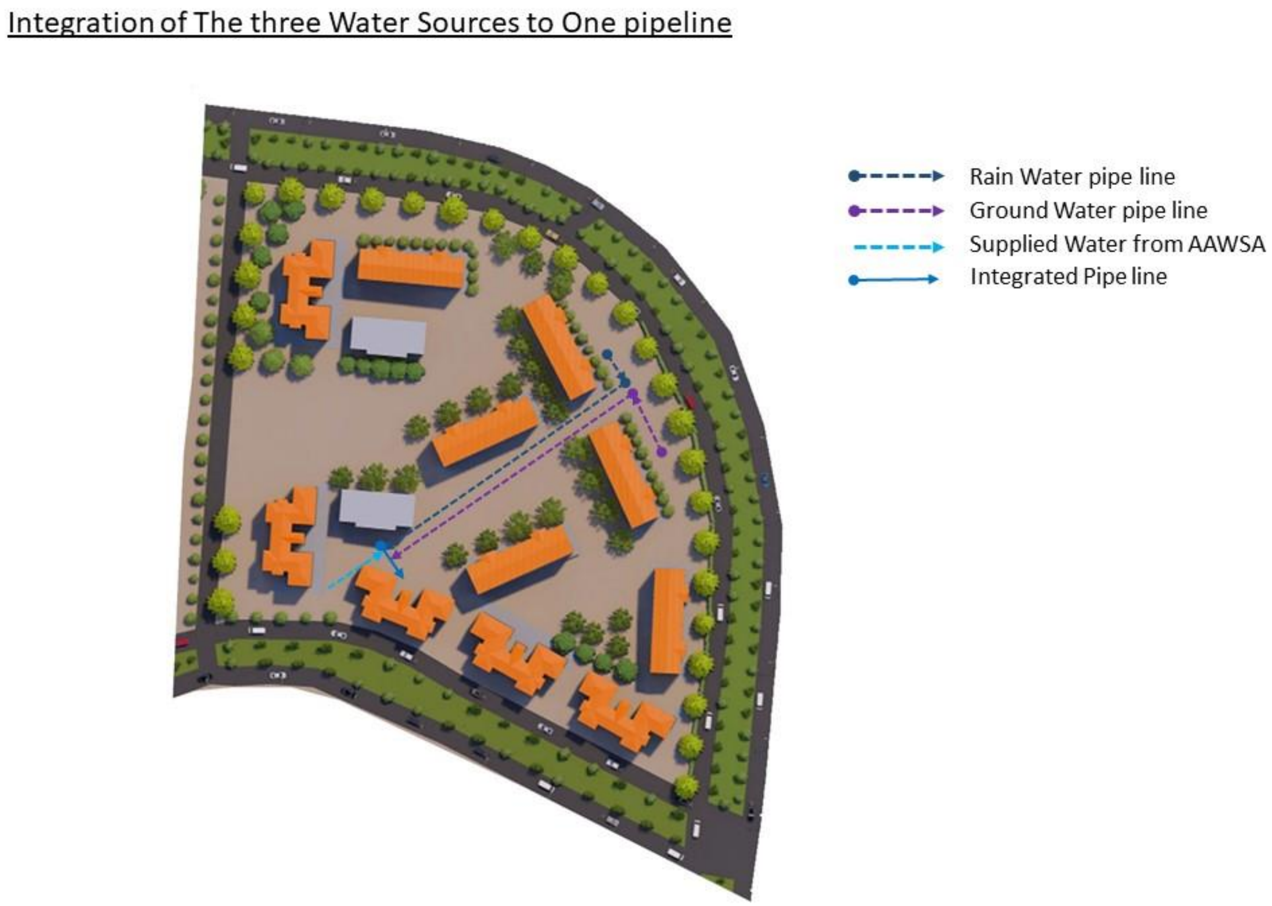


Figure 0.35: Piped Water Supply System Integration

Chapter five: Conclusion and Recommendations

5.1. Conclusion

Urban water management needs to be approached with innovation and openness, especially considering the numerous water challenges cities face. Building water resilience is crucial for addressing local water challenges and ensuring safe, secure, and inclusive water and sanitation services for everyone. Additionally, it helps protect infrastructure and communities from water-related risks. Decision-makers and stakeholders need the knowledge and ability to make informed decisions and investments in their city's water sector.

By collectively rethinking urban water systems using resilience principles, cities have an opportunity to address global water challenges. This approach provides a systemic and transformative way to deliver water supply and sanitation services more sustainably, inclusively, efficiently, and resiliently.

Housing is essential for human existence, offering living spaces that must be comfortable and appropriate. This research paper seeks to suggest the best methods to improve water resilience by introducing alternative water sources for residents. The aim is to ensure that water storage during shortages is efficient and visually appealing, with a focus on optimizing internal space utilization for each household unit.

5.2. Recommendations

For resilient and adaptive use of water resources in Kotair condominium the following recommendations are drawn from the study.

Diversification of water resources is one of the basic tools in achieving water supply to the residents. All potential resources in and around the Kotari Condominium should be used. Surface water, groundwater, and rainwater resources can be used to alleviate the Condominium water resiliency problem in Kotari Condominium.

Different adaptive methods can be applied to the use of water at Kotari Condominium. The most important adaptive methods are; Storage of water for future use, conservation, water treatment, space planning, diversification of water resources, and an integrated approach. Commonly most of the Kotari residents used different storage mechanisms for storing water.

Planning the space within individual units is crucial for storing water without encroaching on limited internal household space. This ensures that residents have comfortable living and working areas while also facilitating easy water storage and upgraded usage compared to traditional methods. The newly designed storage system outlined in this study allows residents to store and access water directly through pipelines rather than manually fetching it with containers.

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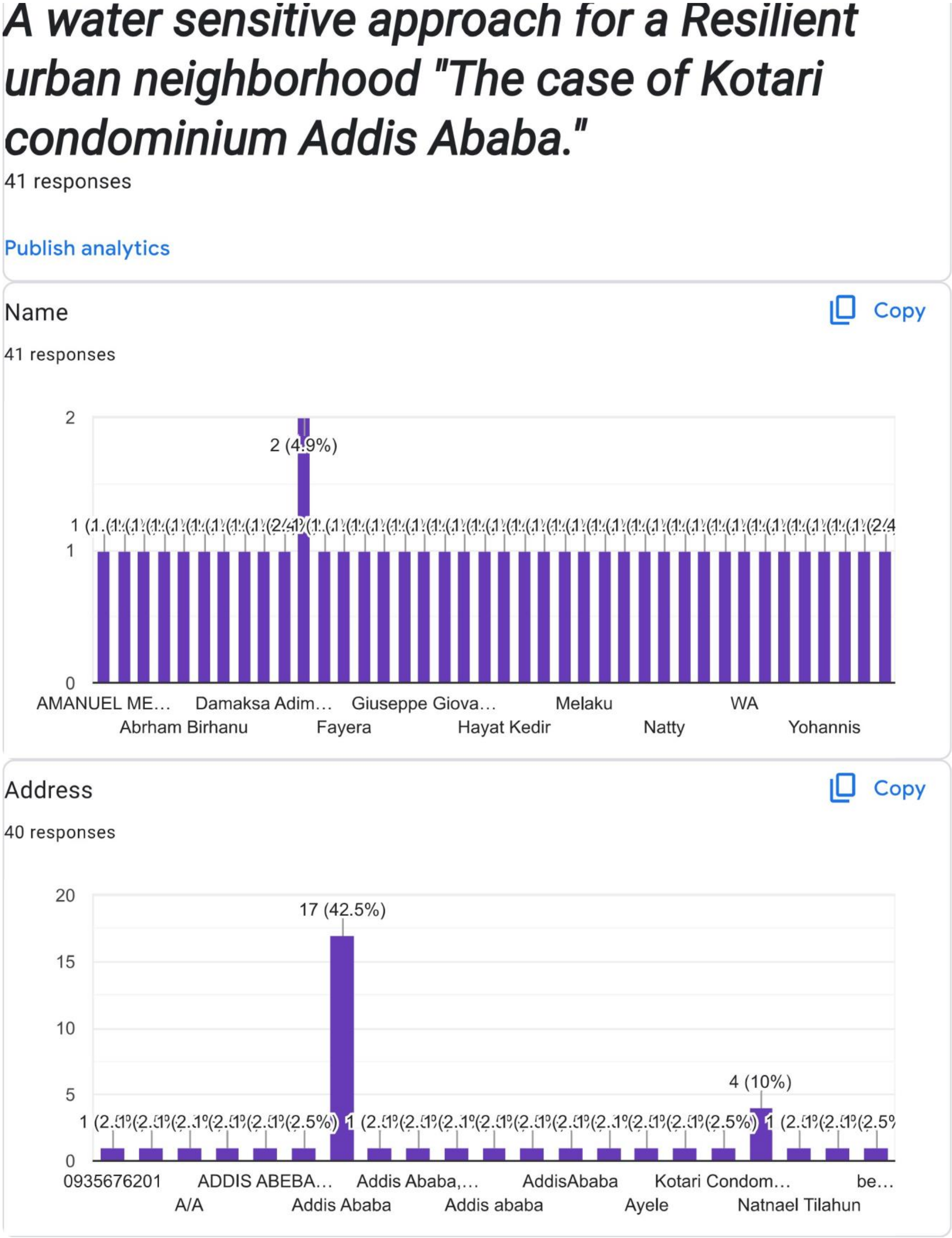
Appendix

A. Questioner



A water sensitive approach for a Resilient urban neighborhood "The case of Kotari condominium Addis Ababa."

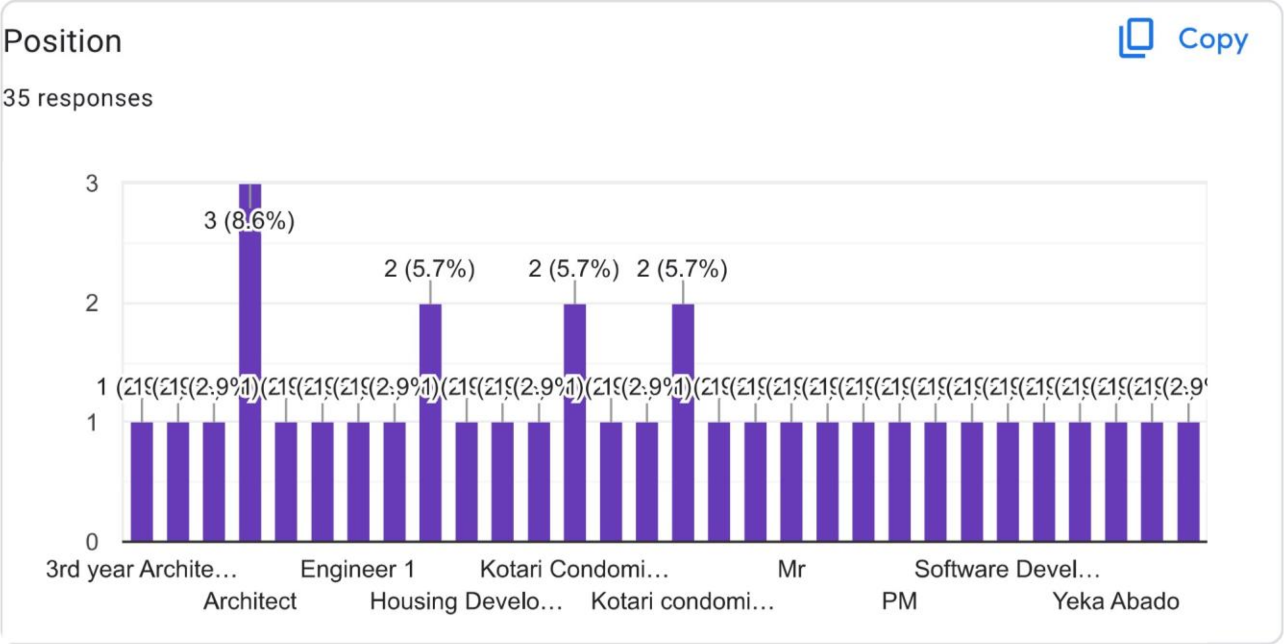
41 responses

Name

41 responses

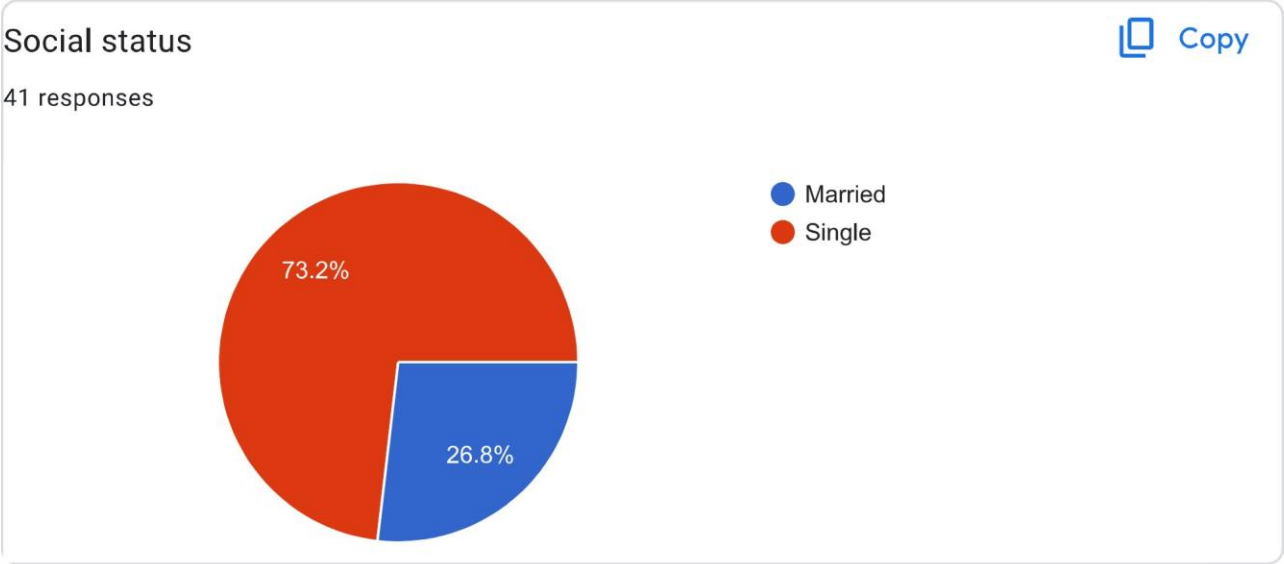
Address

40 responses



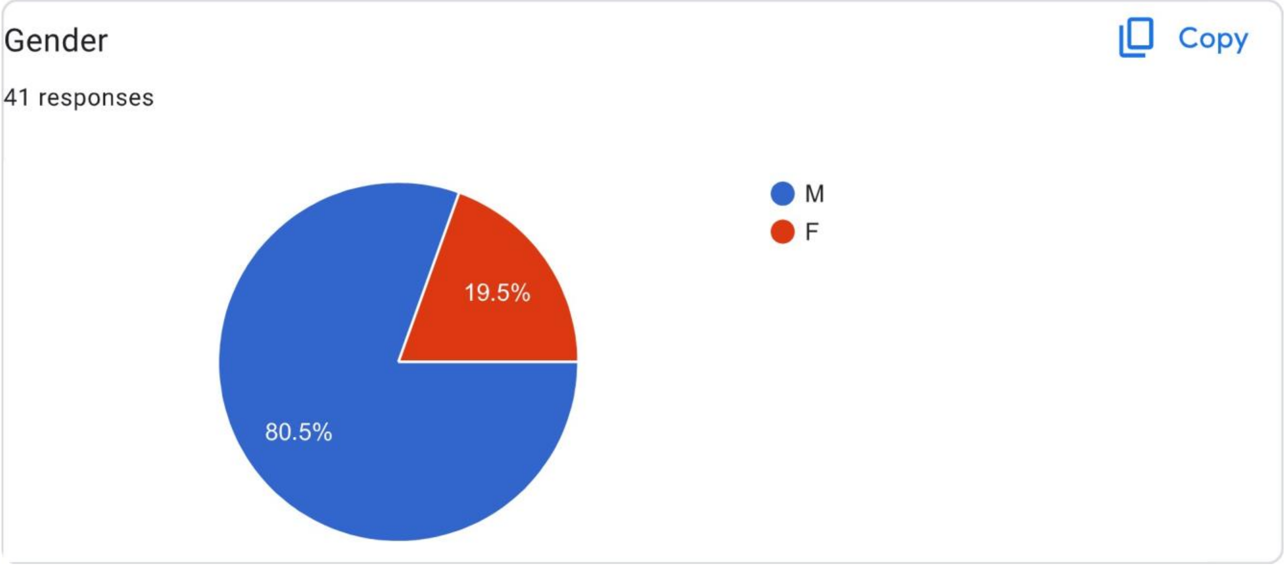
Position

35 responses



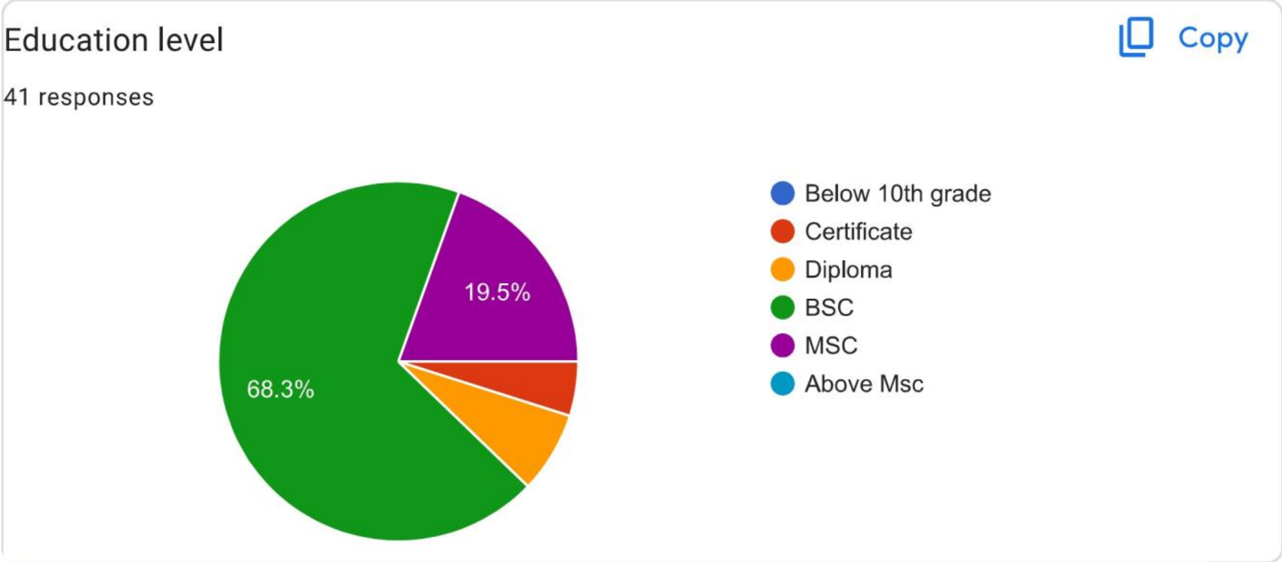
Social status

41 responses



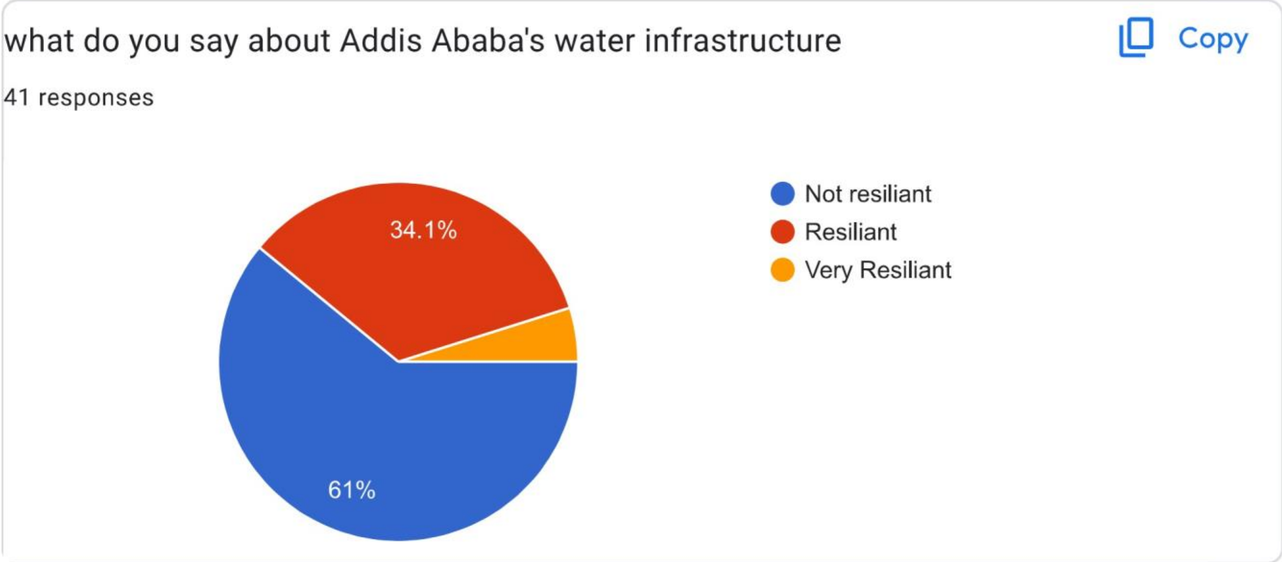
Gender

41 responses



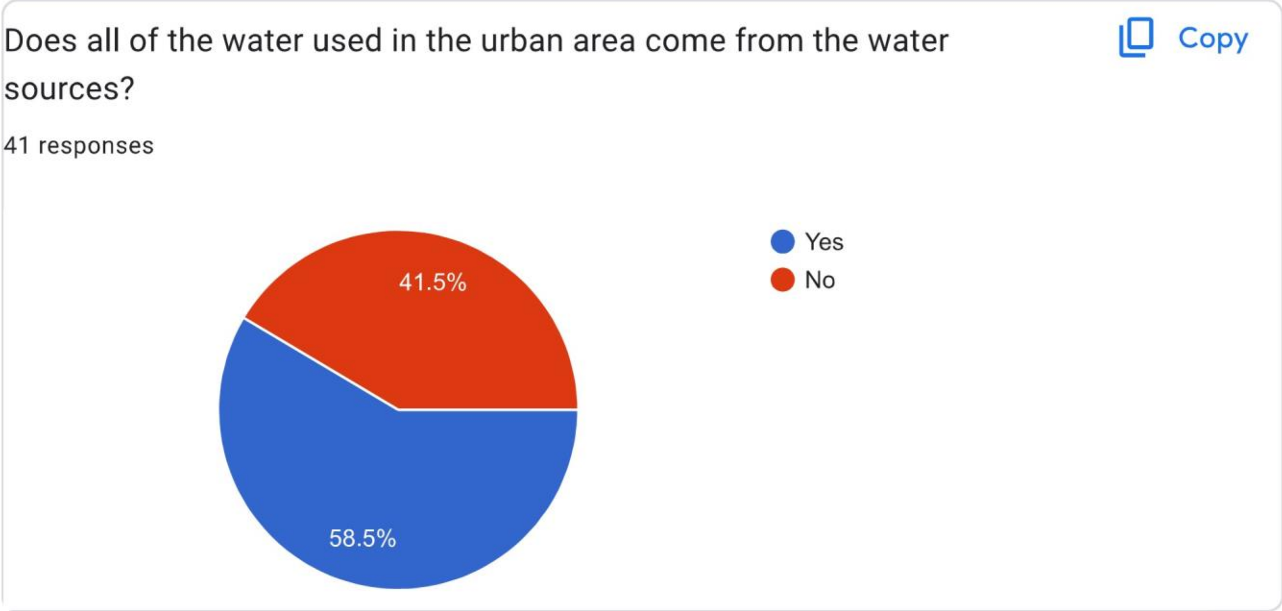
Education level

41 responses



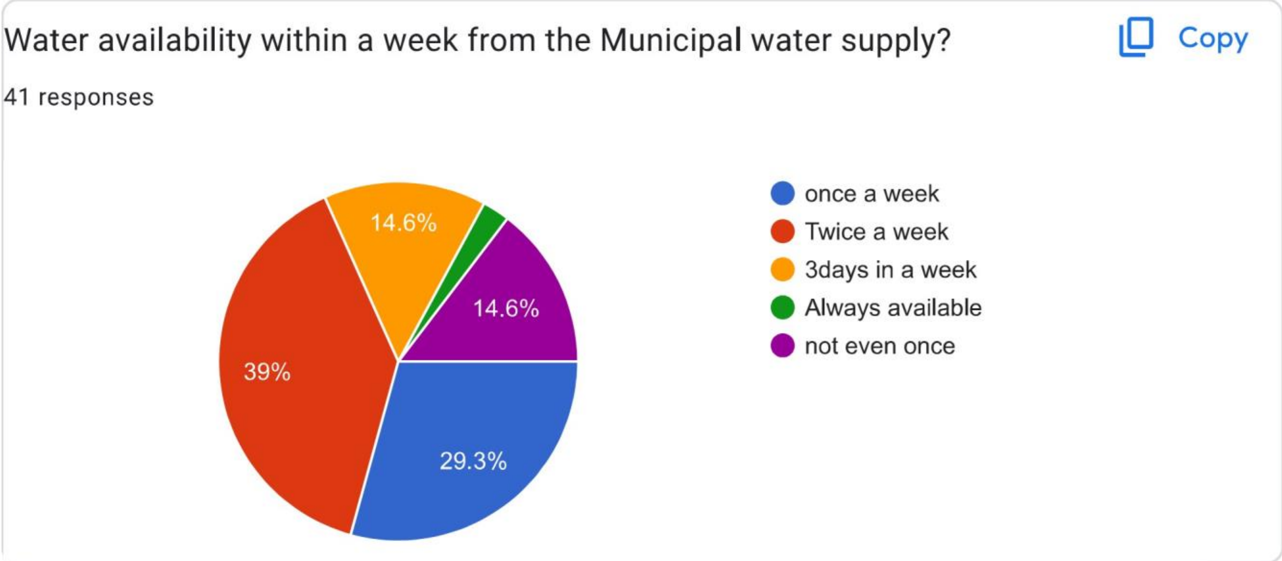
what do you say about Addis Ababa's water infrastructure

41 responses



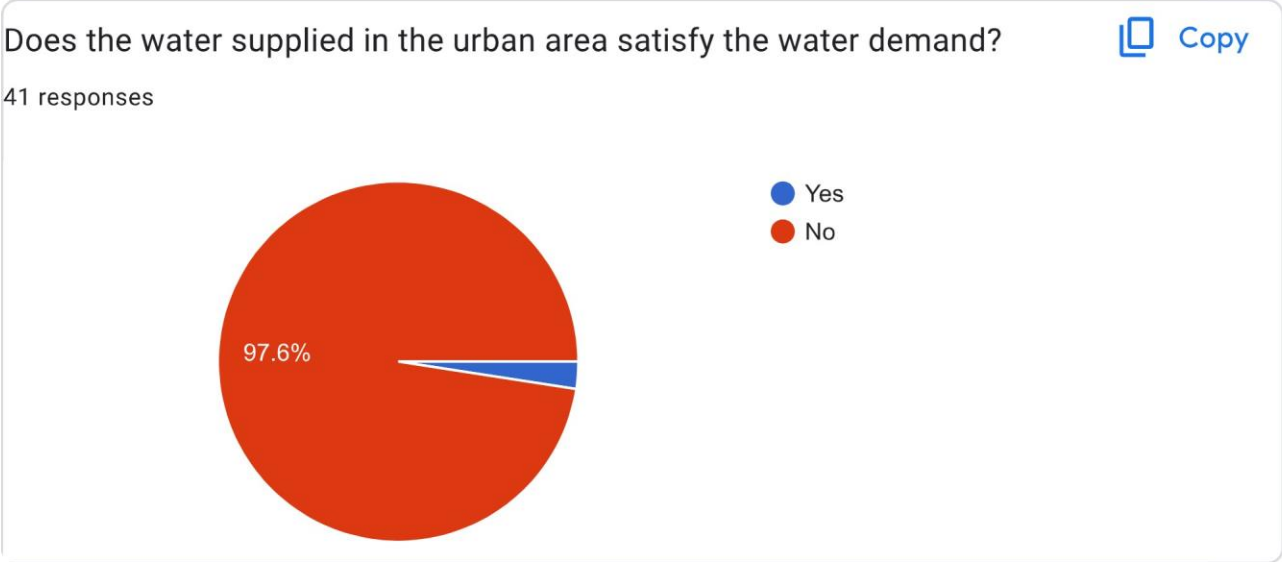
Does all of the water used in the urban area come from the water sources?

41 responses



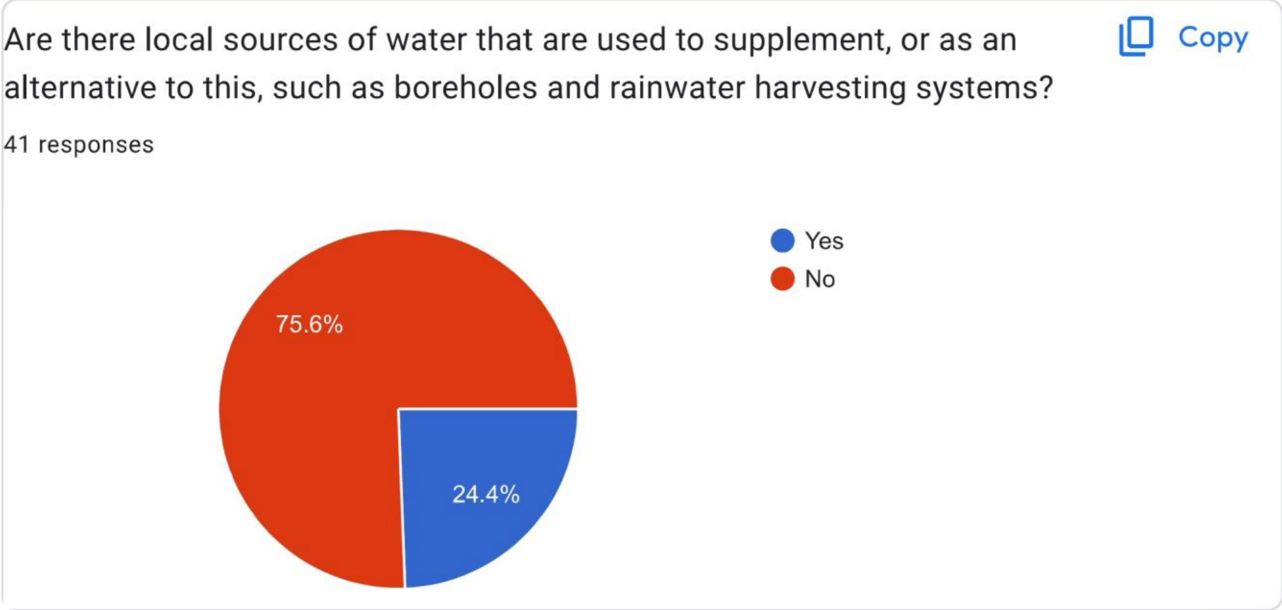
Water availability within a week from the Municipal water supply?

41 responses



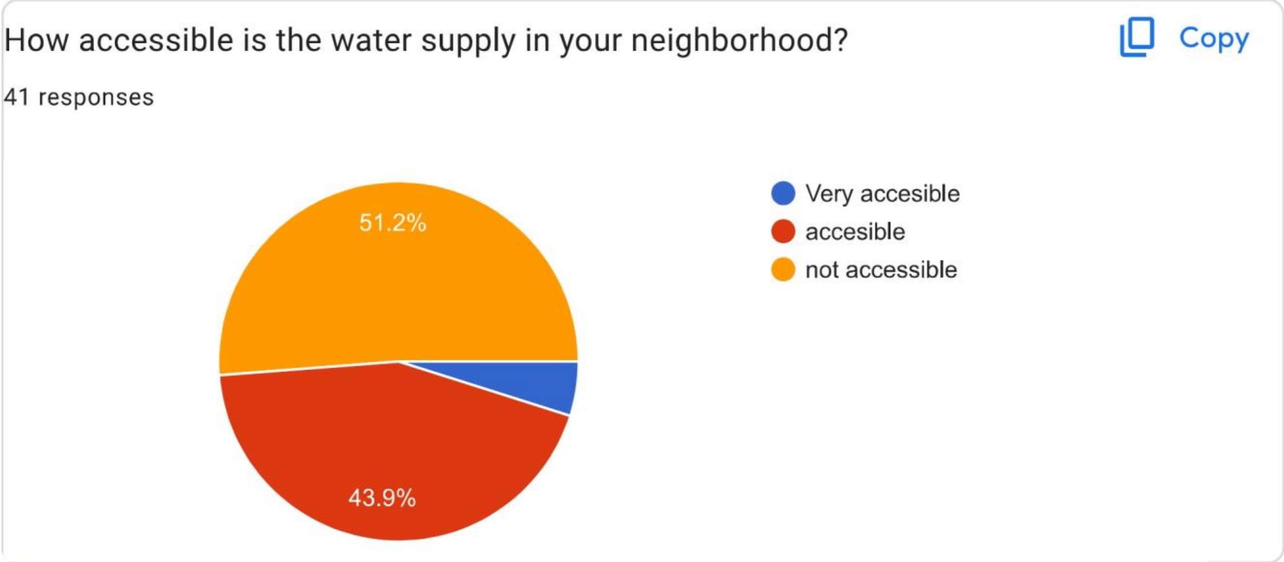
Does the water supplied in the urban area satisfy the water demand?

41 responses



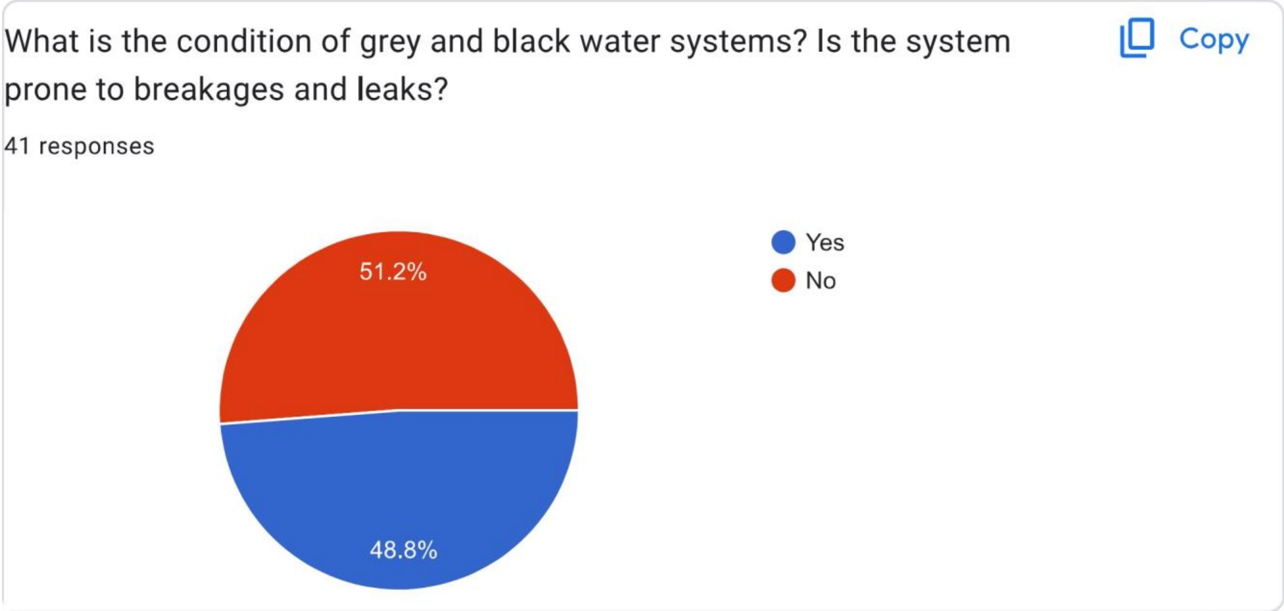
Are there local sources of water that are used to supplement, or as an alternative to this, such as boreholes and rainwater harvesting systems?

41 responses



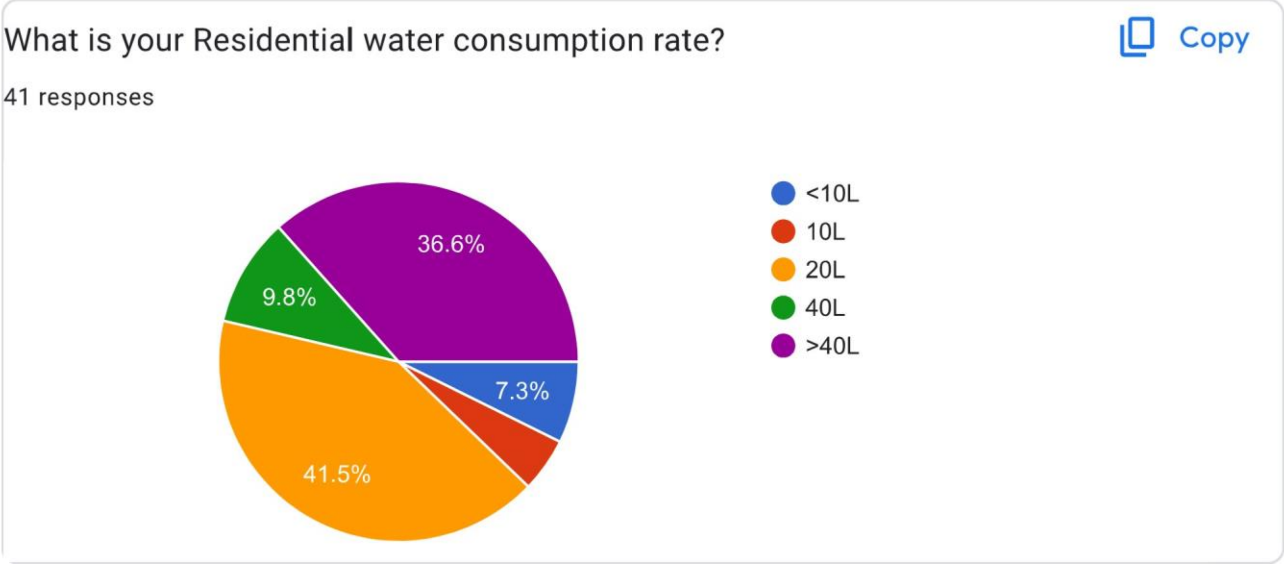
How accessible is the water supply in your neighborhood?

41 responses



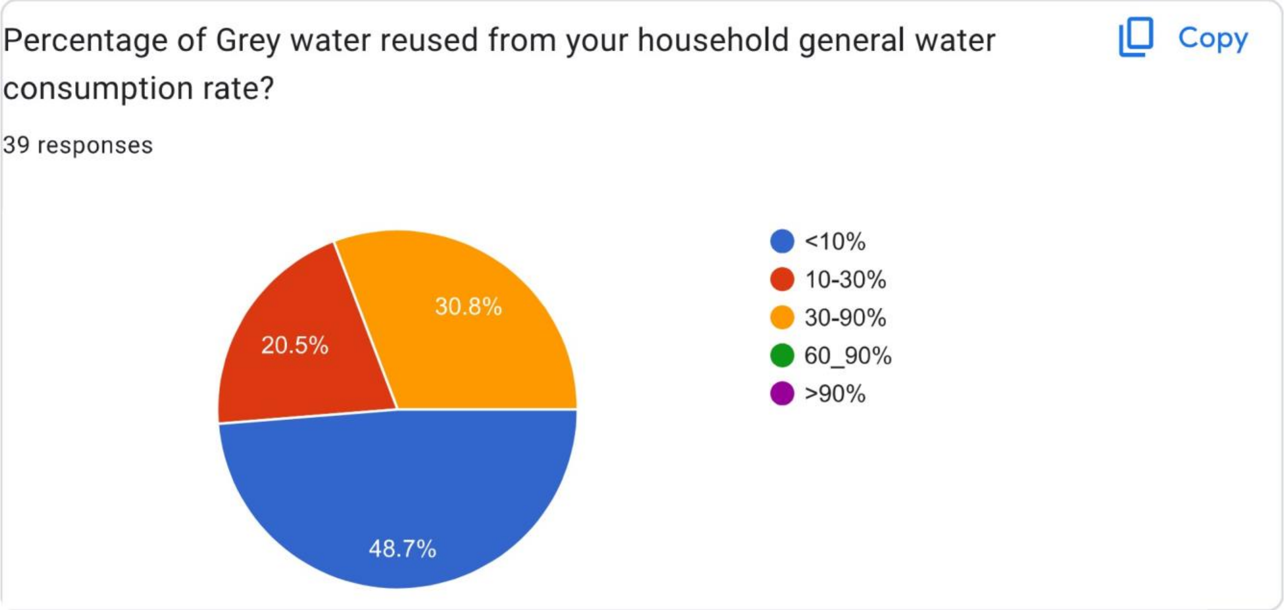
What is the condition of grey and black water systems? Is the system prone to breakages and leaks?

41 responses



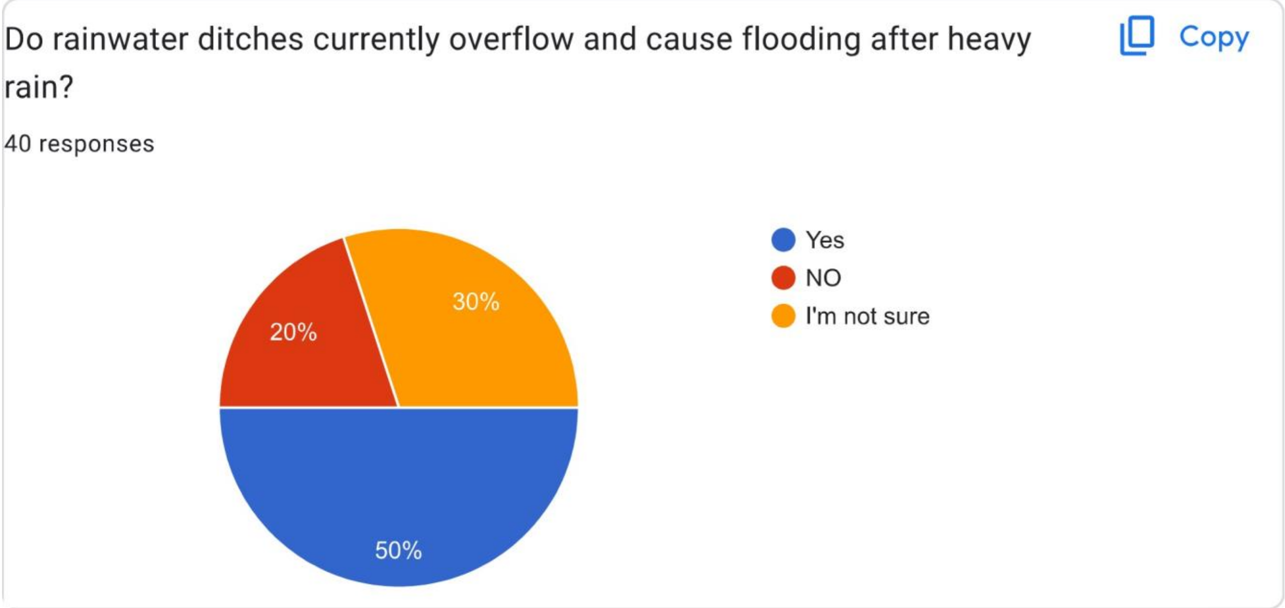
What is your Residential water consumption rate?

41 responses



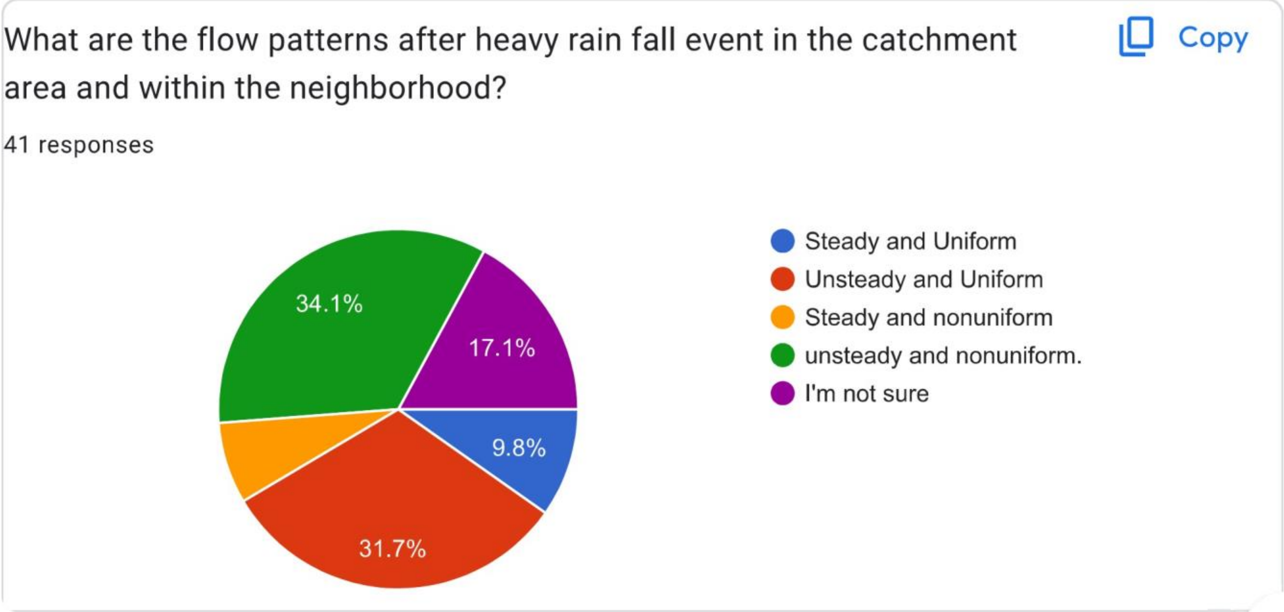
Percentage of Grey water reused from your household general water consumption rate?

39 responses



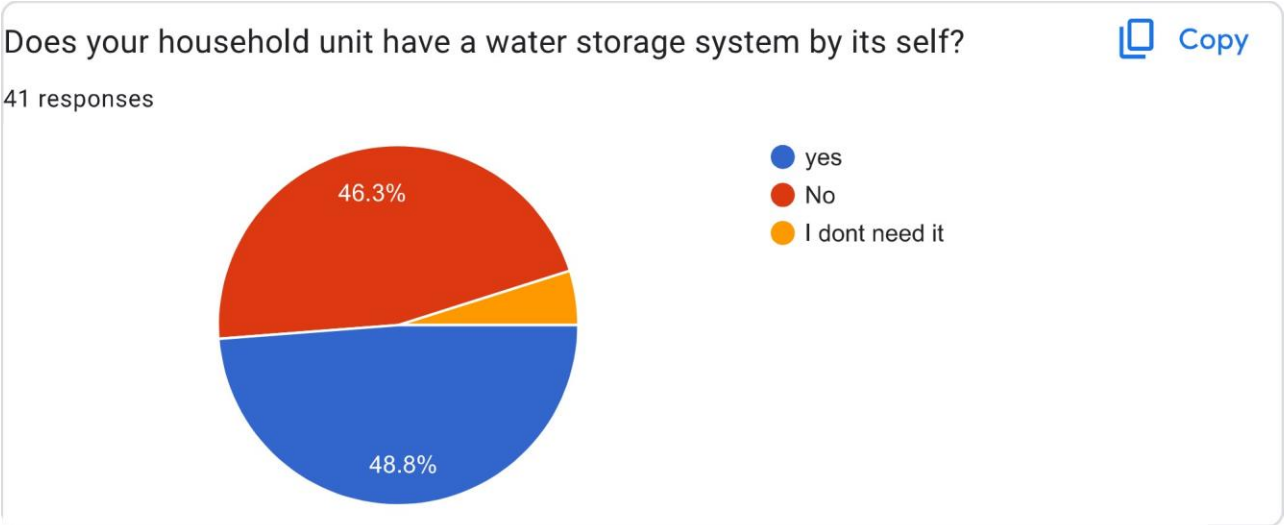
Do rainwater ditches currently overflow and cause flooding after heavy rain?

40 responses



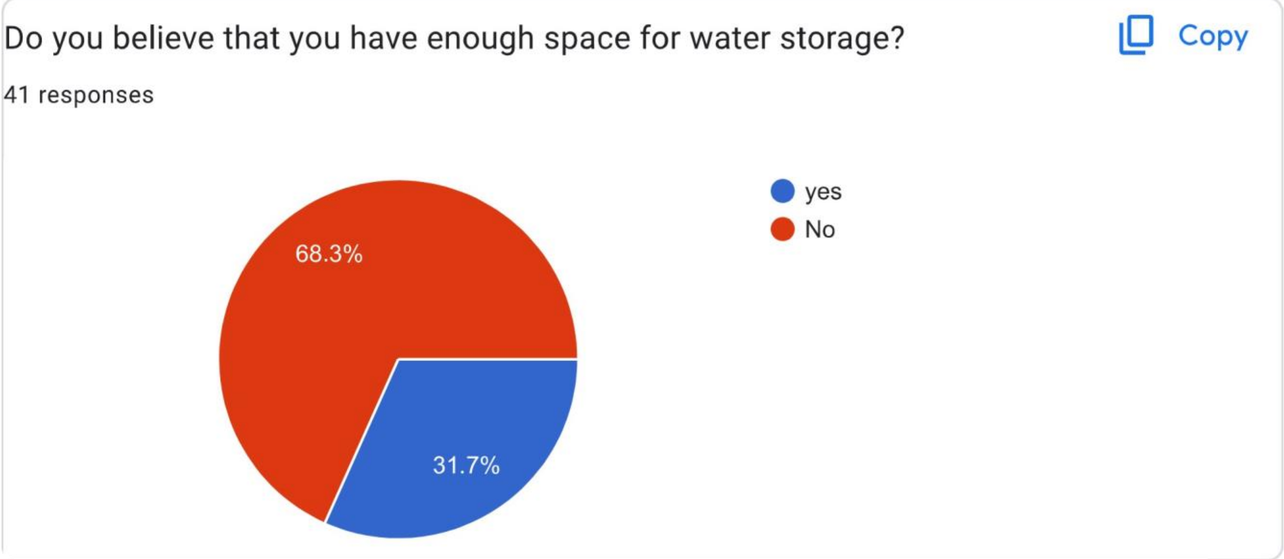
What are the flow patterns after heavy rain fall event in the catchment area and within the neighborhood?

41 responses



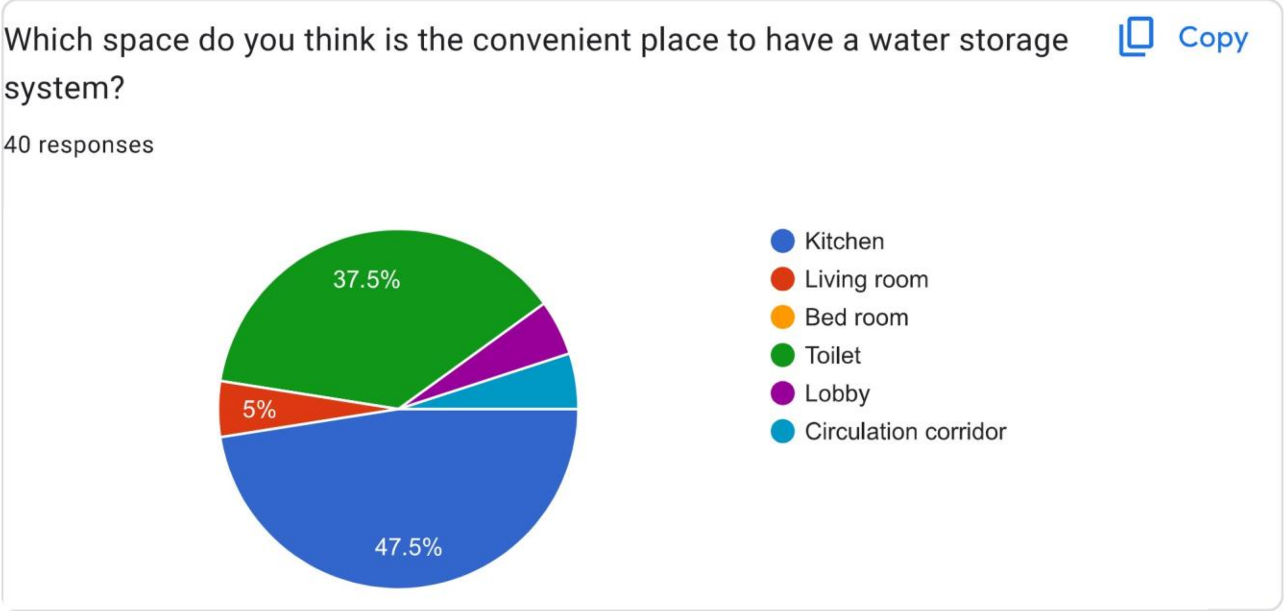
Does your household unit have a water storage system by its self?

41 responses



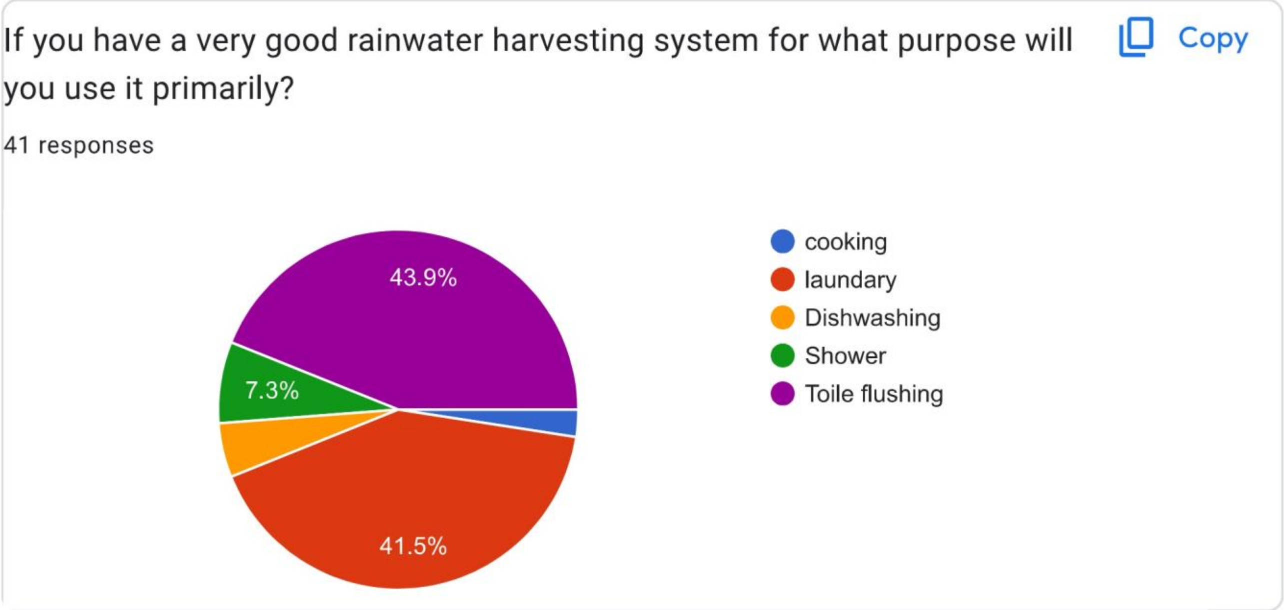
Do you believe that you have enough space for water storage?

41 responses



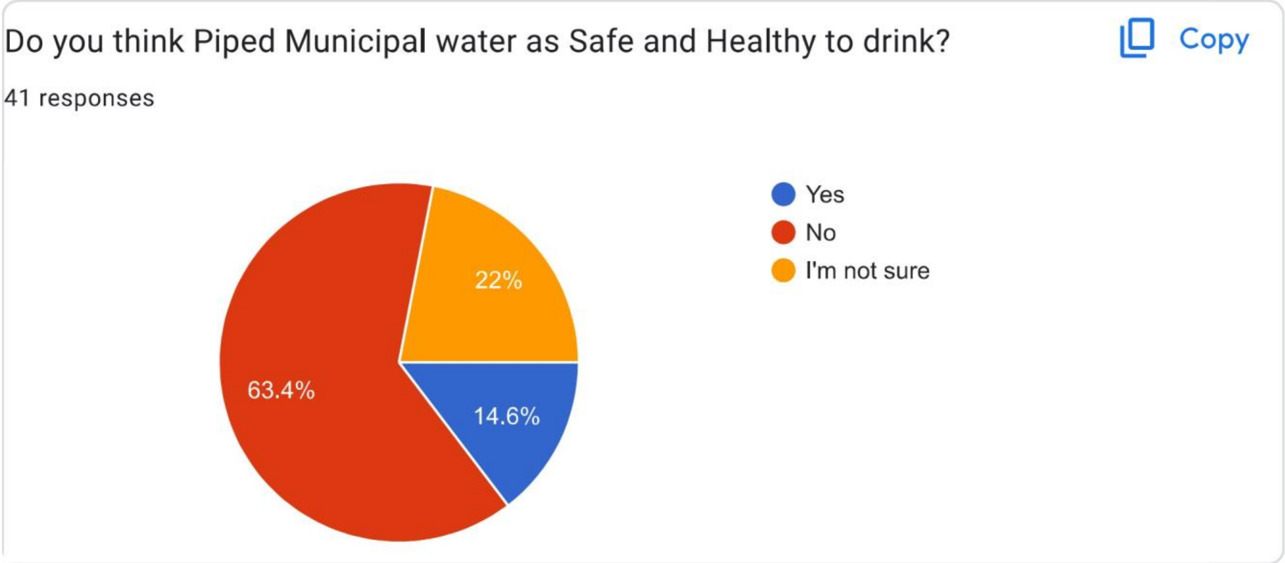
Which space do you think is the convenient place to have a water storage system?

40 responses



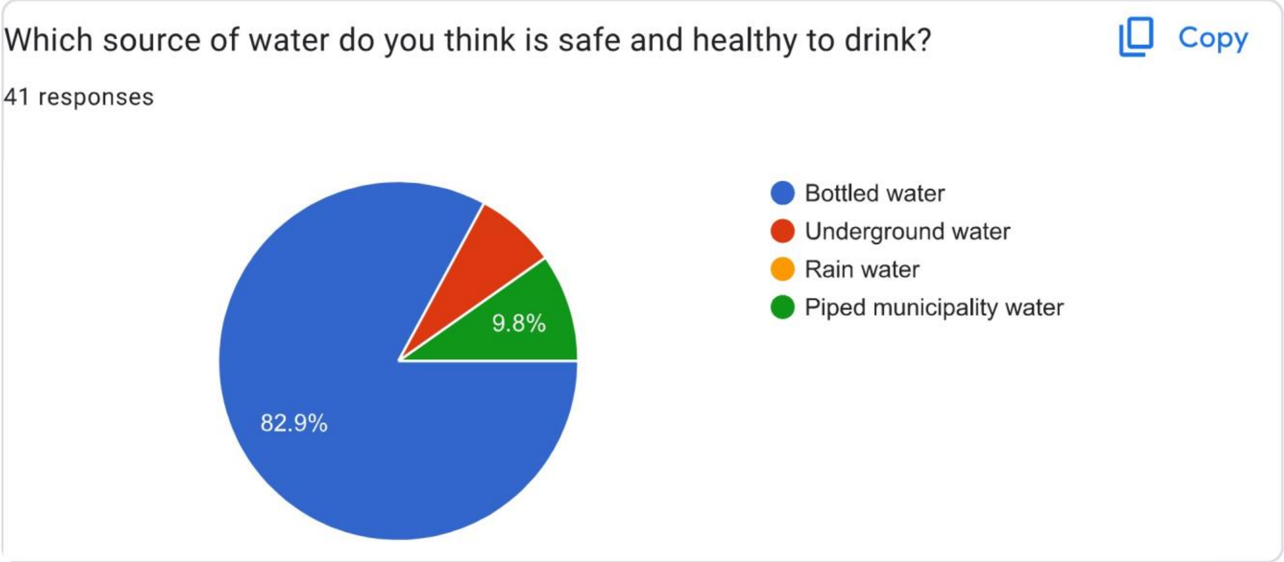
If you have a very good rainwater harvesting system for what purpose will you use it primarily?

41 responses



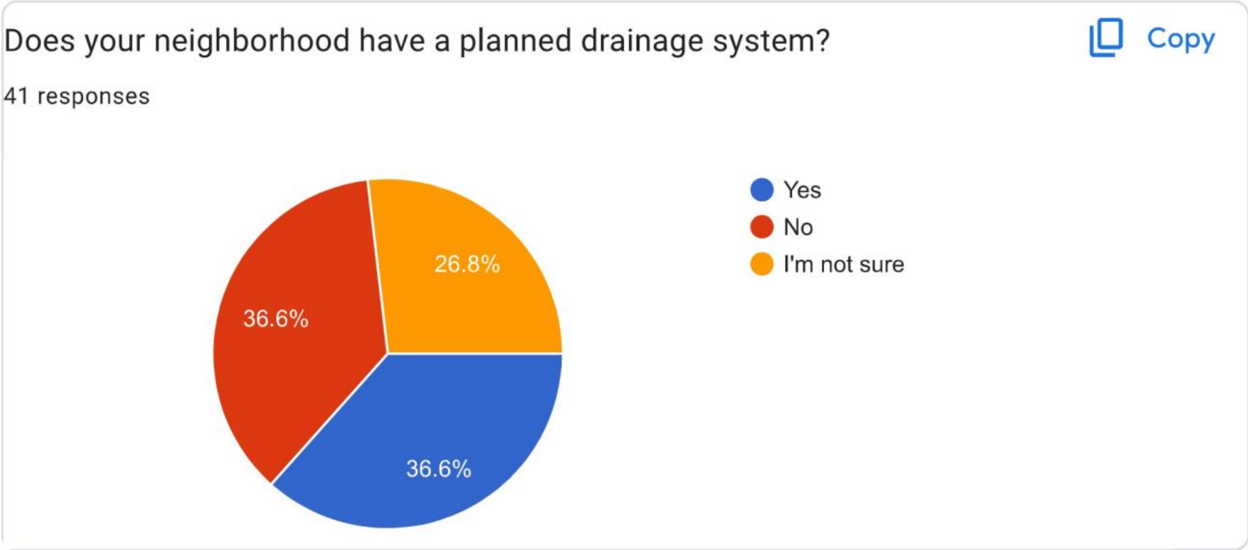
Do you think Piped Municipal water as Safe and Healthy to drink?

41 responses



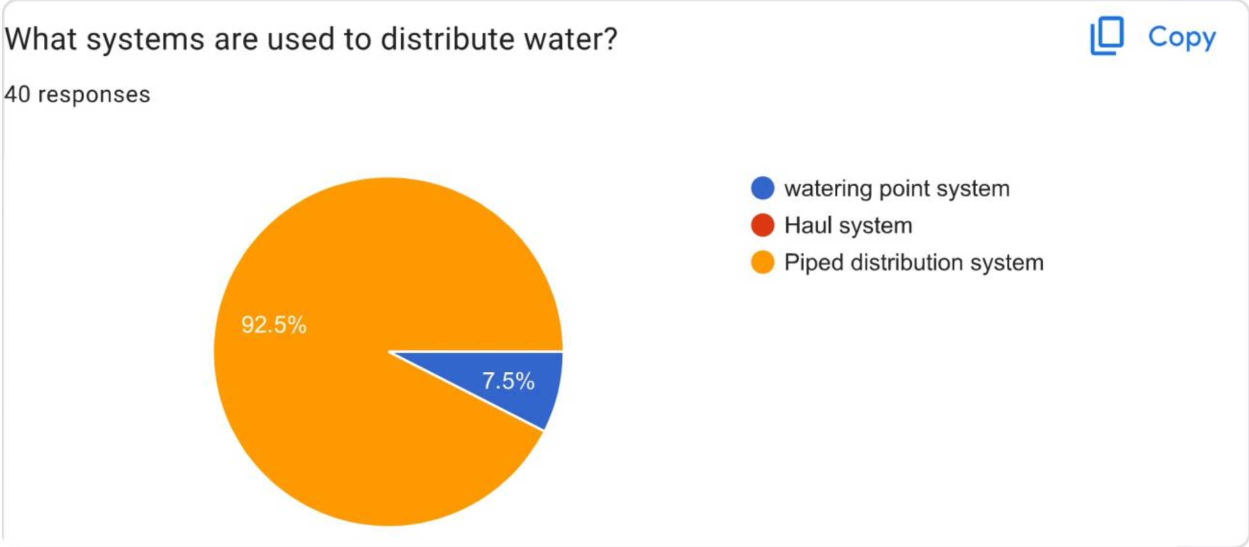
Which source of water do you think is safe and healthy to drink?

41 responses



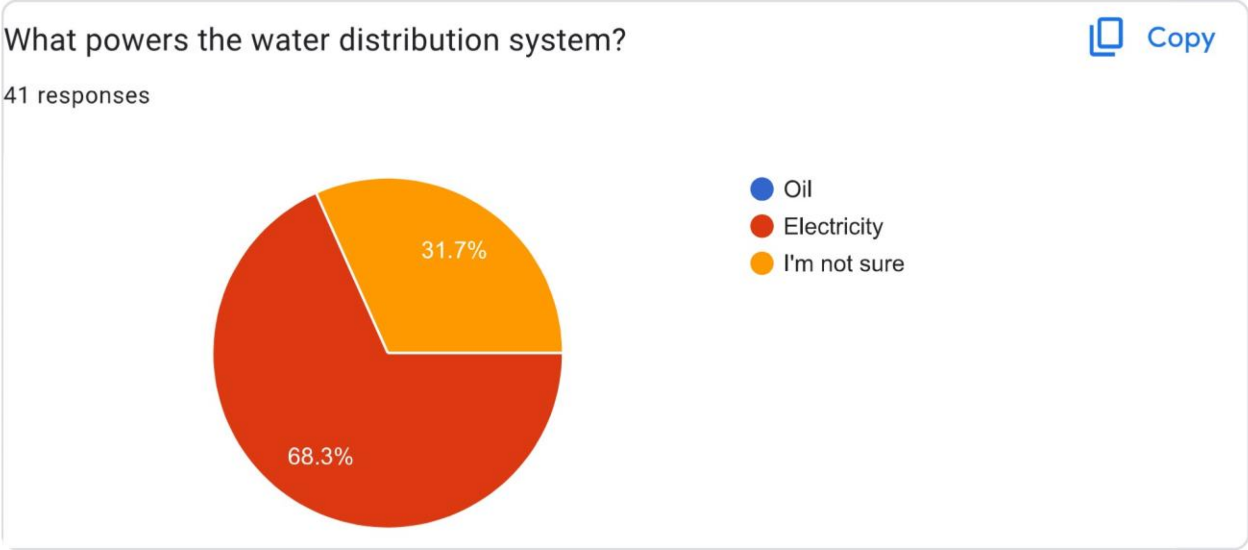
Does your neighborhood have a planned drainage system?

41 responses



What systems are used to distribute water?

40 responses

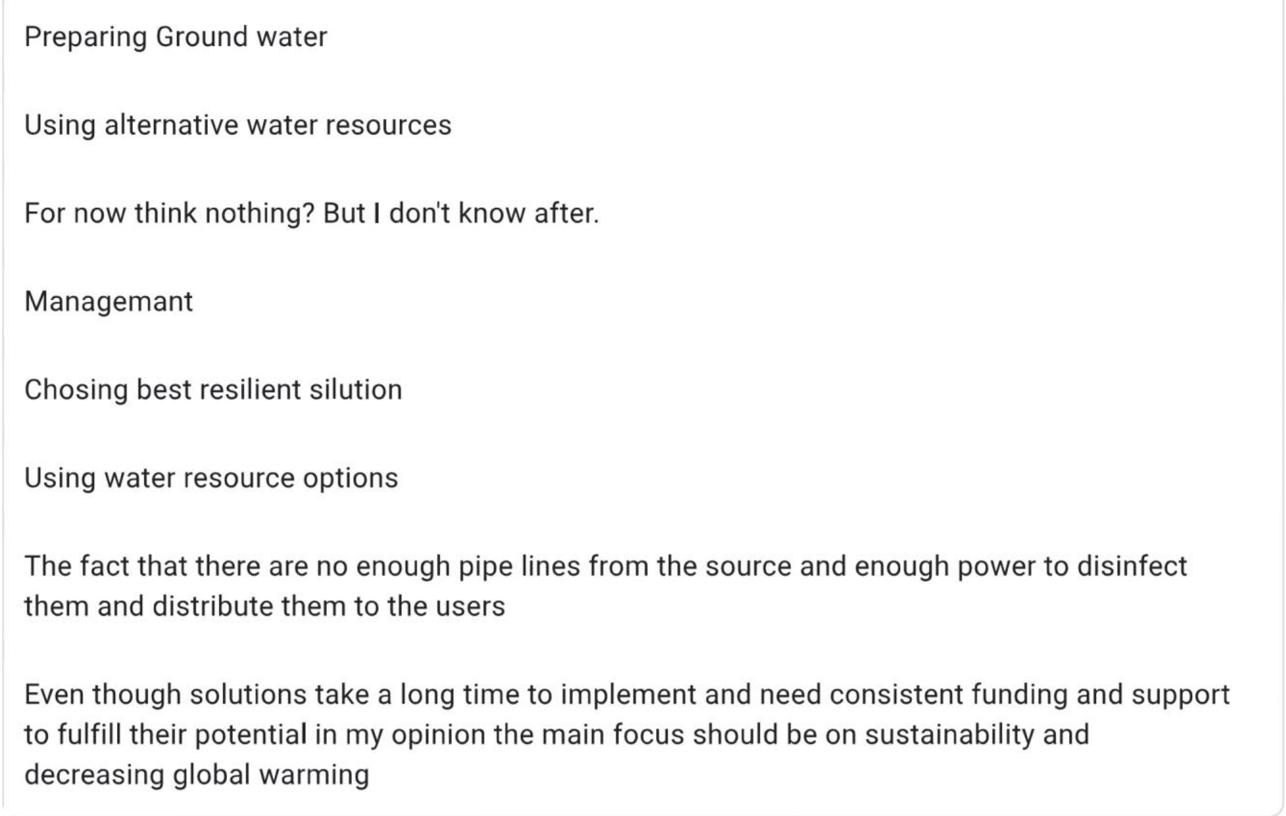


What powers the water distribution system?

41 responses

ent urban neighborhood?
29 responses

- Underground water
- Am not sure
- Make water treatment so it fulfill the demand of city
- Sufficient infrastructure and follow-up.
- Piped distribution system
- you know better
- Good governance and infrastructure
- Good infrastructure and urban plan
- It have to provied good planning and design and also make public awarness and stackholder for any
- Proposal and planning
- properly planned infrastructure development
- managing the distribution system of the city and giving awareness for the community about how to properly use the water.
- By reducing Distribution problem
- i am not sure
- The government need to provided a good water supply with infrustructure
- Proper strategic planning before laying out the pipe system. And consider the city population size currently and in the foreseeable future.
- Constructing and building a good pipeline infrastructure!
- Strong social networks and deviresity
- i don't know
- Make a bigger reseviour for water sotrage and make reusable the wast water



Preparing Ground water

Using alternative water resources

For now think nothing? But I don't know after.

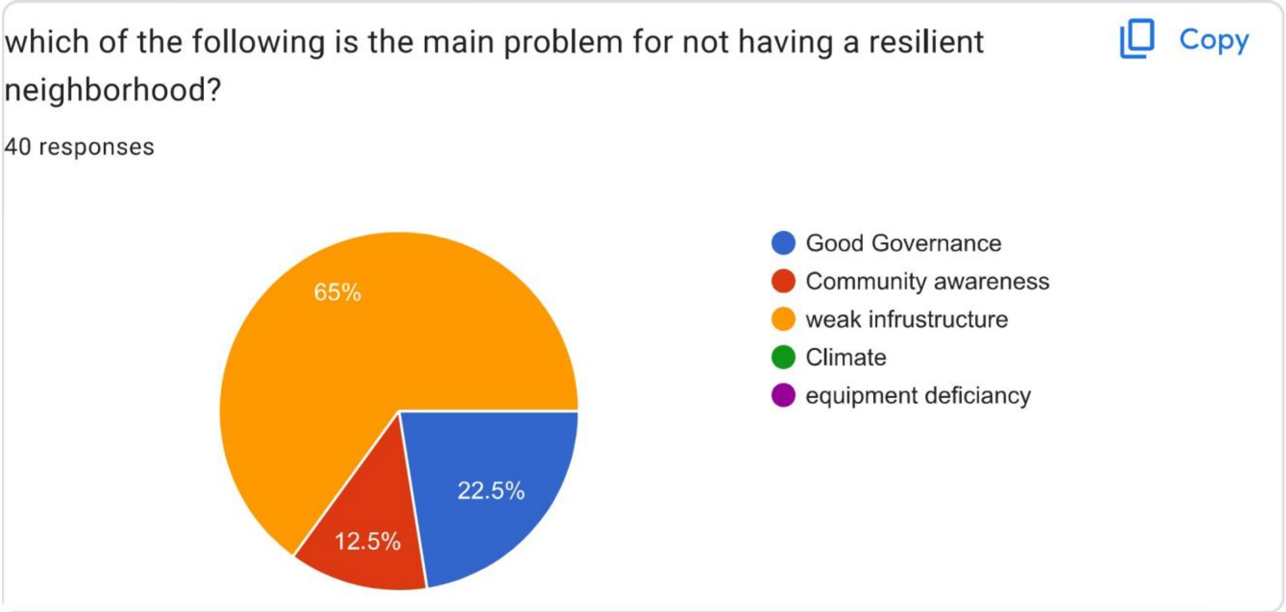
Managemant

Chosing best resilient silution

Using water resource options

The fact that there are no enough pipe lines from the source and enough power to disinfect them and distribute them to the users

Even though solutions take a long time to implement and need consistent funding and support to fulfill their potential in my opinion the main focus should be on sustainability and decreasing global warming



which of the following is the main problem for not having a resilient neighborhood?

40 responses

Explain how water resilience can be achieved in an Urban neighborhood.
33 responses

Am not sure

By teaching the community how to use water safely not misuse it

Using the technology to reuse the water.

It is important to situate challenges facing urban water systems within broader responses to climate change and improved governance of ecosystem services
Generally, water resilience may include ecological aspects of water quality and shortage mitigation, engineered infrastructure to ensure safe and reliable water supply and to mitigate shortage in water supply, and the socially inclusive and equitable governance of these systems.

Piped distribution system

funny, you know better

Good governance and safe infrastructure

Pipeline

Creat public awarness and uses of good planning and design like water sensetive urban design elements by planting of plant, managble lanscape with respect of slopneses, it uses rain water harvesting system

properly planned infrastructure development and implementation

actually, I don't know.

By creating good water distribution management

i am not sure

Its all on the government the infrustructure , the water supply and all need to be fixed by government ,also the people should use the Water in responsible way.

By Using Sustainable water management.

Water resilience can be achieved by shaping good governance, with better infrastructure and timely maintenance system.

By having a good and well infrastructure design of urban strategy and commitments of good governance!

Government must give a focus and attention on this urban development process.

Implement water conservation measures and Develop green infrastructure

i don't know

I think the main solution for resilient water is by creating awareness about water usage and saving.

Good management from government side

The government must work on necessary infrastructure .

Creating enough water resources

Am thinking the only way to achieve resilience is stop using water at all. Or controlling population. The base for all issue arising around is popn related, lets take housing, food, inflation, water, electric, health . and many others. Keep in mind the population of ethiopia growing 3-4 mil annually. And in 2035 gc Ethiopian population expected double. Think your question when the total population of Ethiopian nearly 250 m, thing the popn of adds ababa 1 5-20mil, think the population your project area @2035. then after we can discuss about awareness, then governance, then infrastruc. Let me give you order for the issue By myself

1st - issues with popn growth
2nd - awareness / literacy and etc.
3rd - quality of governance/ govt body are peoples from popn
4th - infra
5th - other

Good Governance $ use alternative water resources

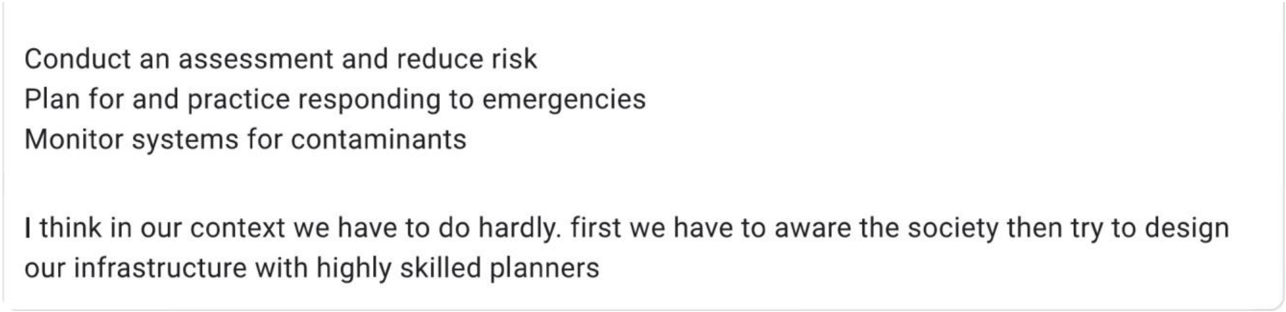
Supplying enough resource

Resources

Preparing alternative sources

With a good mind set and strong government and infrastructure

All communities need safe drinking water and properly treated wastewater. In order to provide these services reliably, utilities should:



Conduct an assessment and reduce risk
Plan for and practice responding to emergencies
Monitor systems for contaminants

I think in our context we have to do hardly. first we have to aware the society then try to design our infrastructure with highly skilled planners

B. Published Manuscript

Indoor & Outdoor Water Sensitive Approach for a Resilient Urban Neighborhood: The Case of Kotari Condominium, Addis Ababa, Ethiopia

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[2] Addis Ababa University; tesfaye.hailu@eiabc.edu.et
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Abstract: This study addresses the critical issue of water shortages in rapidly urbanizing areas, specifically focusing on the Kotari Condominium in Addis Ababa Ethiopia, where residents face recurrent water supply challenges despite the area's ample surface and groundwater resources. The primary aim of the research is to develop architectural and engineering solutions to enhance water resilience in urban neighborhoods. The methods involved a comprehensive analysis of water demand and supply chain infrastructure, assessment of current water resilience strategies, and identification of suitable approaches for both internal and external building spaces. The study also entailed designing a context-specific solution tailored to the unique needs of the Kotari Condominium neighborhood. Key findings from the research highlight significant deficiencies in the existing water supply system, including inadequate infrastructure, poor coordination among stakeholders, and the lack of effective water management practices. These issues have resulted in persistent water shortages and heightened vulnerability to water-related risks. The proposed solutions focus on improving infrastructure through the adoption of advanced water-saving technologies, enhancing stakeholder coordination, and implementing integrated water management strategies that are both sustainable and resilient. Specific recommendations include upgrading the water supply network, incorporating rainwater harvesting systems, groundwater extraction systems, and promoting water-efficient appliances and fixtures within buildings. The conclusions drawn from this study underscore the vital importance of sustainable and resilient water management practices in addressing urban water shortages. The research provides a model that can be adapted to similar contexts in other developing nations facing comparable challenges. By emphasizing the necessity of architectural and engineering interventions, the study offers valuable insights for policymakers, urban planners, and other stakeholders involved in urban water management. These findings contribute to the broader discourse on water resilience, highlighting the need for innovative solutions to ensure equitable access to safe and secure water and sanitation services in rapidly growing urban areas.

Keywords: Water Resilience, Urban Water Management, Water Shortages, Sustainable Infrastructure, Architectural Engineering Solutions

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1. Introduction

The resilience of global water systems is increasingly at risk due to a confluence of factors, necessitating innovative approaches for urban water management [1]. Developing water resilience is crucial for addressing water-related challenges, such as scarcity and pollution, and ensuring equitable access to safe and secure water and sanitation services for all [2]. This not only protects communities from water-related risks but also empowers decision-makers and stakeholders with the knowledge and capacity to make informed decisions and investments in their cities' water sectors [3].

Water shortages present a significant problem, particularly in developing nations, where a mix of drought, economic constraints, and social unrest impedes access to adequate and reliable water supplies [4]. For instance, a recent UNICEF report highlights a severe crisis in Eastern Africa, where over 20 million people, including 10 million children, face urgent water and food shortages [5]. This crisis, exacerbated by drought, instability, economic hardship, and conflict, has led to a dramatic increase in water insecurity and severe malnutrition among children [5]. Ethiopia, despite its ample surface and groundwater resources, struggles with water shortages, worsened by rapid urbanization and the resulting increased water demand [6].

In Ethiopia, rapid urbanization has led to the construction of numerous apartments, yet the water supply, managed by the Addis Ababa Water and Sewerage Authority (AAWSA), remains insufficient [6]. Residents of areas like the Kotari Condominium face recurrent water shortages, highlighting the need for architectural interventions to develop sustainable and resilient water solutions. This research aims to identify and propose architectural and engineering solutions for creating water-resilient urban neighborhoods, specifically focusing on Kotari Condominium.

The objectives of this research are multifaceted. Firstly, it seeks to analyze the water demand and evaluate the supply chain infrastructure around Kotari Condominium. Secondly, it aims to identify suitable building water resilience approaches. Thirdly, it intends to determine the water-resilient internal and external spaces of buildings. Finally, it plans to design a context-specific solution for the Kotari Condominium neighborhood, ensuring that technical and spatial solutions are effectively integrated.

The research is driven by several critical questions: What are the issues related to water sources, supply, usage, and disposal in case of rapid urbanization and water stress environment? What engineering solutions can create resilient urban neighborhoods? How can the water resilience of internal and external building spaces be enhanced? How can technical and spatial solutions be adapted for the Kotari Condominium neighborhood? These questions guide the investigation into developing comprehensive water resilience strategies for urban areas.

Resilience, a concept that has gained prominence in both policy and academic discussions, is essential for managing environmental hazards, technological accidents, climate change, and other crises [7]. In the context of water systems, resilience refers to the ability to withstand and adapt to stresses and shocks [8]. Effective water resilience strategies involve addressing policy ambiguities, coordination challenges, and funding issues, ensuring that water resources are managed collaboratively and efficiently [9]. By integrating architectural and engineering solutions, this research aims to enhance the resilience of urban water systems, providing a model for sustainable water management in rapidly urbanizing areas like Ethiopia.

2. Materials and Methods

This study aimed to understand and explain water resilience in an urban neighborhood, specifically focusing on Kotari Condominium. To achieve credible findings and gain insights into water resilience in urban neighborhoods, a case study approach was chosen. This method aligns with the research objectives, data sources, data types, sample size, and analysis methods, informed by previous studies on the topic. A survey was conducted to select the case area from the target region and measure the water resilience of the urban neighborhood. The sample was selected to draw valid conclusions for the study area. The case study method, as defined by Merriam (1998) and Yin (2003), was deemed appropriate as it allows for an in-depth examination of the case and its context, addressing "what," "how," and "why" questions while considering crucial contextual factors [8].

The Kotari Condominium Neighborhood, also known as Haile Garment Condominium, located near Mekenisa, Lebu area adjacent to the Haile garment factory in Addis Ababa, was selected as the case area. This neighborhood, built in 1997 and inhabited since 2000, faces significant water scarcity issues, making it a suitable site for studying water resilience. The selection was based on reports from the Addis Ababa city administration and urban sanitation and water department indicating instability in water demand and supply chains, existing studies highlighting prevalent water resilience issues in the neighborhood, and a visual survey of all neighborhoods in Addis Ababa for urban water-related issues.

Purposive sampling was used to select the Kotari Condominium neighborhood, ensuring the chosen site met the study objectives. A pre-survey and information from the Addis Ababa city administration water and sanitation department guided the sample selection. Criteria for sample selection included the interplay between water availability (supply) and human needs (demand), and the presence of water resilience problems and attempted resolutions. A formula from Loungrath (2017) [9] determined the sample size. For this study, 80 participants were divided as follows: 41 for questionnaires, 10 for interviews, and 29 for focus group discussions (3 groups of 10 participants each).

Data collection involved both primary and secondary sources. Primary data collection included field observations and photography, semi-structured interviews with residents, NGO representatives, and government officials, and focus group discussions to gather insights into water resilience challenges. Maps and satellite imagery from Google Earth, Arc Globe, and AutoCAD provided spatial analysis and context. Secondary data were gathered from manuals, previous studies, satellite images, and relevant books. The analysis focused on addressing the research objectives and involved evaluating the pre-selected site, sorting interview and observational data into themes, refining research objectives based on identified themes, analyzing satellite imagery and maps for spatial characteristics, and presenting data using maps, tables, graphs, and field survey photographs. The primary aim was to understand planners' and users' strategies and experiences in managing open spaces to inform context-tailored solutions, while also exploring existing legal and institutional frameworks governing these spaces.

3. Results and Discussion

The Ethiopian national large-scale housing development program, particularly the condominium housing practice, reflects the nation's dedication to addressing housing shortages. This effort is part of a broader series of affordable housing initiatives documented by the Housing Policy Section of UN-HABITAT [11], offering practical guidance based on successful examples. One notable project is the Koari condominium in the Nifassilk Lafto sub-city, which comprises over 11 blocks with various building typologies. The topography of the site, characterized by a gentle slope, situates the housing units at a lower altitude.

The Koari condominium features a mix of 30 studios, 115 one-bedroom, 80 two-bedroom, and 80 three-bedroom units, housing approximately 950 residents at the time of the survey. This number fluctuates due to high mobility. The data suggests a correlation between family size and the number of bedrooms, indicating that larger units typically accommodate larger families. The average family size increases with the number of bedrooms, highlighting the need for proportional resource allocation.

Water consumption in urban areas is influenced by several factors, including household size, economic status, and infrastructure. In Koari, the maximum water consumption per family falls below national and international standards. On average, studio units consume 40 liters, one-bedroom units 60 liters, two-bedroom units 80 liters, and three-bedroom units 100 liters of water per day. The residents often store water due to intermittent supply, fetching water two to three times a week and using various storage mechanisms to ensure availability for daily use. To meet the national standard of 20 liters per person per day, the total water requirement for the Koari condominium is approximately 19,000 liters (19 m^3) per day.

The primary source of water for Koari residents is municipal tap water supplied by the Addis Ababa City Water and Sanitation Authority. This water is delivered according to a schedule, typically twice a week, which poses challenges for continuous supply. Residents rely heavily on indoor plumbing for water distribution, although the inconsistent schedule necessitates storage solutions. Groundwater sources, accessed through boreholes, provide an alternative to municipal water. These sources are crucial for meeting water needs, particularly during shortages.

Rainwater harvesting is another practice observed among Koari residents, especially those on the ground floor who collect water during the rainy season. This harvested rainwater is primarily used for non-potable purposes, such as toilet flushing and laundry, due to its untreated nature. The data indicates that integrating multiple water sources, including rainwater, municipal tap water, and groundwater, is essential for meeting the overall water demand.

Adaptive approaches to water management in Koari include various storage mechanisms, water conservation practices, and treatment methods. Storage solutions range from elevated water tanks to underground reservoirs, ensuring water availability during supply interruptions. Conservation efforts focus on efficient use of water, such as installing high-efficiency appliances and adopting water-saving behaviors. Water treatment methods like boiling, chlorination, and slow sand filtration are employed to ensure safe drinking water, though many households use tap water directly without further treatment.

Effective space planning is critical for optimizing water storage and distribution. Residents utilize all available spaces, including kitchens, bathrooms, and communal areas, for storing water. This often disrupts normal activities and movement within residential units, highlighting the need for better-designed storage solutions. Surface and subsurface storage options, such as open ponds and underground tanks, are also explored to enhance water resilience.

To address water scarcity, integrating diverse water sources and adaptive practices is imperative. This includes utilizing municipal tap water, groundwater, and rainwater harvesting in a coordinated manner. Despite the potential for using recycled water and treated gray water, technical and infrastructure limitations currently hinder these practices. However, the adoption of intelligent water management strategies and an integrated design approach can significantly improve water resilience.

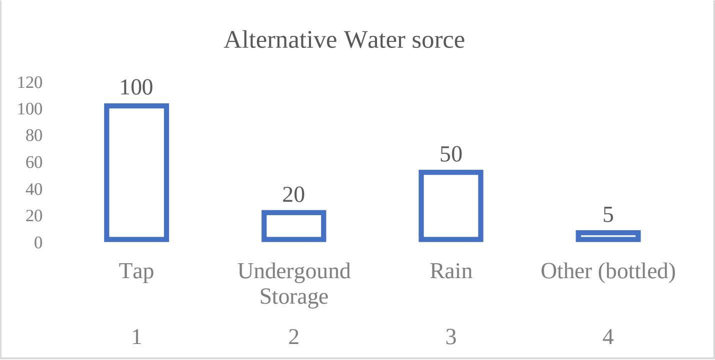

Figure 1. Alternative Water Resource

In general, the Koari condominium project exemplifies the challenges and adaptive strategies associated with urban water management in developing regions. The reliance on multiple water sources, coupled with adaptive storage and conservation practices, underscores the importance of resilience in addressing water scarcity. Efficient space planning and the integration of diverse water sources are crucial for enhancing water security and meeting the needs of urban populations. As the demand for water continues to rise, innovative solutions and sustainable practices will be essential for ensuring a reliable water supply and improving the quality of life for residents.

Figure 2. Indoor water storage mechanism

5. Conclusions

This research emphasizes the critical need for innovative urban water management strategies, particularly in rapidly growing cities like Addis Ababa. The water challenges faced by residents in the Kotari Condominium serve as a stark reminder of the importance of building water resilience. By implementing multifaceted strategies that diversify water resources, encourage water conservation through user education and efficient fixtures, and integrate well-designed storage solutions within individual units, cities can create a more secure and sustainable water future for all.

This research not only proposes potential solutions specifically tailored for the Kotari Condominium but also serves as a blueprint for other urban neighborhoods facing water scarcity. By collectively rethinking urban water systems through a resilience lens, cities have an opportunity to transform the way they deliver water services. This approach prioritizes sustainability by maximizing the use of alternative water sources like rainwater harvesting. It fosters inclusivity by ensuring equitable access to safe water for all residents. Finally, it emphasizes efficiency by minimizing water losses through leak detection and promoting conservation practices.

The successful implementation of a resilient urban water system requires collaboration across various stakeholders. Decision-makers need to create enabling policies and invest in infrastructure upgrades. Water utilities must embrace innovative technologies and promote water conservation awareness. Finally, residents play a crucial role in adopting water-saving practices and maintaining water storage systems within their units.

By fostering a collaborative approach and prioritizing water resilience, cities can move towards a future where water security is not a privilege but a right for all. This not only safeguards the well-being of residents but also contributes to achieving broader goals like Sustainable Development Goal (SDG) 6: Clean Water and Sanitation. The lessons learned from this research on the Kotari Condominium can serve as a catalyst for a global shift towards more resilient and sustainable urban water management practices.

6. Architectural and Engineering Interventions

To achieve water resilience in the rapidly urbanized Kotari Condominium, where water resources are limited, this research proposes a combination of architectural and engineering interventions. These recommendations focus on diversifying water sources, optimizing storage solutions, promoting water conservation practices, and integrating the entire system for efficient management.

One key strategy is diversifying water resources. Rainwater harvesting systems can be installed on rooftops to capture rainwater during the rainy season. This collected water can then be stored in underground tanks and treated for non-potable uses like toilet flushing and laundry.

Figure 3. Collection and storage mechanism of rainwater

Additionally, if data suggests sufficient groundwater availability, extraction can be explored. A surface water storage tank would then be used to hold the extracted groundwater for daily use.

Figure 4. Extraction and treatment mechanism of groundwater

To optimize water storage within individual units, storage tanks can be constructed at the lowest point of the site. This allows for efficient pumping of the stored rainwater and groundwater to the highest point. Integration of diversified water sources into the single pipeline which comes from the municipality will be undertaken for distribution throughout the condominium.

Figure 5. Integrated diversified water source.

Furthermore, flexible bathroom storage solutions utilizing fiberglass water tanks will be implemented. Residents can choose between wall-mounted or ceiling-mounted options depending on their space and needs. Similar storage solutions with wall-mounted options for dishwashing and additional ceiling-mounted options will be incorporated in kitchens.

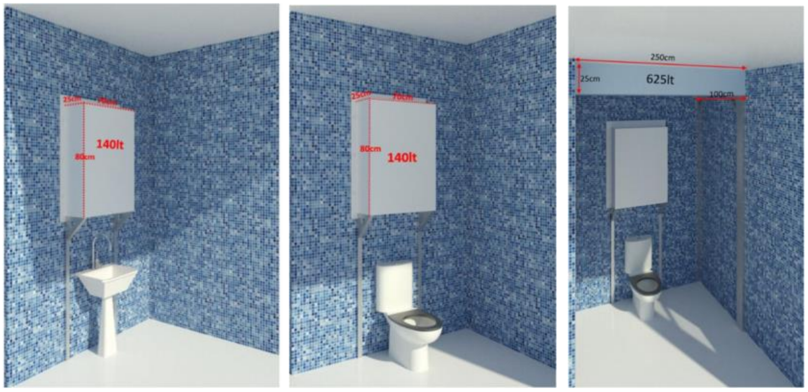

Figure 6. Bathroom water storage solutions

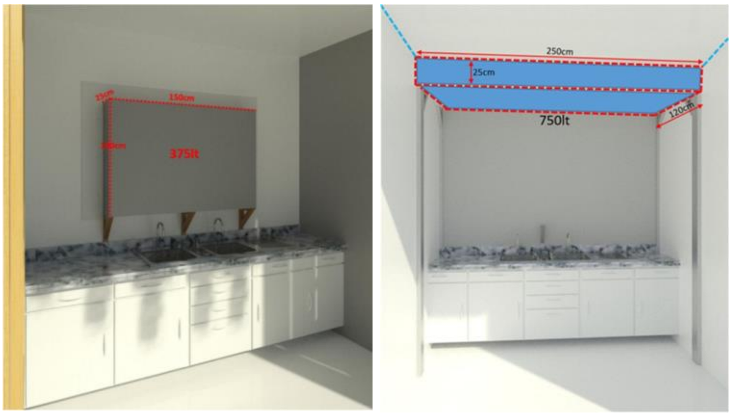

Figure 7. Kitchen water storage solutions

Promoting water conservation practices is another crucial aspect of water resilience. This can be achieved by installing water-efficient plumbing fixtures throughout the condominium. Low-flow showerheads, toilets, faucets, and pressure-reducing valves (PRVs) will minimize water wastage during daily activities. Additionally, a graywater reuse system can be implemented to channel used water from sinks and showers for toilet flushing. This reduces reliance on potable water for non-drinking purposes.

Finally, to ensure efficient operation and maintenance, the system needs to be fully integrated. After treatment, both rainwater and groundwater will be integrated into the existing piped water line managed by AAWSA. This creates a single, diversified water source for the entire condominium. AAWSA will assume responsibility for water treatment, billing, and overall system management.

By implementing these architectural and engineering interventions, the Kotari Condominium can become a model for water-resilient living in rapidly urbanized areas facing water scarcity. The focus on diversification, storage, conservation, and integration creates a comprehensive approach to maximizing water security for residents.

Conflicts of Interest: "The authors declare no conflicts of interest."

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