



Ethiopian Institute of Architecture, Building Construction and City Development

LEVERAGING ON-SITE RAINWATER HARVESTING FOR WATER SUPPLY CHALLENGES OF HIGH-OCCUPANCY MIXED-USE BUILDINGS IN ADDIS ABABA; THE CASE OF CROWN HOTEL 40/60 CONDOMINIUM

**A thesis submitted in partial fulfillment of Master of Science Degree in Urban Design and
Development**

By

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This to certify that the thesis is prepared by **Ashenafi Belina** entitled: **“Leveraging On-site Rainwater Harvesting for Water Supply Challenges of High-occupancy Mixed-use Buildings of Addis Ababa; The Case of Crown Hotel 40/60 Condominium”** and submitted in partial fulfillment of the requirement for the degree of masters of science (urban design and development) complies with the regulation of the university and meet the accepted standard with originality and quality.

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ABSTRACT

Addis Ababa City Administrations has built different types of condominium housing since 2005 through its Housing Development Program. 40/60 condominium is one of the program schemes intends for higher middle income residents. However, most of these housing sites supplied water twice a week. This research aims to investigate the water supply demand gap as well as potential rooftop and surface runoff RWH for supplementary water supply and flood reduction in Crown Hotel 40/60 condominium site. Monthly water demand is projected from household survey data collected from 193 residential and commercial units; the current water consumption determined from six-month monthly water bill. Rooftop RWH potential of site is calculated by interpolating the mean monthly rainfall data of 15 rain gauge stations collected from National Meteorological Agency. As well as, the catchment hydrology is analyzed using rational methods; infiltration trench and basin is proposed for surface runoff harvesting in accordance to the catchment suitability criteria. The result indicates, the study site has a monthly water supply gap of 0.41m^3 per housing units. Each buildings have rooftop RWH potential of 1190.2m^3 annually, this amount can contribute 11 percent of the buildings annual water demand. The required size of infiltration trench and basin are 14.72m^2 for trench and is 22.7m^2 basin. These components have a potential of $22,511.28\text{m}^3$ surface runoff harvesting annually by infiltrating to ground soil. Both rooftop and surface RWH system can reduce 63 percentages of floods generated from the study site. Thus, practicing both surface and rooftop RWH systems are comprehensive to encounter the city water supply challenges and flood related problems caused by the combination of population growth, climate and land use change.

Keywords: Water sensitive urban design, water; rooftop rainwater harvesting; surface runoff, stormwater, 40/60 condominium

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ABBREVIATIONS

AAWSA	Addis Ababa Water and Sanitation Authority
ARI	Average Recurrence Interval
CDA	Contributing Drainage Area
ERA	Ethiopian Road Authority
IDF	Intensity Duration Frequency
IHDP	Integrated Housing Development Program
LDP	Local Development Plan
LID	Low Impact Development
RWH	Rainwater Harvesting

CHAPTER ONE: INTRODUCTION

1.1. Background of the study

Up to now global urban population is more than 50%, and the projection tells us that by 2050 it could overcome 70%, although urban areas occupy just 2% of the global land area (The World Bank, 2019; UNPF, 2018). Such rapid urbanization and population growth, over the last few decades, put intense pressure on the use of urban and global resources. Cities consume about 70% of global resources and energy produced, and at the same time, they produce about 70% of all greenhouse gases and global waste (Paiho et al., 2020). There is a strong positive correlation between increasing water demand and urbanization or population growth (Malmqvist and Rundle, 2002).

Ethiopia's mass-scale subsidized housing delivery program has driven the rapid expansion of middle-income, mid-rise settlements on the outskirts of Addis Ababa, requiring the provision of infrastructure to newly developed areas (Liza Rose, et al, 2021). While condominium housing units have significantly improved the quality of life of low-income residents that previously resided in inner city slums (UTAFITI SERA Policy Brief, 2017); water demand is rising due to population growth and economic developments (Abraha, et al, 2022). On the other hand, the volume of water produced by the city sole water provider (AAWSA) has been decreasing due to hydro climatic changes (Kitessa et al., 2022).

Addis Ababa has two sources of water, surface and groundwater. Failure of any of these water sources would result in a crisis (World Bank Group, 2015). The city water sources are not secured as the sources lie outside the city boundary and there is a political boundary between Addis Ababa and Surrounding Oromia Region. Although the 10th Addis Ababa City Master Plan proposed ways of diversifying water sources such as harvesting rainwater and reusing grey water, its implementation is slow, and the city is relying on surface and boreholes water sources (Addis Ababa Water resilient profile, p.60).

Addis Ababa is one of fastest growing city in the world. The pressure of rapid population growth, coupled with higher living standards, has resulted in increased water demand and per capita consumption. Water demand from industrial, commercial, and construction sectors is also on the rise, fueled by a rapidly expanding economy and unprecedented construction boom. While demand for water has grown in all major sectors, the availability and supply of water is decreasing as a result of intensive groundwater development, natural resource degradation and

climate change. Because of water demand exceeding water availability, water shortages and city-wide water rationing are common in Addis Ababa. Parts of the city are supplied in shifts with some areas only getting water twice a week through distribution lines or water truck (World Bank Group, 2015)

To address these challenges, broader water management perspectives like Integrated Water Resources Management (IWRM), Sustainable Urban Water Management (SUWM) and Water Sensitive Urban Design (WSUD) have emerged. These frameworks promote a holistic approach that considers all aspects of the urban water cycle, from water supply and sanitation to stormwater management. Rainwater harvesting and infiltration practices are key components of these frameworks, offering a sustainable and localized solution for improving water security.

Rainwater harvesting, is a technology used for collecting and storing rainwater for human use from rooftops, land surfaces or rock catchments using simple techniques such as jars and pots as well as engineered techniques (Thamer et al, 2006), including infiltration to ground. Therefore, this study investigates surface runoff and rooftop rainwater harvesting potential of Crown Hotel 40/60 for supplementary water supply and flood reduction.

1.2. Statement of the problem

Since 2005, a significant amount of high-density condominium buildings has been built in Addis Ababa. These factors contribute to an increase in property ownership and the horizontal expansion of the city. This expansion drives the construction of new infrastructure and stimulates economic development, which in turn boosts population growth and raises living standards.

As a result of the water supply schedule, the majority of these condominium complexes only offered piped water once or twice a week. Thus, the residents buy jar water for drinking as well as stream water for cooking, personal hygiene, laundry, and toilet flushing, spending a substantial amount of money.

Crown Hotel site 40/60 saving housing compound is among the earliest project of its type that constructed under AAHDP for higher middle-income residents. This compound is fully occupied and relatively well developed than its kind projects constructed afterward. It has a drainage system that is connected to the nearby municipal drain system with in and adjacent to the compound. However, the system doesn't cover the whole catchment that the compound is located in. As a result, stormwater from the compound and upper catchment area, which have traditional grey drainage systems, flows to the lower catchment area, which lacks sustainable

drainage. This causes flooding, despite the fact that the condominium property is suited for rainwater harvesting (RWH), which might provide residents with water while reducing runoff from impermeable surfaces such as rooftops and pavements.

Previously (Kidist and Kumar, 2015), (Dagnachew, et al, 2018) and (Yalemzewd, et al, 2020) conducted studies on RWH potential in Addis Ababa. These studies scopes are limited on rooftop RWH potentials. While serving as supplement water supply source, rooftop RWH can reduce storm water, However, Stormwater runoff and its environmental impact requires a holistic approach in formulating strategies for its management. Thus, this study will further explore the surface runoff volume and propose infiltration components for flood reduction in Crown Hotel 40/60 condominium sites. Additionally, it will project the study buildings water supply and demand deficit that the previous studies didn't cover.

1.3. Objectives

1.3.1. General objective

To investigate the potential of on-spot rooftop and stormwater harvesting for bridging the water supply challenges of 40/60 housing buildings located around Crown Hotel in Addis Ababa.

1.3.2. Specific objectives:

- i. To identify the deficit between the municipal water supply and demand.
- ii. To identify the potential of rooftop rain water harvesting for supplementary domestic water supply.
- iii. To propose stormwater infiltration component for flood reduction.

1.3. Research question

The main question the research will answer is; how much water supply demand gap can bridge through rooftop and surface runoff rain water harvesting from Addis Ababa mixed use 40/60 saving condominium buildings?

Specifically, the research will answer the following questions:

- i. How much gap has municipal water supply with respect to the demand?
- ii. How much water demand gap can be filled through rooftop and surface runoff rain water harvesting?
- iii. What type of WSUD is suitable to infiltrate surface runoff water of the study site to ground soil?

1.4. Scope of the study

The thematic scope of the study is the analysis of On-site rainwater harvesting for sustainable water management of High-occupancy buildings, addressing water supply deficit, optimizing rainwater collection and infiltration capacity for runoff reduction. Spatially, the study is limited on Crown Hotels' 40/60 Condominium site. The temporal scope of the rainfall study is 30 years; it ranges from 1992 to 2022.

1.5. Significance of the study

The study will significantly show alternative water supply method to real estate developer, urban managers, planners, engineers, designers, and policymakers. It will also help in realization of creating water resilience city. If implement, it is more significant to elevate living standard of Addis Ababa residents of high-rise apartments and condominium housing units by providing additional water supply. The study also contributes to the lack of literature regarding 40/60 condominium housings.

1.6. Organization of the study

The Organization of the study is divided in to five chapters. Chapter one is Introduction, this section provides explanations on background, statement of problem, as well as objectives and the research question. Chapter two: Literature Review; this chapter provides theoretical foundation with the formulation of some propositions, which are the basis for the research methodology and contextual review. Chapter three Methodology; this section explains the research design, strategies, data types, data collection and analysis methods. Chapter four: Analysis and Discussions; this section will provide the results from the studies and analysis to makes a comparison with the existing literature. Chapter five: Conclusions and Recommendations; summarizes the main issues of the research and it provides an overview of the main findings. It also concludes if the project met the proposed objectives and the way in which the research is useful to answer the problems that the paper is intend to address as well as recommendations for academician and practitioners future work.

CHAPTER TWO: LITRATURE REVIEW

2.1. Introduction

This chapter reviews the theoretical background of rainwater harvesting and multi-story water supply systems. It also presents the contextual review of Addis Ababa water supply, policy toward water supply-demand and rainwater harvesting practice in Ethiopia as well as empirical review of RWH potentials. The summary of key findings from theoretical, contextual and empirical reviews is presented. Additionally, conceptual framework of the study is developed.

2.2. Theoretical background

2.2.1. Water Sensitive Urban Design

The gradual increasing water shortage has raised the need to develop efficient water resource management initiatives (Ameen, et al, 2020). Water Sensitive Urban Design (WSUD) is among one of initiatives to change the conventional means by which urban areas are planned and built. It was introduced in Australia in 1994 (Wong). WSUD aims to manage the water cycle by producing qualitative and quantitative impacts on land, water, aesthetic values and biodiversity as well as maintaining economic endurance. WSUD focuses on sustainability of environment and water cycle in urban development or even in redevelopment of urban structures (Tennessee Water Resources Symposium, 2011). The objective of WSUD is to incorporate rainwater into the landscape, conserve water quality and natural system and reduce runoff and peak flows (Ameen, et al, 2020).

Rooftops, sidewalks, roadways, and other impervious surfaces of an urban center, on streams and rivers have two major impacts. First, as drainage areas become increasingly impervious, stormwater runoff volumes, flows, and velocities increase, while base groundwater flows decrease. Small annual storm events that would be captured by the plants and soils of an undeveloped landscape are delivered quickly and efficiently to the receiving pipe network and streams in a city. Second, human activities in the city generate increased pollutant loads, ranging from heavy automobile traffic to use of various chemicals. These pollutants, as well as the deposition of atmospheric pollution, build up on impervious surfaces during dry weather, and rain and snow events wash these pollutants into sewer pipes, streams, and rivers (Center for Watershed Protection, 2012).

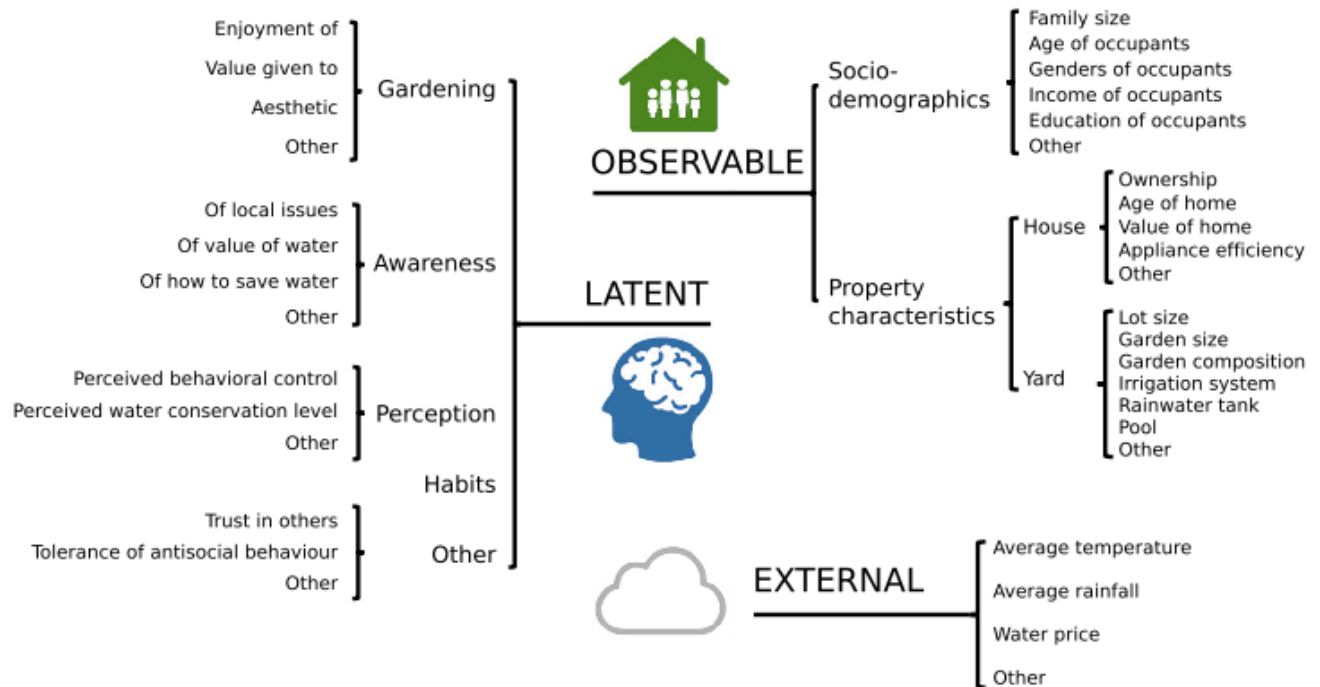
WSUD functionalities include, but not limited to, storm water quality management, flood control, rainwater harvesting, biodiversity, (Pipil, et al, 2022) and others. The storm water

quality management and flood control can be achieved by filtration, sedimentation, adsorption, rainwater harvesting, flow volume attenuation, biodegradation and uptake by plants, detention, retention, etc. so that it can find its utility for the purpose of domestic or industrial use, irrigation, ground water recharge, etc. (Argue, 2004). Rainwater harvesting can be an important alternative to increase available domestic water and sustain groundwater (Hayysam and Marwa, 2015).

2.2.2. Domestic water consumption

WHO defines residential water as being, water used for all usual domestic purposes including consumption, bathing and food preparation (WHO, 1993). Residential water use covers all use of waters by household, both within and outside the confines of residence. Thus, includes for food preparation, flush toilet, laundry, and bathing within a house and outside and also for car washing and lawn sprinkling outside (S. H. Hanke and L. de Mare. 1984). Residential water uses standards vary with climatic conditions, life style, culture, technology and economy. There is no fixed data to estimate the amount of water needed to maintain acceptable of minimum living standard (Zhang, 1999).

(Cominola A., et al, 2023) classified water use determinants in three categories, namely observable, latent, and external; see figure 2.1 below.



1Figure 2.1: Household water use determinant
Source: (Cominola, et al, 2023)

Observable determinants are those determinants that can be physically seen or measured. These are socio-demographic which related to the people inside the household, and house characteristics related to the yard, size and its irrigation. (e.g. occupant age, household size, household income, number of toilets). The Latent determinants relate to the way the occupants of the household think, feel, or act. Examples include attitude to water saving, individual habits, and beliefs and External determinants are external to the house and might influence a suburb or groups of houses at a regional level. Examples might include weather variables, such as rainfall and/or temperature.

2.2.3. Water supply systems in high-rise buildings

There are two types of domestic water supply systems in high-rise buildings: indirect systems also known as: down-feed and gravity system and direct systems also called: up-feed systems. Down-feed” and” up-feed” terms refer to the way the water is distributed to the plumbing fixtures in buildings. Down-feed domestic water supply systems are based on lifting water to an elevated tank or tanks with a pump, then allowing water to flow down through the distribution network under the force of gravity. Tanks are directly linked to plumbing fixtures in down-feed systems. Up-feed domestic water supply systems are based on the use of booster stations to ensure water to all floors. Booster stations are directly linked to plumbing fixtures in up-feed systems. (Binggeli, 2010)

2.2.4. Rain Water Harvesting

Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops, land surfaces, road surfaces, or rock catchments using simple techniques such as pots, tanks, and cisterns, as well as more complex techniques such as underground check dams (Appan 1999; Prinz 1995; Zhu et al. 2004). Rainwater harvesting can also mean collecting rainwater before it infiltrates into the ground and becomes underground water. Harvested rainwater is a renewable source of clean water that is ideal for domestic and landscape uses. Water harvesting systems provide flexible solutions that can effectively meet the needs of new and existing water demand for domestic and agricultural uses (Fayez, et, al. 2021).

Many cultures throughout the world have used captured rainwater. The Middle East, Asia, ancient Rome, and Mexico utilized rainwater harvesting. In India, simple stone-rubble structures for capturing rainwater date back to 3000 BC (Gould and Erik, 1999). Civilization as early as

2000 BC survived in the Negev Desert of what is now Israel by storing hillside runoff in cisterns (Pacey and Adrian, 1996).

A historical document of the time mentions water cisterns and the habit of having at least one rainwater-collecting cistern per home that would range in size from 35 to 200 cubic meters. These residential cisterns were typically below ground and were pear or bottle shaped. The first community cisterns ranged in size from 4,000 cubic meters to large reservoirs such as the one found in Madaba that could hold 42,750 cubic meters. These cisterns were technologically sophisticated with sediment traps or “first-flush” systems to catch sediment, mud, and sand prior to allowing the water to enter the cistern (Wahlin, 1997).

In Rome, rainwater was collected from the covered walkways and diverted to small pools located in gardens for esthetic purposes and for future use as irrigation water (Winterbottom, 2000). The Romans designed villas and entire cities to take advantage of collected rainwater and the used the water as the primary source for drinking and other domestic uses (Gould and Erik, 1999).

Underground cisterns in central Mexico stored collected rainwater from plazas and rooftops for human consumption and irrigation. In the Yucatan Peninsula, archaeological remains from AD 300 indicate ground catchment systems known as Chultuns were used to collect rainwater. In the United States and Canada, rainwater collection systems have historically been used by native inhabitants and settlers in isolated areas where there were no existing municipal water supplies. In many areas they are still used, as demonstrated by a 1995 survey, which concluded that in that year there were roughly 250,000 rainwater harvesting systems in use in the United States (Wilson, 1997).

Rainwater harvesting has a long history in Ethiopia. (Fitsume, et, al., 2014) describe by referring (Habtamu, 1999), “history of rainwater harvesting in Ethiopia date back to pre Axumit period (560 BC). During this period rainwater was harvested and stored in ponds and tanks for agriculture and water supply purposes. The remains of an ancient roof- water harvesting system is still visible in the oldest palaces in Axum. Other evidences include the remains of one of the old castles in Gondar, constructed in the 15th and 16th century and Lalibela Rock hewn churches (over 800 years ago), including a pool that was used to store water used for religious rituals”.

In south of the country, the Konso people have had a long- and well-established tradition of building level terraces to harvest rainwater that is used to produce sorghum successfully under extremely harsh environment characterized by low, erratic and unreliable rainfall (Gharp,2003).

In the Ogaden (Eastern Ethiopia), Brikas are used to store rainwater. People in North Omo (Gatto Valley), Eastern Hararge, and other parts of the country have been practicing the art of conserving soil and water (Fitsume, et. al., 2014).

2.2.5. Types of Rainwater Harvesting

According to (Saeid and Faezeh, 2021), there are three ways of harvesting rainwater; Surface runoff harvesting, Rooftop rainwater harvesting and Rainwater harvesting in situ. Rooftop rainwater and surface stormwater harvesting have broadly similar benefits in reducing pollution loads, downstream stormwater flows and demand for mains water. However, there are some differences in costs, stakeholders, maintenance, and health risks between these two approaches. Combined rainwater and stormwater collection and reuse schemes can be implemented successfully for medium-density developments, in which reticulation costs are relatively low (Fatema, et. al., 2014). For this paper purpose, surface runoff and rooftop rainwater harvesting will be discussed below.

2.2.6. Rooftop Rainwater Harvesting

Rooftop rainwater harvesting involves capturing, diverting and recharging or storing of rainwater from the roof catchments of domestic houses or commercial buildings into storage tanks. Rooftop rainwater harvesting is a system of collecting rainwater where it falls. In this method, the effective impervious area (EIA) is the building's roof, which directs the runoff to the drainage channels. This roof is considered as the catchment and the rainwater is harvested from house or building's roof. The collected water can be store in a tank or can be directed to an artificial groundwater recharge system (Saeid and Faezeh, 2021).

2.2.7. Components of Rooftop Rainwater Harvesting

Most of the rainwater harvesting systems around the world is composed of the roof; gutter, down pipes, and collecting tank (Thamer, et al, 2006). (Hayssam and Marwa, 2015), proposed rainwater harvesting system that collects and stores rainwater directly in tanks already installed on building roof. The system will eliminate the need for a special ground or underground storage tank, submersible pump, first flush diverter and other less expensive materials.

Depending on the degree of water quality required, rainwater harvesting system consists up to six components. These components include catchment, conveyance, filtration, storage, distribution, and purification (Heather, 2007).

2.2.7.1. Catchment Area

The catchment of a rainwater harvesting system is the surface upon which the rain falls; the surface has to be appropriately sloped, preferably in the direction of the storage facility or the recharge area. The collection area in most cases is the roof of a house or a building; however, catchment areas may include driveways or swales in yards. Rainwater harvested from catchment surfaces along the ground should only be used for irrigation because of the increased risk of contamination. The effective roof and the material used in constructing the roof influence the efficiency of collection and the water quality (Saeid and Faezeh, 2021).

Smoother, cleaner, and more impervious roofing materials are preferred; they contribute to better water quality and greater quantity. Tiled roofs or roofs sheeted with corrugated mild steel, etc., are preferable since they are the easiest to use and give the cleanest water. Cement and tiled roofs are the most common roofs used in many parts of the world (Abdulla and Al-Shareef, 2009).

These types of roofs have good durability and provide good quality water. Composite asphalt and some painted roofs are recommended only for non-potable water use because they could leach toxic materials into rainwater as it touches the roof surface. Roofs that have lead materials should be prohibited because acidic rain may cause contamination of collected water from these roofs. Regardless of the roof material, many designers assume about a 20% loss of annual rainfall. These losses are due to roofing material texture, evaporation, losses occurring in gutters and storage tanks, and inefficiencies in the collection process (Abdull and Al-Shareef, 2009).

2.2.7.2. Conveyance System

A conveyance system usually consists of gutters or pipes that deliver rainwater falling on the rooftop to cisterns. Gutters or pipes must be properly sized, sloped and installed in order to maximize the quantity of harvested water. The most common materials of gutters are galvanized steel, fiberglass, plastic, stainless steel, copper, cast iron, and UPVC (unplasticized polyvinyl chloride). The gutters and downpipes are usually installed in the wall of the building, and sometimes the downpipes are fitted inside the wall during construction. The size of the gutters depends on the area of the roof and the rainfall amount; the size of the gutters used ranges between 5 and 10 cm diameter (Abdulla and Al-Shareef 2009).

The diameter of the gutters can be determined using the Rational Equation ($Q=CIA$), where Q is discharge in m^3/sec , C is runoff coefficient (0.8), A is the roof area in m , and I is the rainfall intensity in mm/hr and can be obtained using the Intensity-Duration-Frequency (IDF) curves. Both drainpipes and roof surfaces should be constructed of chemically inert materials such as

wood, plastic, aluminum, or fiberglass, in order to avoid adverse effects on water quality. Leaf screens are important to keep leaves and other debris from entering the system; the gutter should have a continuous leaf screen made of 0.4 mm fine mesh installed along their entire length (Saeid and Faezeh, 2021).

To keep leaves and other debris from entering a rooftop rainwater harvesting system, the gutters should have continuous leaf screens made out of one quarter-inch wire mesh screen in a metal frame or an equally efficient product covering the entire length of gutter. Installing leaf screens will help reduce a rainwater harvesting system's maintenance, eliminate flammable material from the roof area, reduce mosquito breeding habitat, and eliminate the need for frequent and potentially hazardous use of a ladder to clean the gutters (Heather, 2007).

2.2.7.3. First flush

Roof washing or first flush is the initial process in reducing the debris and soluble pollutants that may enter a rainwater harvesting system (Heather, 2007). Contaminants washed from a roof are usually concentrated in the first part of the runoff. Such contaminants contain various impurities such as bird droppings and dust. After this initial runoff has washed the roof, the collected water can be considered safe. This process is called the first-flush diversion. The purpose of the first-flush diversion is to collect and disposal of the first flush of water from a roof, especially where the collected rainwater is to be used for human consumption. First-flush devices ensure a certain degree of water quality in harvested rainwater (Saeid and Faezeh, 2021).

The first flush volume is assumed to be 40I for 100m² of roof area. Many first-flush devices are simply and cleverly designed. Such devices include tipping bucket that dump when water reaches a certain level. The simplest of these systems consists of a stand pipe and gutter downspout located ahead of the downspout from the gutter to the cistern; the gutter downspout and top of the pipe are fitted and sealed so water will not flow out the top, and once the pipe has filled, the rest of the water flows to the downspout connected to the cistern (Saeid and Faezeh, 2021).

2.2.7.4. Distribution

Stored rainwater may be conveyed or distributed by gravity or by pumping. If a tank is located uphill or above the area proposed for irrigation, gravity may work. Most plumbing fixtures, appliances, and drip irrigation systems require at least 20 pounds per square inch (psi) for proper operation. Standard municipal water supply pressure is typically in the 40 psi to 80 psi range. As a general rule, water gains 1.0 pound per square inch of pressure for every 2.31 feet of rise or lift.

Pumps, rather than elevated tanks, are typically used to extract both below-grade and at-grade cistern or tank-stored water. Submersible or at-grade pumps may be used in any rainwater storage system. Self-priming pumps with floating filter intakes and automatic shutoffs—for times when water levels are insufficient—are optimal equipment. As mentioned previously, the bottom few inches of stored water will typically contain very fine settled sediment and should be avoided if possible. Depending on the proximity of the rainwater inlet and pump intake, as well as the time rainwater is left to settle or calm, the pumping process may need to be delayed for a short duration after a rain event (Heather, 2007).

The storage system overflow may act as a distribution system that delivers excess water to an adjacent landscape. All overflows exposed or out-letting above ground should have some means of stopping rodents and insects from entering the storage system. Fine screens may be placed over the end of pipes and, in areas of high rain quantities, water traps similar to sinks and toilets may be used (Heather, 2007).

2.2.7.5. Purification

If harvested rainwater is to be used for potable supplies, the rainwater would be pumped from the cistern to the purification system and then distributed to the points of use such as a kitchen sink faucet. In a non-potable system, no purification process is required. Potable water treatment systems normally include filters, disinfection, and buffering for pH control. Filtration can include any of the following: in-line or multi-cartridge, activated charcoal, reverse osmosis, nano-filtration, mixed media, or slow sand. Disinfecting can include boiling or distilling, chemical treatments, ultraviolet lights, and/or ozonization. Rainwater intended for human consumption should undergo several steps, including screening, settling, filtering, and disinfecting. Filtering and disinfecting are two components of rainwater harvesting that will enhance a potable system (Heather, 2007).

2.2.8. Calculation of Rooftop RWH Potential

The volume of rainwater that could be harvested from roof can be calculated considering the annual rainfall data, the total roof area, and a runoff coefficient using Equation (1.1) below (Eslamian and Eslamian, 2021).

$$VR = R \times A \times C \dots\dots\dots (2.1)$$

Where;

$$VR = \text{Annual volume of rainwater that could be harvested (m}^3\text{),}$$

R = Average annual rainfall in each rainfall zone (m/y),

A= Roof area (m²),

C =Runoff coefficient (non-dimensional), See table 2.1 for different surface runoff coefficient.

The runoff coefficient factor accounts for the loss of rainfall falling on a catchment due to evaporation, clogging, leakage, infiltration, overspill, and retention (Eslamian and Eslamian, 2021).

1Table 2.1 Runoff coefficient for different surfaces

Types of catchments	Runoff Coeff.
Roof Catchments	
• Tiles	0.8-0.9
• Corrugated metal sheets	0.7-0.9
Ground surface coverings	
• Concrete	0.6-0.8
• Bricks Pavement	0.5-0.6
Untreated ground catchment	
• Soil on slopes less than 10%	0.0-0.3
• Rocky natural catchments	0.2-0.5

2Table 2.1 Runoff coefficient for different surfaces
(Source: Pecey Arnold and Cullis Adran, 1989)

2Table 2.2 Coefficient for composite runoff analysis

Surface	Runoff Coefficient
Street: Asphalt	0.70-0.95
Concrete	0.80-0.95
Drives and walks	0.75-0.85
Roofs	0.75-0.95

(Source: Hydrology, Federal Highway Administration, HEC No. 19, 1984)

2.2.9. Surface Runoff Harvesting

Stormwater (surface runoff) harvesting refers to the collection and storage of stormwater during significant stream flow and reuses it at later times when less water is available (Fatema, et. al., 2014). In urban areas, rainwater turns into surface runoff and flows over the catchment's surface. This runoff can be collected and used for recharging aquifers, as well as domestic and agricultural uses, by choosing appropriate methods (Morey et al, 2016). The water runoff flowing on the streets come from streets themselves, the buildings in the cities or received from remote catchment's areas with different land uses (Hamdan, 2009).

2.2.10. Surface runoff rainwater harvesting components

In a stormwater harvesting and reuse scheme, various combinations of elements can be used depending on the nature of the site and the end users. But the most common four components are collection, storage, treatment and distribution (Fatema, et. al., 2014).

2.2.10.1. Collection

Collection systems divert stormwater from either an urban creek, stormwater drain (including WSUD components) or general urban runoff into storage for harvesting. The specific characteristics of a collection system will vary depending on the type of receiving storage. For example, storage online with a waterway it harvests from will have a different collection system to one offline from a waterway receiving stormwater through pumping (Philp, et al, 2008).

Online storages receive storm water flows directly from a waterway or drain. This storm water can be collected through either the traditional urban drainage system of gutters, pipes and channels; or through WSUD storm water conduits designed for improving storm water quality. Offline storages require an additional collection system to harvest from an urban waterway once storm water has been collected through either the traditional urban drainage system or WSUD design features (Philp, et al, 2008). This can be achieved through either a diversion weir which diverts low flows into the harvesting scheme and bypasses high flows, or pumping (DEC 2006; EPHC *et al.* 2008).

2.2.10.2. Distribution

The required form of distribution is determined by a number of factors, including the spatial scale of the distribution area (e.g. a single open space area such as a park or golf course, through to thousands of residential properties), the density of the end uses (if there is more than one) and the inclusion or exclusion of firefighting requirements within the stormwater distribution system (Mitchell et al. 2007b). The provision of collected and treated stormwater on a regional scale would require a storage and distribution system which is separate from the potable water supply system (WBM 1999). Currently stormwater use practices for larger scale systems employ two broad categories of stormwater distribution systems: open space irrigation systems and non-potable distribution systems (also referred to as dual reticulation) (Mitchell et al. 2007b). Hatt et al. (2004) showed that irrigation systems are the most common method employed for stormwater distribution, followed by dual reticulation and pumping. The use of irrigation systems was restricted to use schemes with catchment area under 200 ha. Dual reticulation, where potable

water is piped through the usual mains and recycled water is distributed through a separate purple pipe, is a viable distribution option for use schemes from the neighborhood scale (Hatt et al. 2004).

2.2.10.3. Storage

Optimal design of stormwater storages forms a key part of effective use schemes as they are central to related space constraint, public safety and aesthetics issues. Typical examples include open storages; above or underground tanks; and aquifers through aquifer storage and recovery (ASR). The availability of suitable storages for large-scale stormwater harvesting varies among cities in Australia (Productivity Commission 2008).

Each storage type has respective advantages and disadvantages (see Table 3.3). Open storages are susceptible to losses due to seepage along the wetted perimeter and evaporation. Seepage losses may be substantial as it is a continuous process, while evaporative losses may be reduced by designing the storage to have a small surface area to volume ratio (Mitchell *et al.* 2006a). Alternatively, during extended dry periods stormwater can be preferentially stored in sections with the smallest surface area to volume ratio (Hatt *et al.* 2004). Storage tanks can minimize water losses but they may be large and inconvenient to position, require deep excavation to install below ground, create aesthetic issues if above ground, and may require sheltering from weather.

Table 2.3 Stormwater storage types

Storage type	Potential advantages	Potential disadvantages
Open storages	<ul style="list-style-type: none"> • Low capital and maintenance cost 	<ul style="list-style-type: none"> • Public safety • Mosquito-breeding potential • Higher potential for eutrophication • Aesthetic issues with fluctuating water levels
Above-ground	<ul style="list-style-type: none"> • Moderate capital and maintenance cost • No public safety issues 	<ul style="list-style-type: none"> • Aesthetic issues
Underground	<ul style="list-style-type: none"> • No visual issues • No public safety issues 	<ul style="list-style-type: none"> • Higher capital cost • Higher maintenance costs
Aquifer	<ul style="list-style-type: none"> • Little space required • Cost effective • Prevents saltwater intrusions to aquifer 	<ul style="list-style-type: none"> • Requires suitable geology • Potential to pollute groundwater unless pre-treated

(Source: Philip, et al, 2008)

Pratt (1999) discussed the problems associated with developing sufficient storage space in the urban environment and suggested the storages could be constructed under paved areas. Stormwater could then be stored in either tanks or a suitable soil medium under an appropriate paved surface enclosed within an impermeable membrane. This would optimize the space currently available, reduce construction costs and could be completed as part of the urban renewal process when infrastructure upgrades or maintenance are required. It is also highly unlikely that there will not be adequate areas of paved surfaces to provide the required storage of a harvesting scheme in the urban environment.

2.2.10.4. Treatment

Treatment of storm water is a vital part of storm water harvesting and reuse. The aim of water treatment is the elimination of unwanted contaminants such as pathogens and pollutants (Kolarik, and Priestley, 1996). But the degree of required treatment varies depending on the specific reuse application of water and associated water quality requirements (Lens, et. al., 2002). For example, most waters need to purify if they are used for potable purposes, but water treatment is rarely required for agricultural purposes (Fatema, et. al., 2014).

These levels of treatment are discussed below.

2.2.11. Storm Water Treatments

The stormwater treatments levels applications performed through two techniques, WSUD treatment techniques and advanced treatment and disinfection. For the purpose of this paper, only WSUD treatment technique is discussed.

2.2.11.1. WSUD Treatment Techniques

Water Sensitive Urban Design (WSUD) play an important role tackling the adverse impacts of urbanization on urban water ecosystems is, as it integrates the main aspects of urban water management (urban water cycle, water supply, wastewater, stormwater, groundwater and potable water management, and urban design) and treat all sources of water generated in a catchment as a resource (BMY_WBM, 2009). There are three levels of storm water treatment in WSUD on the basis of effectiveness and application of treatment (Pirpil, et al, 2022);

- At the primary level, physical screening (or trapping) and rapid sedimentation are the dominant processes. This removes floating, suspended the inflow impurities and coarse sediment through sedimentation tanks, gross pollutant tank (OPT), and trash rack.

- At the secondary level, sedimentation and filtration dominates. It removes suspended solids, some nutrients and metals through swales, infiltration basin, and porous pavement.
- At the tertiary level, the dominant processes are enhanced sedimentation filtration, biological uptake and adsorption. Removal of dissolved and micro impurities through adsorption and biological degradation, uptake by plants through bio-retention system, and wetlands.

(Philp, et al, 2008), categorized the application of Stormwater WSUD treatment techniques in to physical processes, infiltration methods, bio filters and proprietary devices.

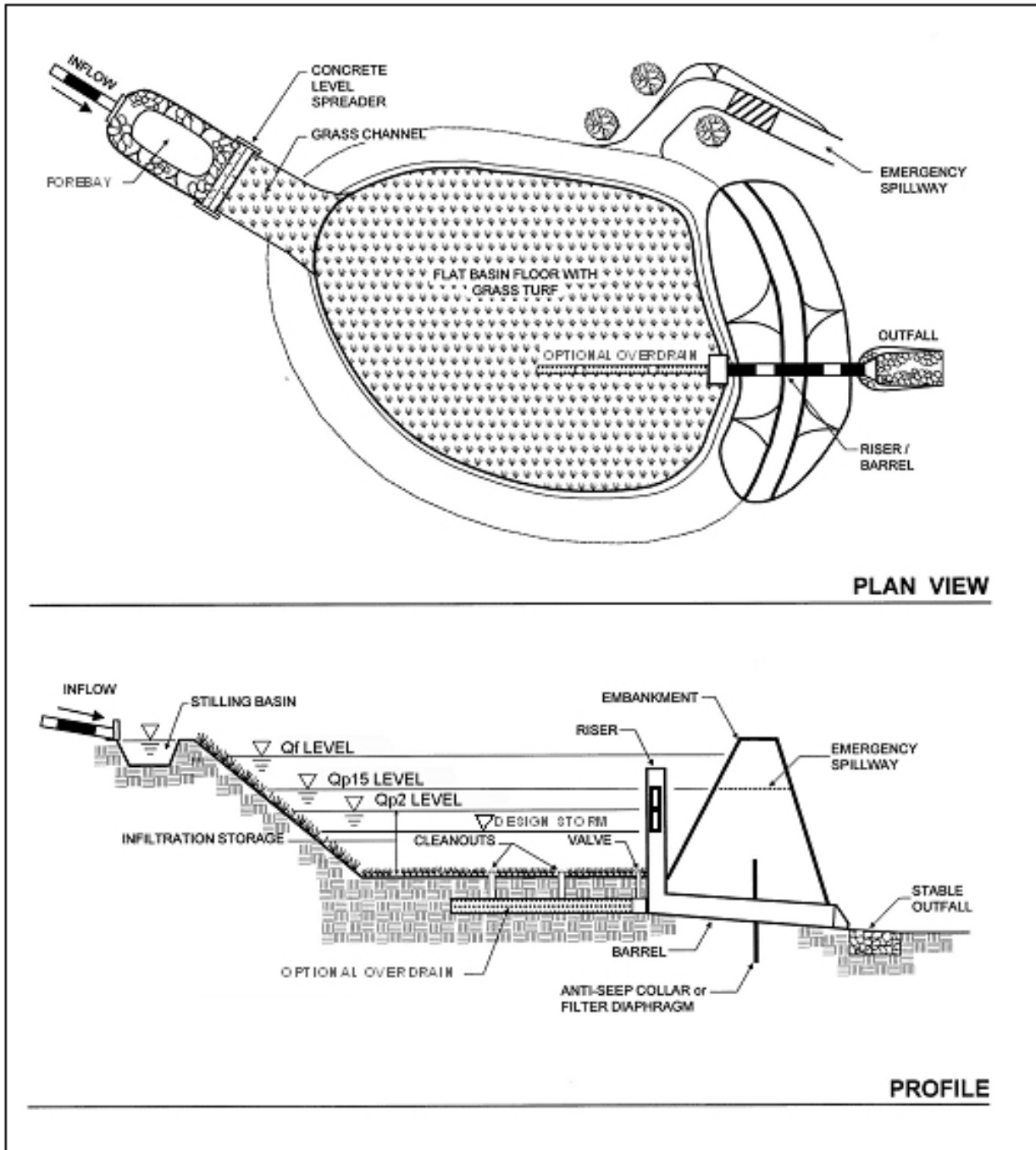
A. Physical Processes

Physical Processes is the category used here to describe WSUD treatment devices that rely on hydraulic properties for treatment. These treatment techniques include swales, buffer strips, and open water bodies (natural and constructed). It is unlikely that these processes alone will provide significant treatment to allow use of harvested water; however, they may provide important preliminary treatment to reduce pollutants such as sediment loads before subsequent steps in the treatment train approach. These physical processes work on the principle of reducing flow velocities to allow sediments to settle out of the water column. The open water bodies also have the combined benefit of exposure to UV light to provide some level of disinfection. Principally these techniques used in the cases, stormwater is used directly on site for irrigation, primarily of golf courses where public access is restricted (Philp, et al, 2008).

B. Infiltration Methods

Infiltration treatment measures use the physical process of infiltration to provide treatment to the collected stormwater. These processes include porous and permeable pavements, infiltration basins and trenches, sand filters and biologically engineered soils. Infiltration devices can also be combined with vegetation to assist with the treatment of the water (Philp, et al, 2008).

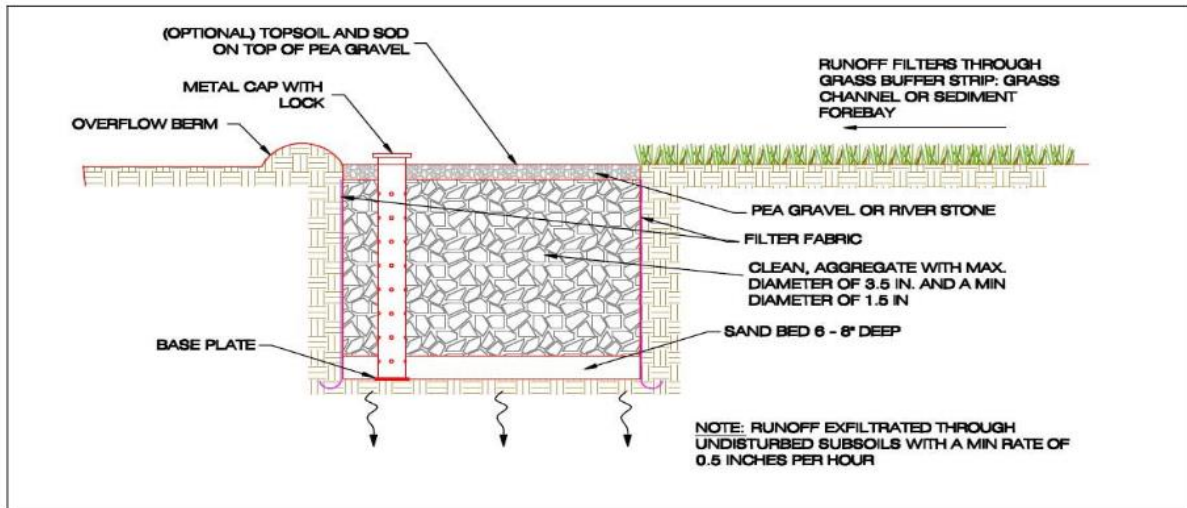
Infiltration trench is a shallow ditch filled with gravel or rubble that is used to filter rainwater into a groundwater aquifer by permeating permeable soil. It is frequently used to transport sewage from impermeable surfaces like sidewalks and parking lots in areas with poor rainwater drainage. Seepage ditches are used to create underground reservoirs for runoff that seep into the surrounding soil over the design period. These are relatively narrow construction pits filled with gravel or other highly porous material. Infiltration trenches are thought to have the ability to dampen the flow and are a low impact development (Pusalkar et al., 2020).



3Figure 2.2 Typical infiltration basin layout
 (Source: Center for Watershed Protection, 2012)

Design considerations: The ditch geometry should allow the drain pipe to drain in 96 hours. The surface gravel layer should be at least 0.5 feet thick. Observation wells of at least 4 inches in diameter are required. Use weatherproof caps. Seepage: Do not dig trenches within 100 feet of private wells, septic tanks, or sewers due to potential groundwater contamination (Stauffer, 2018).

According to studies by (Booth *et al.* 2003, Fletcher 2003, Melbourne Water 2005, Jayasuriya 2007) conducted in Australia, if pervious pavements are correctly designed and maintained they can remove up to 80% of sediment, 60% of phosphorus, 80% of nitrogen, 70% of heavy metals and 98% of oils and greases in stormwater.



4Figure 2.3 Typical infiltration trench layout
(Source: Center for Watershed Protection, 2012)

C. Bio filters and Wetlands

Bio filters, including wetlands (natural and constructed), use biological and physical methods to treat storm water. Bio filters involve a soil filter medium planted with vegetation, and containing a collection pipe to convey the filtered water to receiving waters or downstream storage facilities. There have recently been a number of promising results in the treatment effectiveness of bio filters in relation to storm water use (Philp, et al, 2008):

- Hatt et al. (2007a) conducted trials that showed biofilters could be designed to achieve the required water quality standards for stormwater use.
- Read et al. (2008) found that percolation of stormwater through soils with or without plants, effectively reduced concentrations of suspended solids, trace metals, and to a lesser degree phosphorus. Vegetated biofilters reduced nutrient levels relative to the soil-only control.
- Henderson et al. (2007) demonstrated that the best media choice for biofiltration treatment of stormwater appears to be sand or sandy-loam. Vegetation in the media was found to greatly improve the removal efficiency of nitrogen and phosphorus, and retains more nutrients during the initial flush after an inter-event dry period.

D. Proprietary Devices

Gross pollutant, oil and grease, and sediment trap devices are available in a range of styles for a range of applications. These traps are generally used at the beginning of the treatment train to give some preliminary treatment to the stormwater before entering another treatment process. Hydrodynamic separating devices have been extensively applied especially in the USA, and have been the subject of a number of verification studies (Faram *et al.* 2000, 2005a, 2005b, 2007; Pratt 2000; Phipps *et al.* 2005). (Faram, 2007) considered seven hydrodynamic separators located across the United Kingdom. Proprietary interceptor devices were shown to remove fine sediments from urban runoff, preventing them from entering downstream watercourses or further treatment facilities. The optimal design or selection of stormwater sediment management systems can be aided through an understanding of individual site conditions and requirements, and related sediment physical and chemical characteristics (Philp, et al, 2008).

2.2.12. Hydrology Analysis

The method used to predict surface runoff RWH potentials is based on design storms. The methods to estimate the peak flood discharge are rational methods, Runoff Curve Number Methods (RCNM), Statistical analysis of stream data and regional regression equations. (ERA Drainage Design Manual, 2013).

2.2.12.1. Rational Method

The rational method is widely used in engineering practice to estimate peak flood discharges for the design of hydraulic structures on small watersheds. Typical applications include culverts, small bridges, and storm water drainage systems in urban areas (C. Bryan Young, 2009). In its most common form, the rational method is written as:

$$Q = 0.00278 CIA$$

Where;

Q = maximum rate of runoff, m³/s

C = runoff coefficient

A = catchment area tributary to the design location, ha

I = average rainfall intensity for a duration equal to the time of concentration, for a selected return period, mm/hr.

Less frequent, higher intensity storms will require modification of the coefficient because infiltration and other losses have a proportionally smaller effect on runoff (Water Resources Council, 1981). The adjustment of the Rational Method for use with major storms can be made by multiplying the right side of the rational formula by a frequency factor C_f . The rational formula now becomes:

$$Q = 0.00278 C C_f IA$$

The product of runoff coefficient (C) and frequency factor (C_f) shall not exceed 1.0, and see table 2.2 below for values of (C_f) of different recurrence interval.

4Table 2.4 Frequency factor (C_f) for rational formula

Recurrence Interval (years)	Frequency Factors (C_f)
5	1.0
10	1.0
25	1.10
50	1.20
100	1.25

(Source: Ethiopian Roads Authority Drainage Design Manual, 2013)

Hydrological Soil Groups for Ethiopia (HSG)

Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Permeability and infiltration are the principal data required to classify soils into HSG. Based on infiltration rates, the Soil Conservation Service (SCS) has divided soils into four hydrologic soil groups as follows:

Group A: Sand, loamy sand or sandy loam. Soils in this group have a low runoff potential due to high infiltration rates. These soils primarily consist of deep, well-drained sands and gravels.

Group B: Silt loam, or loam. Such soils have a moderately low runoff potential due to moderate infiltration rates. These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Sandy clay loam. Such soils have a moderately high runoff potential due to slow infiltration rates. These soils primarily consist of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.

Group D: Clay loam, silty clay loam, sandy clay, silty clay or clay. These soils have a high runoff potential due to very slow infiltration rates. These soils primarily consist of clays with

high swelling potential, soils with permanently-high water tables, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious parent material.

5Table 2.5 Recommended runoff coefficient C for rural catchment

Factor		Description	C
Cs	Average slope of catchment	< 3.5% Flat	0.05
		3.5% - 10% Soft to moderate	0.10
		10% - 25% Rolling	0.15
		25% - 45% Hilly	0.20
		> 45% Mountainous	0.25
Cp	Permeability of soil	Well drained soil e.g. sand and gravel	0.05
		Fair drained soil e.g. sand and gravel with fines	0.10
		Poorly drained soil e.g. silt	0.15
		Impervious soil e.g. clay, organic silts and clay	0.25
		Water-logged black cotton soil	0.50
		Rock	0.40
Cv	Vegetation	Dense forest/thick bush	0.05
		Sparse forest/dense grass	0.05
		Grassland/scrub	0.10
		Cultivation	0.20
		Space grassland	0.25
		Barren	0.30
$C=C_s+C_p+C_v$			

(Source: Ethiopian Roads Authority Drainage Design Manual, 2013)

2.2.12.2. Runoff Curve Number Methods

The Natural Resources Conservation Service (formerly Soil Conservation Service) developed the runoff curve number method as a means of estimating the amount of rainfall appearing as runoff. Technical Report 20 (TR 20) employs the Runoff Curve Number Method and a dimensionless unit hydrography to provide estimation of peak discharges and runoff hydrographs from complex watersheds. The procedure allows the designer to estimate the effect of urbanization, channel storage, flood control storage, and multiple tributaries. Additionally, it can be applied to design culverts, bridges, detention ponds, channel modification, and analysis of flood control reservoirs (ERA Drainage Design Manual, 2013). However, the SCS Curve Number method is applicable to small catchments (maximum area 6,500 ha) with a time of concentration for any sub-area of 0.1 – 10 hours (NRCS, 2002).

The method should be used only when the watershed has one main channel or when there are two main channels that have nearly equal times otherwise, hydrograph method should be used. Other methods should also be used when channel or reservoir routing is required, or where watershed storage is either greater than 5 percent or located on flow path used to compute the etc (ERA Drainage Design Manual, 2013).

2.2.12.3. Statistical Analysis of Stream Gauge Data

Where stream gauge data are available, stream gauge data can be used to develop peak discharges. The Ministry of Water & Energy keeps annual stream gauge data. The method commonly used for estimating the peak discharges is usually Log-Pearson Type III distribution. However, as the record length is increased, a Log-Normal distribution or General Extreme Value (GEV) distribution could also be used. The recent data analysis demonstrated that GEV can be used to estimate the peak flow in Ethiopia (ERA Drainage Design Manual, 2013).

2.2.13. Advantages and Disadvantages of Rainwater Harvesting

2.2.13.1. Advantages

Rain water harvesting has different environmental and economic benefits. (Eslamian and Eslamian, 2021). Summarized advantage of rainwater harvesting as below:

- Saves water and energy.
- Water for domestic use: Rainwater harvesting is beneficial because it provides a source of water for domestic use. The collected water can be used for house cleaning purposes, washing laundry, and for cooking. When treated, rainwater is good for drinking. It is an easy way of obtaining water for use in the home.
- Sources of energy are not needed to operate the system.
- Water for industrial use: Industries can also harvest rain-water for use in some of their processes. Rainwater meant for industrial use is normally harvested in large scale. Such companies can construct their own dams or have underground tanks to store rainwater.
- Supplementary water source: Many areas experience water shortages during summer due to lack of rain and as a result of the high rate of evaporation. It can be difficult to get a reliable source of water during these periods. Those who sell water may also increase their prices because of the high demand and short supply. Harvesting rainwater is therefore seen as a way of preparing for the sunny days when water is scarce.

- Quality of rainwater can be used as a primary source for specific uses and so reduce the water bill.
- Does not come into contact with soil and rocks where it dissolves salts and minerals. It is soft and can significantly reduce the quantity of detergents and soaps needed for cleaning.
- Very good for areas that are not served with water.
- Relatively limited technical knowledge is required
- It uses local construction materials and labor.
- The owner user can easily maintain the system.
- Decreases local erosion and flooding caused by runoff from impervious cover such as pavement and roofs.
- The RRWH is usually found to be socially and environmentally acceptable.

2.2.13.2. Disadvantages

Disadvantages of rainwater harvesting technologies are mainly due to the limited supply and uncertainty of rainfall. Adoption of this technology requires a “bottom-up” approach rather than the more usual “top-down” approach employed in other water resource development projects.

The main disadvantages are (Eslamian and Eslamian, 2021):

- The high initial cost of building the permanent storage facilities; the primary expense is the storage tank.
- The quantity of rainwater available depends on rainfall; for long periods of drought, it is necessary to store excessively large volumes of water.
- The mineral-free water is tasteless and could cause nutritional deficiencies; people prefer to drink water rich in minerals.

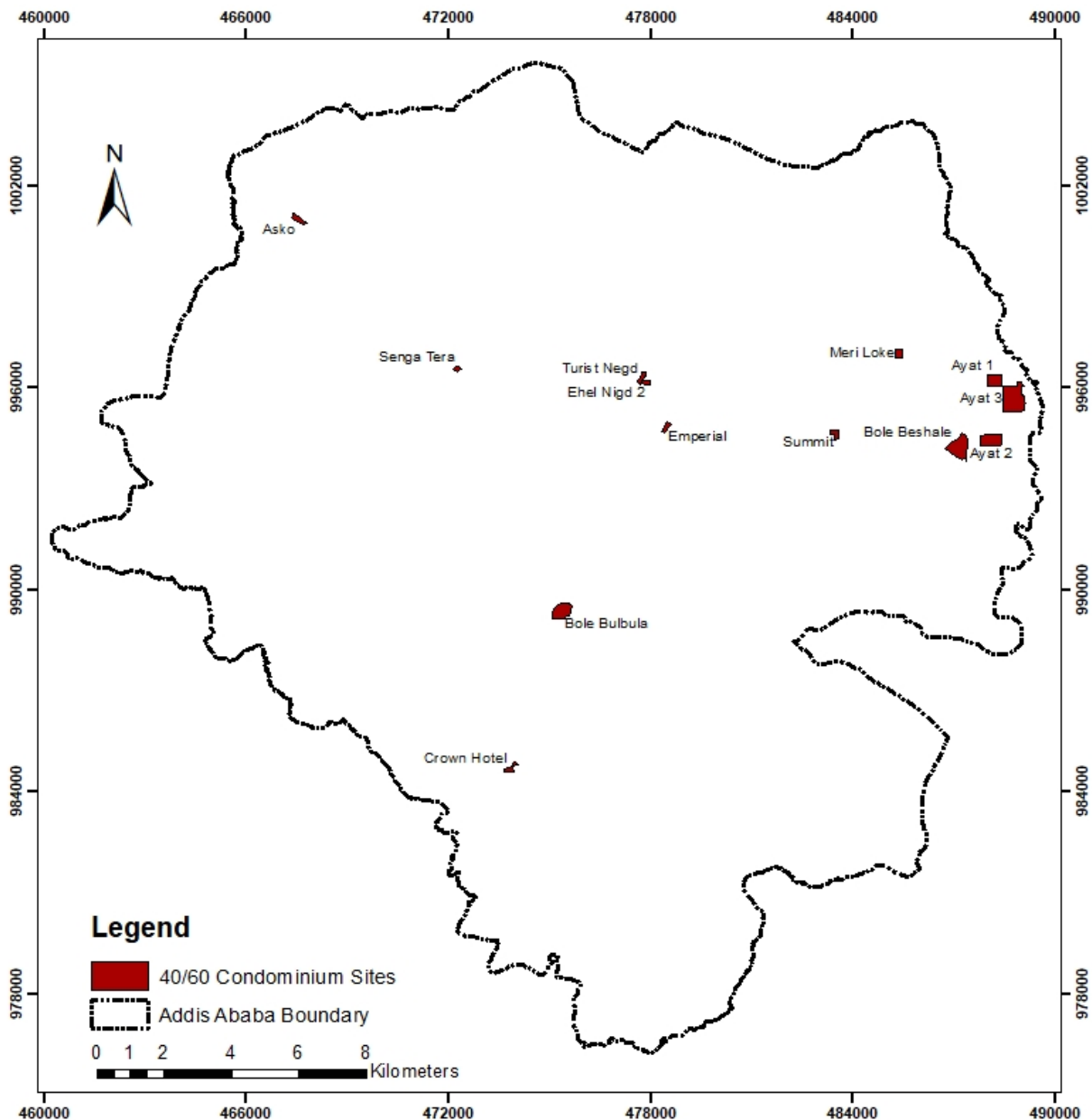
2.3. Contextual review

2.3.1. 40/60 saving condominium housing.

Addis Ababa 40/60 Condominium saving housing is one of the three housing supply schemes of Integrated Housing Development Program (IHDP) implemented since 2005 in Addis Ababa, with the objectives of drastically increasing the supply of housing, creating employment, promoting the development of micro and small enterprises, regenerating inner city slum areas, and promoting homeownership for low-income households.

According to Addis Ababa Housing Development Agency, over 38,700 housing units were built on thirteen sites by Addis Ababa Savings Housing Enterprise between 2005 and 2012 E.C. These buildings have different typologies from G+7 to G+18 and also four types of residential house units and different types of commercial spaces.

The two earliest 40/60 saving condominium project sites are Sengatera (G+12) and Crown (G+9). Both sites respectively consist five and fourteen block of buildings with two-bedroom, three bedroom, and four-bedroom residential house units. Other sites have one-bedroom, two-bedroom and three-bedroom housing units.



5Figure 2.4: Addis Ababa 40/60 Condominium sites

2.3.2. Water Sources

The city currently gets its water from three surface water sources (Gefersa, Lagadadi and Dire dams, which are located in Oromia regional state) and groundwater sources (Akaki well fields and small boreholes distributed in different parts of the city). This indicates that the city is largely dependent on water sources outside its jurisdiction (Addis Ababa Resilience Project Office, 2021). Failure of any of these water sources would result in a crisis (World Bank Group, 2015).

According to the residents, Sengatera site 40/60 saving housing compound uses their own water sources (deep wheel) constructed by funds from the dweller's own contribution. The six-month AAWSA monthly water consumption result also shows, only six consumers of AAWSA water supply in that compound. The rest twelve housing sites are connected to the city water distribution line and AAWSA is the only supplier.

The water supply of 40/60 condominium buildings is indirect water supply system. The municipal water mains are connected to underground water reservoir placed in basement floors of the buildings, and the water pumped to elevated water tanker on the roof top. The water distribution line of each housing units connected to elevated water tank and the fixtures supplied via gravity from the elevated water tank.

2.3.3. Water supply and demand

Currently the total water supply is 580,000 m³ per day, while the city demand is 1.1 million m³ per day. Production of 450,000 m³ /day is sourced from surface and groundwater, and it is estimated that about 36.5 percent of this water is lost due to leakage and other system inefficiencies (Addis Ababa Resilience Project Office, 2021). Addis Ababa, water demand is continuously increasing, disproportionally to supply from both surface water and groundwater sources. The current supply system provides only 58 liter/capita/day of water to the city's inhabitants. With the standard domestic water demand for a basic quality of life considered 100 liter/capita/day, the existing water supply sources can only meet the water demand of about 82% of Addis Ababa's population (Tefera, et al., 2022).

The main cause for water supply deficit in Addis Ababa, other than the condition of the network, is the reliance on groundwater. The groundwater-focused supply approach has not been able to bring substantial change in the water supply of the city. Between 2016 -2019 this source has added 74,00m³/d to total supply but on the other hand, the capacity of existing ground water

sources dropped by 129,000 m³/day with a negative growth balance. Moreover, the groundwater supply system relies on foreign currency availability (for fuel and spare parts), which made this type of water production very challenging. Consequently, the yearly growth of the city water production is 6-7% which can barely keep up with the annual population growth and fails to address the existing backlog UN-Habitat, 2021).

Addis Ababas' weekly water supply schedule differ from one 40/60 housing site to the other. While Crown Hotel and Ehil Negd site supplied water six to seven days a week; Ayat 1 site gets water supply three days a week; Asko, Summit, Meri Loqe, Ayat 2, Imperial, Bole Arabsa and Bole Beshale site get water twice a week, however there are a lot of buildings did not connect to the municipal water supply line. The most affected Tourist site gets water only once a week.

Therefore, resident store water in plastic container in their house until their next water supply schedule. In some sites resident install additional water tank for their individual housing units. See Figure 2.3 Individual water tank picture taken from one of Tourist site building.



6Figure 2.5 Individual water tanks

2.3.4. Rain water harvesting in Ethiopia

The promotion and application of rainwater harvesting systems as an alternative to address water scarcity were started in Ethiopia through government initiatives of soil and water conservation programs in response to the 1971-74 droughts with the introduction of the Food-for-Work (FFW) program. The initial rainwater harvesting activities included construction of ponds, micro dams, bunds, and terraces in most parts of the drought affected areas (Kebede, 1995).

A large number of waters harvesting technologies have also been implemented with support from the Government of the Federal Democratic Republic of Ethiopia (FDRE, 2000). The most

notable achievements registered in promotion of the water harvesting technologies range from raising tree seedlings for fruit production in some parts of the country during the dry season, establishing of nurseries, supplementary irrigation and diversification of crops and use of improved agricultural technologies. Hence the importance of water harvesting technologies is implicitly unquestionable in addressing those pressing problems as shortage of water during a rainy season (Fitsum and Tilhaun, 2014).

2.3.5. Policy and regulation review

Ethiopian 10-year development plan have an objective of water resource development, to ensure equitable provision and accessibility of potable water, sanitation and hygiene services that meet quality standards; and to enhance the development and utilization of the river basin and irrigation resource of Ethiopia. One of the main targets that can help achieve the above objective is expand water accessibility and supply coverage to increase urban residents access to 100 liters of precipitate water for grade one city such as Addis Ababa.

According to EBCS-9-2013; water consumption of residential buildings depends on type of delivery of water to the end consumer and the living standard of the community. The living standard classified as below:

- I. Low consumption is dwelling unit with only one wet corner, fitted with shower, Hand wash basin, WC, traditional kitchen without kitchen sink, but with manual laundry trough.
- II. Medium consumption is dwelling unit with two wet corners, fitted with shower, Bath tub, Hand wash basin, WC, kitchen sink and laundry sink or machine.
- III. High consumption is dwelling unit with more than two wet corners, fitted with all mentioned in (ii) above and sauna facilities and others.

6Table 2.6 Residential water requirements

Type of building occupancy	Consumption per head per day
a) Dwellings with house connections*	
• Low consumption	80 – 120
• Medium Consumption	120 – 200
• High Consumption	200 – 300
b) Offices (per person)	35
c) Restaurants (per seat)	75

Source: (EBCS-9-2013, page 40 - 41)

Further, EBCS-9-2013 recommends overhead tank (OHT) or underground tank (UGT), the minimum capacity of storage tanks depends on the type of the tank as below;

- a. In case only elevated water tank is provided, it may be taken as 33 to 50 percent of one day's requirement;
- b. In case only underground water tanks is provided, it may be taken as 50 to 150 percent of one day's requirement; and
- c. In case combined storage is provided, it may be taken as 67 percent underground tank and 33 percent elevated water tank of one day's requirement.

2.5. Empirical review

Handfuls of RWH study are conducted in Ethiopia so far. (Dagnachew, et al, 2018) assessed the RWH potentials of large public institutions such as, University, Collage, Health Center, Hospital, Wereda, Sub-city, Addis Ababa City Administration and Federal Government buildings in Addis Ababa. The roof size of 588 buildings area digitized in Arc GIS from Google Earth satellite image; ten years monthly rainfall recorded data from three rain gauge station was used to analyze the Addis Ababa monthly rainfall distributions, and one-year monthly water consumption of the study buildings are collected from AAWSA. The study result shows, the study buildings have a potential to collect 2.3% of their annual water consumption.

(Yalemzewd, et al, 2020) investigates rooftop RWH potential, water demand supply gap between harvested rainwater and toilet flushing water demand of Tulu Dimtu Condominium, as well as, roof catchment area measurement techniques from Google Earth, Citywide structure plan and field measurement. The comparison measurement techniques result shows, measuring roof catchment areas from citywide structure plan is better than the others. The potential RWH analysis result showed that **18.13%** of water consumption of toilet flushing of the study area could be covered by the harvested rainwater.

(Asheber, 2015) Assessed the potential of rain water harvesting practice to solve problems of both increasing water demand and storm water in Addis Ababa city Jemo One Condominium. The result indicates, rooftop RWH potential is be 90,290.2 m³ annually. This can cover about 10% of domestic water demands of the site. Additionally, the total cumulative runoff generation from this site is 723,450m³ annually; RWH from roof tops at Jemo condominium site can reduce 12% of runoff. (Demisu, 2020) Assessed Mojo town drainage system and proposed LID then

modeled both system performances using SWMM. The result indicates the total runoff reduction by 25.9% using infiltration trench.

2.5. Conclusion

Water Sensitive Urban Design (WSUD) is an initiative aimed at managing the water cycle in urban areas, focusing on sustainability and environmental sustainability. It aims to incorporate rainwater into the landscape, conserve water quality and natural systems, and reduce runoff and peak flows. Urban impervious surfaces, such as rooftops, sidewalks, and roadways, have two major impacts: increasing stormwater runoff volumes and decreasing base groundwater flows. WSUD functionalities include storm water quality management, flood control, rainwater harvesting, biodiversity, and other measures. Rainwater harvesting can be an alternative to increase available domestic water and sustain groundwater.

Rainwater harvesting is a technology used to collect and store rainwater from various sources, including rooftops, land surfaces, road surfaces, and rock catchments. This renewable source of clean water is ideal for domestic and landscape uses. Rooftop RWH systems can consist of up to six components, including catchment, conveyance, filtration, storage, distribution, and purification, depending on the degree of water quality required.

Stormwater harvesting and reuse schemes involve four components: collection, storage, treatment, and distribution. Collection systems divert stormwater from urban creeks, stormwater drains, or general urban runoff into storage for harvesting. Distribution is determined by factors such as the spatial scale of the distribution area, density of end uses, and firefighting requirements. Currently, two broad categories of stormwater distribution systems are used: open space irrigation systems and non-potable distribution systems (dual reticulation). Optimal design of stormwater storages is crucial for effective use schemes, as they are central to space constraint, public safety, and aesthetics issues.

Water Sensitive Urban Design (WSUD) is a crucial approach to addressing the adverse impacts of urbanization on urban water ecosystems. Infiltration methods, such as porous and permeable pavements, infiltration basins, and trenches, use the physical process of infiltration to treat collected stormwater.

CHAPTER THREE: RESEARCH METHODOLOGY

2.4. Introduction

This chapter discusses the methodological process that used to conduct the research based on the objective of the study. This comprises the detail section that description of study area, data collected, questionnaires survey, personal interview and detail process of how the analysis of the data was made.

3.2. Study area description

Addis Ababa located between, 8°50' N to 9°5' N and 38°38' E to 38°54'E; the city altitude ranges from 2050m to 3040m above sea level and average annual rainfall is 1184mm. Addis Ababa, the climate is warm and temperate. Summers are much rainier (June to September) than winters and the average annual rainfall is 1184mm. The average maximum and minimum temperatures range between 22.9oC and 10.2oC. The average humidity of the city is 57.67% (Feyissa et al, 2018 and Metaferia, 2017).

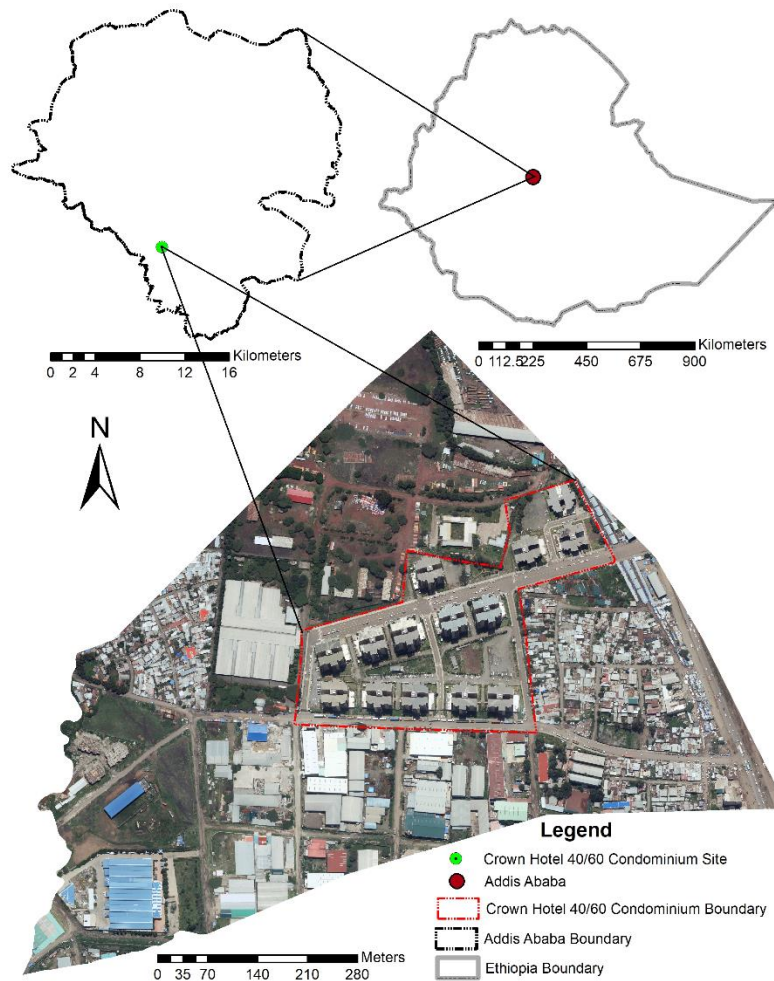
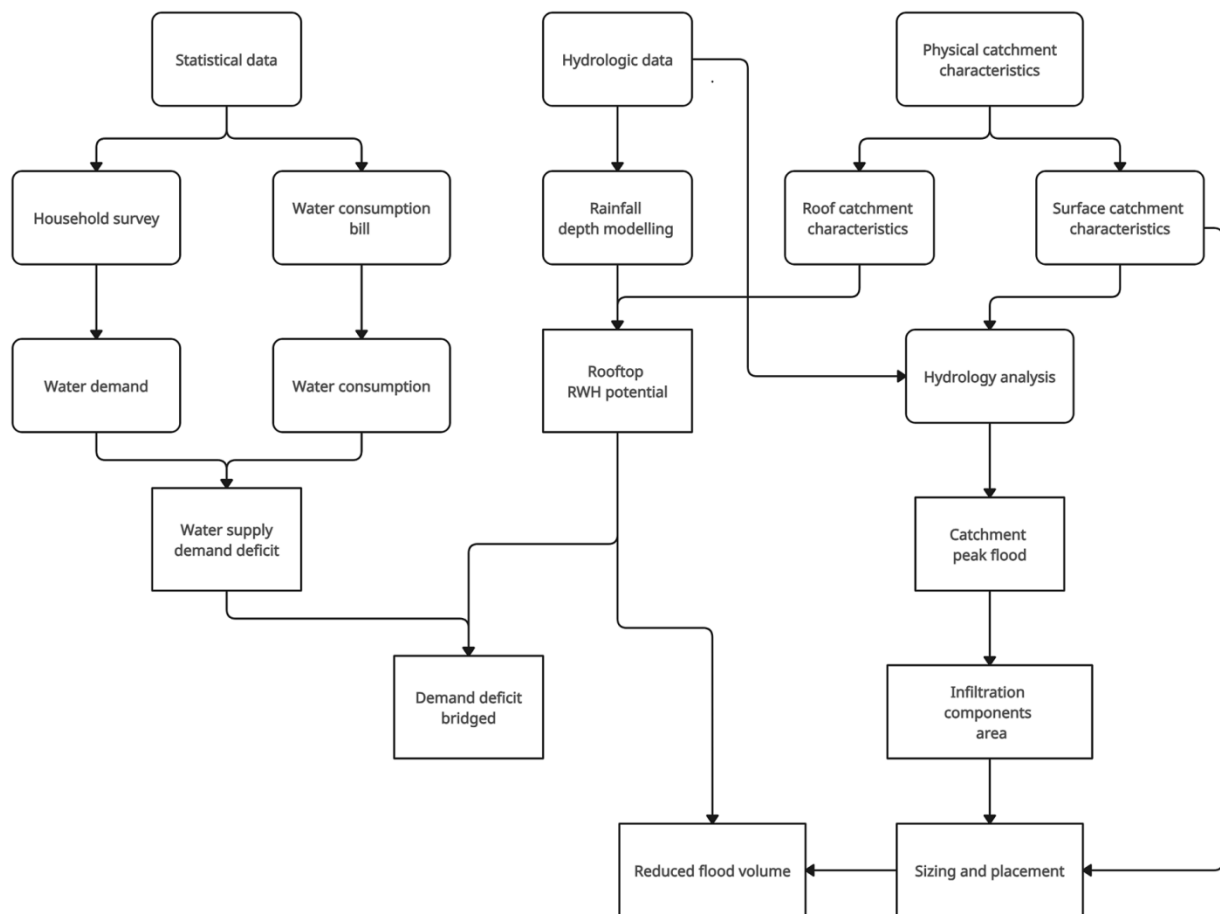


Figure 3.1 Location map of study area

The study site, Crown Hotel 40/60 condominium located southern west of Addis Ababa. It is among the earliest project of its kind next to Sengatera site. It has fourteen buildings; each has commercial space from ground to second floors and residential housing units from third to eighth floors. The basement floor of the buildings serves dwellers for car parking area, storage and placement of the buildings underground water reservoir. Unlike other 40/60 condominium building typologies, the study buildings residential housing units are two-bedroom, three-bedroom and four-bedroom.

3.3. Research design

Both qualitative and quantitative research types employed to collect and analyze relevant data for the study. A questionnaire survey, personal interview, desk study, and field observations are the methodologies used. Figure 3.2 below shows, the conceptual frame work of the study developed based on reviewed literature to show the study variables relationship.



8Figure 3.2 Conceptual framework of the study

3.4. Type and Source of Data

Both primary and secondary data relevant data for the study were obtained using household survey, field observation, desk study and intensive review of different documents from governmental organizations, official reports, books, magazines, journals, and online sources, published and unpublished previous researches.

3.4.1. Primary data

To project the study buildings water demand, primary data was collected through household surveys from the study buildings dwellers. The structured face-to-face interview survey method was used for commercial spaces and questionnaire interview methods were used for residential household surveys. The study catchment land cover and soil property were identified through field observation.

3.4.2. Secondary data

Daily recorded seven to thirty years rainfall data from fifteen stations (See table 3.1) were provided from National Meteorological Agency. Five of the rain gage stations, Sendafa, Sululta, Boneya, Sebeta and Dire Gidib are located outside Addis Ababa. This was to ensure that the spatial interpolation catches any clusters the city and correctly interpolating them. The precipitation data ranges from seven to thirty-one years.

3.5. Sampling design

3.5.1. Sample population

Populations of the study are 882 residential and commercial housing units of the study site. Residential unit are 672 and commercial units are 210.

7Table 3.1 Crown Hotel site 40/60 housing units' data

No	Housing types	No. unit/building	No. Blocks	Total
1	Two Bed	16	14	224
2	Three Bed	16		224
3	Four Bed	16		224
4	Shops/Office	14		196
5	Café/Restaurant	1		14
Total				882

3.5.2. Sample size

Sample size of the study is determined using (Cohran, 1977) formula for both finite and infinite population.

For infinite population:

$$n_o = (Z^2 * p * q) / e^2$$

Where, n_o is the sample size, Z is the selected critical value of desired confidence level, p is the estimated proportion of an attribute that is present in the population, $q=1 - p$ and e is the desired level of precision.

Assuming 25% degree of variability, 95% confidence level and 5% margin of error. Z value for 95% confidence level is 1.96.

Therefore;

$$\begin{aligned} n_o &= \frac{1.96^2 * 0.2 * (1 - 0.2)}{(0.05)^2} \\ &= 245.9 = 246 \end{aligned}$$

For finite population:

$$n = n_o / (1 + (n_o - 1) / N)$$

Here n_o is the sample size derived from equation (1) above and N is the population size

Thus;

$$\begin{aligned} n &= 246 / (1 + (246 - 1) / 882) \\ &= \underline{\underline{192.52}} \end{aligned}$$

Thus 193 sample sizes are taken.

3.5.3. Sampling techniques

For household interview and questionnaire survey, non-probability sampling technique is used based on availability and willingness of respondents. However, proportional amount of survey is conducted between the number of residential and commercial housing units.

3.5.4. Sample Selection

In order to make the sample size proportional to the numbers of residential and commercial housing units, 147 questionnaire interviews were collected from residential housing units and the rest 46 personal interview were from commercial activity housing units.

3.6. Method of Data Analysis

3.6.1. Household survey

The primary data, household survey questionnaire have four parts, the first part is about demography of respondent's household, the second is about the characteristics of housing, the

third part is about indicator of water use activities and the last one is demand of water use activities.

The household monthly water demand is calculated, using the household demography, indicator of water use activity and demand of water use activity value, from household survey. If the water uses indicator and demand value is for one person in the household, the values are multiplied by household size number of days or weeks in a month depending the water use indicator.

The monthly water demand of a building is calculated by multiplying the average water demand of household of each housing types and the number of each housing types in one building.

3.6.2. Water consumption bill

To identify the water consumption bills in the study site, each month excel data is converted to a point shapefile and projected to Adindan_UTM_Zone_37N using the GIS geographic transformation tool. Then, the point's shapefile with in the study site boundary is selected using GIS proximity analysis.

To determine the average monthly water use of a housing unit, the cumulative total monthly water consumption volume of each month is divided for the number of bills; then the cumulative average of housing unit consumption is used to project the total consumption of a building.

3.6.3. Catchment

The study site catchment slope is analyzed from Nortec contour using GIS 3D, and Spatial Analyst tools. Roof catchment materials, size and rainwater drainage system are determined from each buildings Architectural drawing. As well as the study site sub catchment area is converted to Arc GIS shapfiles from the sites' Neighborhood Design and the catchment land use and soil properties were determined through field observation. The attributes of catchment land use are surface cover types and their area.

3.6.4. Runoff Coefficient

The cumulative average runoff coefficient of the study site is calculated using the combination of (Pecey Arnold and Cullis Adran, 1989, Federal Highway Administration, HEC No. 19, 1984) and ERA (Ethiopian Road Authority) Drainage design manual (2013) runoff coefficient value of different surfaces covers.

3.6.5. Rainfall data

To identify the mean monthly rainwater depth of study site, monthly rainfall data obtained from National Meteorological Agency were interpolated for each month by Inverse Distance

Weighting (IDW) method using ArcGIS spatial analyst tool; the interpolated each month's monthly rainfall distribution raster map is reclassified in to five equal intervals and the average result of rainfall amounts is used as monthly rainfall depth

8Table 3.2 Recorded annual rainfall value

No	Station Name	Longitude (Deg)	Latitude (Deg)	Elevation (m)	Average annual rainfall (mm)	Remark
1	Abssinia School	38.72333	9.04472	2501	1208.55	20 years
2	Addis Ababa Bole	38.79871	8.98108	2354	1040.76	30 years
3	Addis Ababa Obs	38.7475	9.01891	2386	1212.87	30 years
4	Akaki	38.788	8.872	2057	962.12	30 years
5	Kotebe	38.839	9.048	2462	1121.04	18 years
6	Medhanalem/School	38.727	9.059	2539	1011.84	18 years
7	Sebeta	38.629	8.915	2220	1107.60	7 years
8	Sendafa	39.0215	9.15217	2558	1289.31	30 years
9	Sululta	38.758	9.179	2595	1146.11	30 years
10	Yekatit 23 School	38.73056	9.0335	2456	1291.00	23 years
11	Ayertena	38.69639	8.98306	2325	1272.23	19 years
12	Boneya	38.648	8.7845	2244	812.39	30 years
13	Dire Gidib	38.943	9.15783	2564	1166.36	19 years
14	Intoto	38.725	9.08367	2903	1311.16	30 years
15	Kolfe Keranio School	38.70214	9.01536	2413	1211.93	14 years

Source (National Meteorological Agency, 2023)

However, there are some missing values in the rainfall data. The missing data was estimated using simple arithmetic mean method.

$$P_x = 1/m [P_1 + P_2 + \dots + P_m] \dots\dots\dots \text{(Equation: 3.1)}$$

Where:

P_x is the estimated value of the missing data

P is the value of same parameter at *mth* nearest weather station, and

m is the number of the nearest stations

Arithmetic mean method is the simplest method commonly used to fill in missing meteorological data in meteorology and climatology. Missing data is obtained by computing the arithmetic average of the data corresponding to the nearest weather stations (Mohammad-Taghi S., et.al, 2016). This method is satisfactory if the gauges are uniformly distributed over the area and the individual gauge measurements do not vary greatly about 10% of the mean (Te Chow et al. 1988).

3.6.6. Monthly rooftop rainwater harvest potential

The volume of monthly rainwater that could be harvested from roof were calculated using (Eslamian and Eslamian, 2021) equation by interpolating monthly rainfall data, the total roof area, and a runoff coefficient.

$$VR = (R \times A \times C) / 1000$$

Where;

VR = Monthly volume of rainwater that could be harvested (m³),

R = Average monthly rainfall in each rainfall zone (m/y),

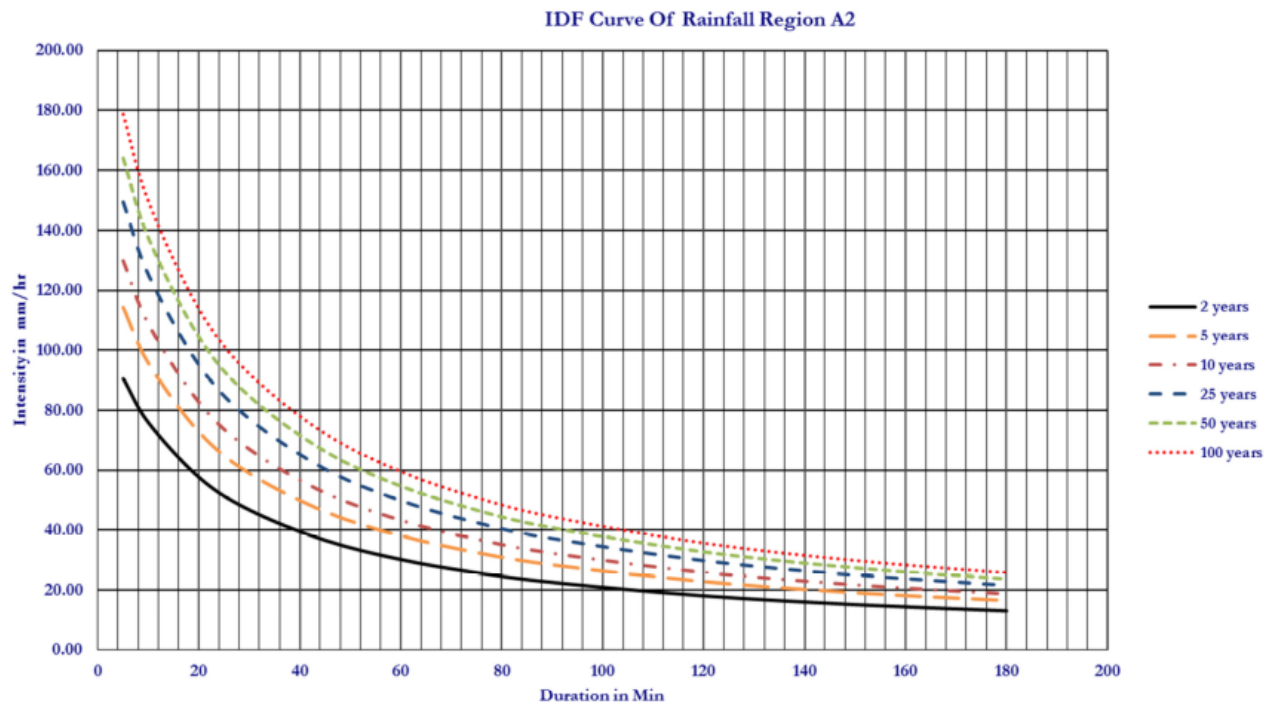
A= Roof area (m²),

C =Runoff coefficient

1000 = Conversion rate to cubic meter

3.6.7. Rainfall intensity

Rainfall intensity is the rate of rainfall upon a watershed, usually expressed in centimeters per hour. ERA has categorized Ethiopia in to eight rainfall regions, and Addis Ababa located in A2 rainfall region. Thus, ERAs' A2 region IDF rainfall intensity curve is used to calculate the catchments' peak flood.



9Figure 3.3 Addis Ababa region IDF curve of rainfall
Source (ERA drainage design manual, 2013)

3.6.8. Peak Flood

The study sites' peak flood is analyzed using rational methods of hydrology analysis. The method can provide satisfactory estimates of small catchments peak discharge.

3.6.9. Infiltration component

Infiltration basin and trench are components of WSUD that infiltrates surface runoff water to ground soil. The surface area required for both infiltration types design is calculated using design storm result of hydrology analysis and soil infiltration rate, maximum drawn down time, stone reservoir porosity and time to fill infiltration facility normally 2 hours from different literatures. The sizing of infiltration components and placement in the catchment is done based on the feasibility of the site.

3.6.10. Feasibility criteria

Generally accepted feasibility criteria for Infiltration basin and trench are derived from reviewed literature. The study follows the following general criteria:

Infiltration facility should not be hydraulically connected to structure foundations or pavement, in order to avoid harmful seepage. Thus, there should be setbacks in between. Setbacks to structures vary based on the size of the infiltration practice; typical setbacks from buildings are (Center for Watershed Protection, 2012):

- 76.25 to $762.5\text{m}^2 = 1.5\text{m}$ if down-gradient from building; 7.6m if up-gradient.
- 762.5 to $6100\text{m}^2 = 3\text{m}$ if down-gradient from building; 15.2m if up-gradient.
- 6100 to $30500\text{m}^2 = 7.6\text{m}$ if down-gradient from building; 30.5m if up-gradient.

The maximum Contributing Drainage Area (CDA) to an individual infiltration practice should be less than 2 acres and as close to 100% impervious as possible. Site Topography, infiltration shall not be located on slopes greater than 6%. Every infiltration system shall have pretreatment mechanisms to protect the long-term integrity of the infiltration rate. One of the following techniques must be installed to pretreat 100% of the inflow in every facility (Center for Watershed Protection, 2012):

- Grass filter strip (minimum 6.1m only if sheet flow is established and maintained)
- Gravel diaphragm (minimum 0.3m deep and 0.6m wide and only if sheet flow is established and maintained)
- If the basin serves a CDA greater than $6,100\text{m}^2$, a forebay or sand filter cell must be used for pretreatment.

- Forebay (minimum 25% of the design storm volume)

3.7. Validity

To measure usability and practicability of the interview questions, a pilot study was conducted on twelve household residents of Asko site 40/60 condominium. The households included are from three housing typology exist on the site (one-bedroom, two-bedroom and three-bedroom).

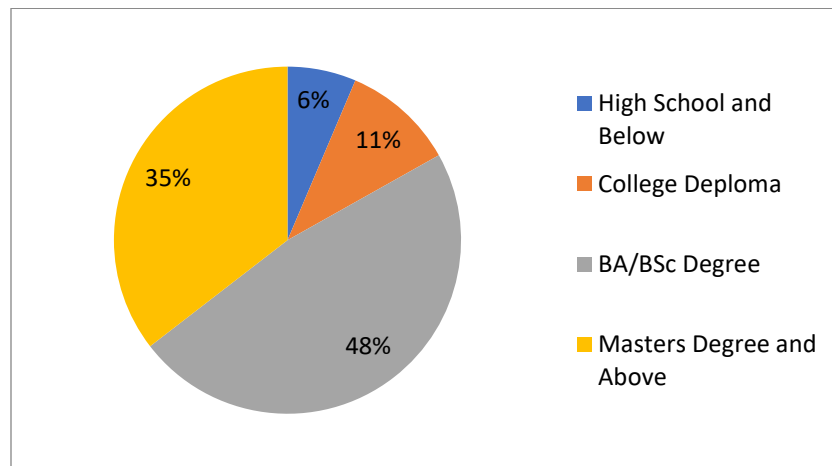
CHAPTER FOUR: RESULT AND DISCUSSION

4.1. Introduction

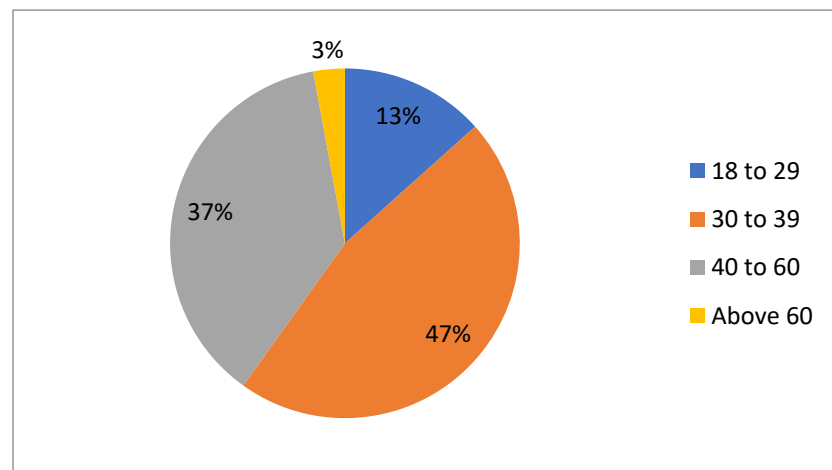
This chapter presents the analysis of the study buildings projected water consumption and demand from survey result, estimated monthly rooftop RWH potential and surface runoff. Additionally, the results were discussed with previous studies and established theoretical foundation.

4.2. Demographic profile and response rate of respondent

The number of collected response is 147 from residential housing units and 46 from commercial, 172 in total. The respondent's demographic profile (see figure 4.1 and 4.2) result indicates, more than 80% of respondents have at least first degree and above; as well as their age group ranges from 30 to 60.



10 Figure 4.1: Respondent's education level



11 Figure 4.2: Respondents Age group

4.3. Water supply and demand deficit

4.3.1. Water demand

Table 4.1 below shows, the questionnaire and interview survey result, count column shows the number of respondent respect to the housing types, total monthly demand is the summation of all respondents demand and the, and the mean monthly demand is the average both results. The monthly average water demand of the residential housing units from household survey result is 13.52m³, 14.33m³ and 15.05m³ respectively for two-bedroom, three bedroom and four-bedroom residential housing units. The average monthly water demand of the commercial housing unit is 17.23 m³.

9Table 4.1 Monthly household water demand survey result

Housing type	Count	Total HH size	Average HH size	Total Monthly demand (m ³)	Mean Monthly demand (m ³)
Two Bedroom	29	125	4.34	392.03	13.52
Three Bedroom	82	376	4.59	1175.36	14.33
Four Bedroom	36	188	5.22	542.83	15.08
Commercial	46	-	-	792.58	17.23

From survey result, the current monthly water demand of a building in the study site is projected by dividing the summation of average monthly water demand of each housing types by the number of housing types and multiplying it with the number of housing units per building. Thus, the average monthly water demand per housing unit is 15.04m³ and 947.52m³ per building per months.

4.3.2. Current water supply

From the six-month monthly September 2022 to January 2023 water supply bill, the number of bills, water consumption volume and the average water consumption volume varies in each month (see table 4.2). To calculate mean monthly water consumption per housing unit, the summation of the six months water consumption volume is divided by the summation each month's water bill. Thus, the average monthly water supply is 14.63m³ per unit. Similarly, multiplying the average monthly consumption with the number of units, monthly consumption projected is 923.69m³ per building.

10Table 4.2 Current water consumption

	Sep, 2022	Oct, 2022	Nov, 2022	Dec, 2022	Jan, 2023	Feb, 2023
Total Conss. (M ³)	4274	3266	2384	5043	1829	5250
Number of bills	287	295	227	299	126	273
Mean	14.9	11.1	10.5	16.9	14.5	19.2

Analysis of both water demand and consumption projection result reveals that, the study site has a water supply demand deficit of 25.83m³ per month per building. It means, 0.41m³ deficit per housing unit per month. This volume accounts about 2.73 percentage of housing units' monthly demand.

According to (Cominola, et al, 2023), Family size, income, garden size, appliance efficiency and awareness of occupants about value and savings water are the major determinants that highly impact on domestic water demand and consumptions. Three variables of the survey data which are household size, housing types and monthly water demands statistical relationship is tasted (table 4.3).

11Table 4.3: Household size, housing type and water demand relationship

	Household size	Housing type	Monthly demand (m ³)
Household size	1.00		
Housing type	0.22	1.00	
Monthly demand (m ³)	0.93	0.09	1.00

The statistical relationship test result indicates, monthly water demand volume and household size have significant relationships. Housing type (bedroom numbers) and household size have 22% relationship and monthly water demand volume and housing type have less relationship. Similarly, the study site gardens are mostly owned and watered by the occupants of commercial units on ground floors. Maybe that's why; the average monthly demand of commercial units is higher than the residential ones. These results are consistent with (Cominola, et al, 2023).

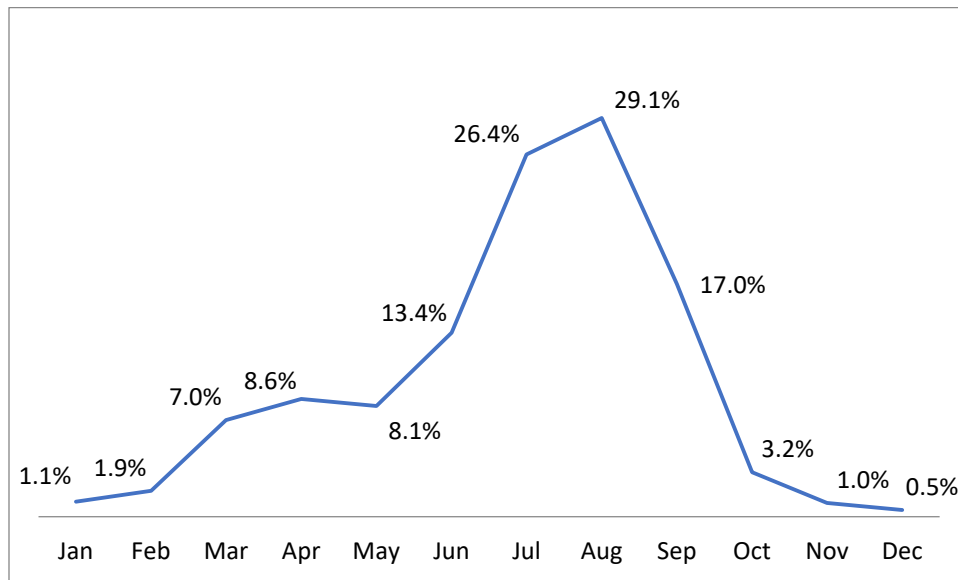
4.4. Potential of rooftop RWH to supplement the municipal water supply

The potential of rainwater harvested from rooftop is calculated by multiplying the rooftop surface area with runoff coefficient of the roof material and average interpolated mean monthly rainfall depth of the site in millimeter. The studied building's roof catchment area is 1265.01m² and the roof surface material is concrete. Thus, 0.85 runoff coefficient is used. Table 4.4 below shows, the monthly RWH potential in cubic meter.

12Table 4.4 Rooftop monthly RWH potential

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean rainfall	10.4	18.0	66.7	81.4	76.6	127.1	250.2	275.4	160.8	30.7	9.6	4.6
RWH potential	11.2	19.4	71.7	87.5	82.4	136.7	269.0	296.1	172.8	33.0	10.3	4.9

As shown in Table 4.4 above, during eight months from March to October, the study buildings can fully cover their water supply demand deficit fully, as well as they can cover substantial volume of water demand supplied from municipal water supply system. The findings are consistent with previous studies by (Dagnachew, et al, 2018) on eleven categories of public institutions in Addis Ababa have potential shown that; six of them can replace their monthly consumption of water during July and August months. The study building's rooftop RWH potential during July and August months are higher than other months. Figure 4.3 below shows the rooftop RWH potential contribution in each month with respect to the water demand.



12 Figure 4.3 Contribution of rooftop RWH volume to monthly water demand

According to (Hayysam and Marwa, 2015) proposed rooftop rainwater harvesting system, Lebanon could harvest around 23 million cubic meter of rainwater a year and it can cover around 70 % of the deficit in the domestic water supply estimated at 33 million cubic meters.

All Addis Ababa 40/60 condominium buildings water supply is indirect supply system. The municipal water mains connected to underground water reservoir placed in basement floors of the buildings, and the water pumped to elevated water tanker on the roof top. The water distribution line of each housing units connected to elevated water tank and the fixtures supplied via gravity.

The storage capacity of 40/60 condominium varies from one site to the other as well as based on the buildings typology. The Crown hotel site underground tank is 30m³ and elevated tank is 20m³. The widely common reasons for impracticalities of RWH are related to the cost and space

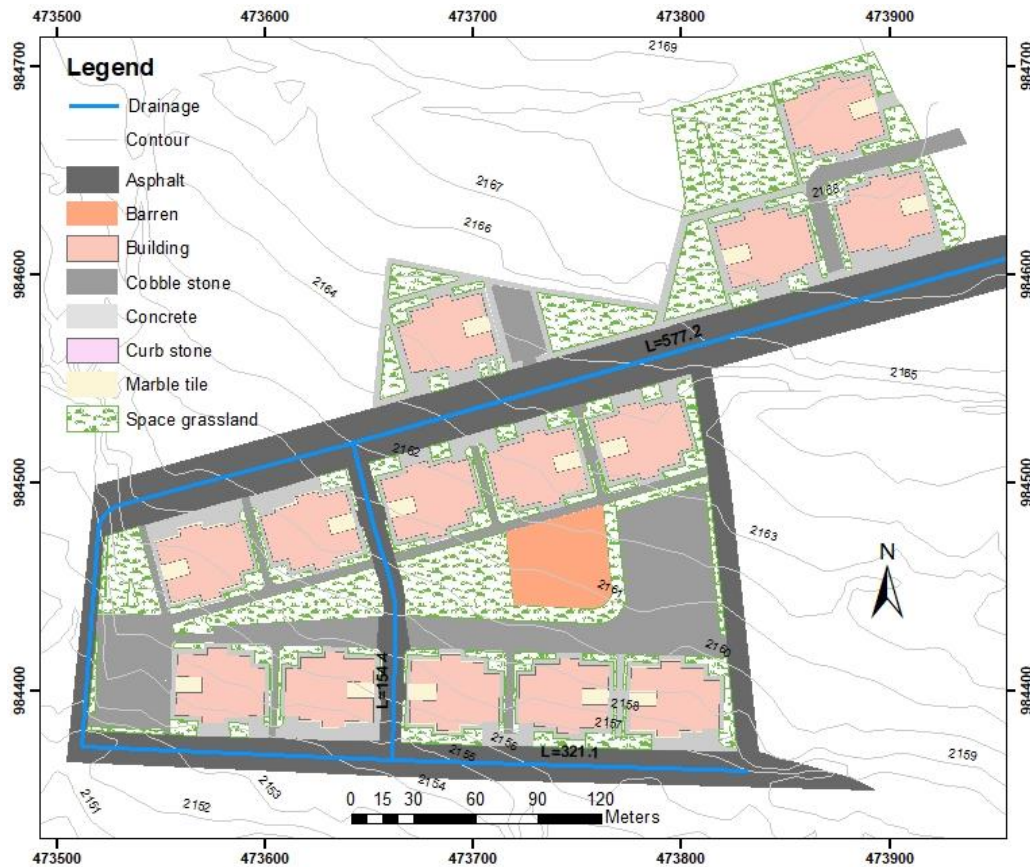
needed for the construction of water storage tanks (Hayssam and Marwa, 2015). However, the study buildings have not such problems. Additionally, the building's has concrete gutter that and PVC downpipe that drains rainwater from rooftop to concrete open channel surrounding the buildings, then flow to street side ditch and municipal drainage system with surface runoff rainwater.

The building's existing rooftop concrete gutter, downpipe, underground water tank and pumps are the component that enables to implement RWH with few additional components. These required additional components are, first flush, mesh cover for roof gutter to filter debris, dust and bird drops, as well as, connecting downpipe to underground water tank.

4.5. Stormwater infiltration trench and basin for flood reduction

4.5.1. Catchment Characteristics

Crown hotel 40/60 condominium site catchment total area is 7.9 hectares. It divided to three sub catchments by the nearby street. Each sub catchment surface runoff drains to these streets' drainage. The site has occupied by different land uses (See figure 4.3). The catchment soil type is well drained black soil.



13Figure 4.4 Crown Hotel 40/60 Condominium Land Use Map

4.5.2. Hydrology analysis

Since the catchment area is less than 50 hectares, a rational method of hydrology analysis is used as follows;

A. Rainfall intensity

The rainfall intensity from the IDF curve of Addis Ababa, for 90 minutes time of concentration, the catchment rainfall intensity for different rate of return is:

$$I_2 = 22\text{mm/hr}; I_5 = 29\text{mm/hr}; I_{10} = 32\text{mm/hr}; I_{25} = 38\text{mm/hr}; I_{50} = 40\text{mm/hr} \text{ and } I_{100} = 43\text{mm/hr}$$

B. Runoff coefficient

Each sub-catchment's land use and runoff coefficient is listed in table 4.5 and 4.6 below depending on the slope, permeability of the soil and vegetation cover and the catchment average runoff coefficient is calculated by multiplying each sub-catchment area with runoff coefficient and dividing by the summation of each sub-catchment's area.

13Table 4.5 Crown hotel 40/60 site pervious catchment

Pervious surface	Soil type	Slope (%)	Runoff coefficient				Area (m ²)
			Cv	Cp	Cs	Cv+Cp+Cs	
Grassland	Purely drained	< 3.5	0.15	0.15	0.05	0.35	15245.3
Barren	Sand and gravel	< 3.5	0.3	0.1	0.05	0.45	2045.4

The surface and soil properties are identified through field observation, slope is analyzed using GIS and the runoff coefficient is determined from ERA Drainage Design manual, 2013.

14Table 4.6 Crown hotel 40/60 impervious catchment

Impervious surface	Runoff coefficient	Area (m ²)
Asphalt	0.8	20862.2
Cobble stone	0.75	12701.9
Concrete	0.85	26594.2
Tile	0.85	1507.4

The average overland flow runoff coefficient is (C_{avg}):

$$\frac{(0.35*15245.3+0.45*2045.4+0.8*20862.2+0.75*12701.9+0.85*26594.2+0.85*1507.4)}{(78956.4)}$$

$$C_{avg} = \mathbf{0.714}$$

D. Peak flood

The catchment peak flood for different rate of return period is calculated in table 4.7 below.

Using the equation:

$$Q = 0.278 C C_f I A$$

Where:

Q = Maximum rate of runoff m^3/s

C = Runoff coefficient

C_f = Frequency factor

I = average rainfall intensity for a duration equal to the time of concentration, for a selected return period, mm/hr

A = catchment area tributary to the design location, (km^2)

15Table 4.7 Catchment peak flood result

	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years
I (mm/hr)	22	29	32	38	40	43
C	0.714	0.714	0.714	0.714	0.714	0.714
C _f	1	1	1	1.1	1.2	1.25
A (km ²)	7.9	7.9	7.9	7.9	7.9	7.9
Q (m ³ /s)	34.50	45.47	50.18	65.55	75.27	84.28

4.5.3. Sizing and placement of Infiltration component

(ERA Drainage Design Manual, 2013) recommends two years ARI for Sediment basins and related structure design. Thus, the size of two years rate of return period is selected. Based on feasibility criteria discussed in chapter three; two potential places are identified, one for each infiltration basin and trench (See figure 4.4). Both proposed infiltration components are placed on the lowest point of their CDA and the runoff conveyed to the components through open channel. The infiltration trench CDA is 10,138.36m² and the infiltration basin CDA is 17,661.7m².

According to District of Columbia storm water management guidebook, the recommended maximum depth of micro infiltration basin and trench are, 0.3 meter and 0.9 meter respectively. The surface area required equations for both infiltration types design is (Center for Watershed Protection, 2012):

For Infiltration Basins

$$SA = DesignStorm / (d + 1/2 i * t_f)$$

For Infiltration Trenches

$$SA = DesignStorm / (n_r * d + 1/2 i * t_f)$$

Where:

SA = Surface area (sq. meter)

i = Field-verified infiltration rate for the native soils (m/day)

n_r = Available porosity of the stone reservoir (assume 0.35)

d = Infiltration depth (0.3m meter for basin and 0.9m for trench.)

t_f = Time to fill the infiltration facility (days – typically 2 hours, or 0.083 days)



14Figure 4.5 Proposed Infiltration trench and basin

The study catchment soil type is black cotton. As (Donny H. and Evi N. Cahya, 2020) such types soil has a field verified infiltration rate of 1.34. Thus, the value 1.34 is used as an infiltration rate of the study catchment soil.

The design storm of infiltration trench and basin CDA are $4.4\text{m}^3/\text{s}$ and $7.13\text{m}^3/\text{s}$ respectively. Using the equations above, the surface area of infiltration is trench 14.72m^2 .and infiltration basin is 22.7m^2 .

4.5.4. Surface runoff Harvesting potential

Crown Hotel 40/60 condominium site generates $62,401.34\text{m}^3$ of floods annually, Rooftops RWH system potential is $16,662.8\text{m}^3$, Surface runoff harvesting potentials using infiltration trench and basin are respectively $8,565.9\text{m}^3$ and 13945.38m^3 .

In general, 40/60 saving housings in Addis Ababa has a potential for RWH system; they have a good rooftop drainage system that can enable to rooftop RWH. Their indirect water supply system with underground and rooftop elevated water tank is also an advantage to collect, store and resupply for domestic consumption.

If both surface and roof top RWH system are implemented in these compounds, huge amount of water can be collected for domestic consumption that can ease the pressure from AAWSA as well as surface runoff RWH will increase the ground water table of Addis Ababa while reducing the storm water.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Introduction

This chapter summarizes the main issues of the study and provides overview of the major findings. Additionally, recommendation is outlined for academicians, practitioners and administrative bodies for future work.

5.2. Conclusion

This study has demonstrated that, Water supply demand deficit; rooftop and Surface runoff RWH potential of Crown Hotel 40/60 Condominium sites is studied for supplementary water supply and flood reduction. Water supply demand deficit is calculated from water demand of the site projected from household water demand survey and Six-month monthly water use bill collected from AAWSA. The rooftop RWH potential is calculated using roof catchment size, roof material runoff coefficient and rainfall depth of the site interpolated from rainfall. Infiltration trench and basin are proposed for surface runoff harvesting based on the suitability criteria. The size of infiltration trench and basin is determined from their respective CDA design storm.

The main findings of the study are, there is monthly water supply demand deficit of 2.8 percentages. The study site buildings have rooftop RWH potential of 1170.2 cubic meters per building annually. The monthly rooftop RWH potential can cover the water supply demand deficit from March to October months. The total rooftop RWH potential volume of the site is 16,382.8 cubic meters annually; this volume can cover the 10.3 percent of each building annual water demand.

The study site has two suitable locations for Infiltration basin and trench. Thus, one infiltration trench and one infiltration basin are proposed for surface runoff RWH. The proposed infiltration components sizes are 14.13m² for trench and 22.7m² for basin. Infiltration trench can harvest 8,565.9m³. The proposed basin has a potential harvest to 13945.38 m³ of storm water annually. Both surface and roof top RWH systems are a potential to reduce 63 percentage of flood generated from the study site while supplementing the existing water supply system.

The implications of these findings are the combination of rooftop RWH for supplementary water supply and surface runoff RWH for flood management are more efficient to encounter the Addis Ababa city water supply challenges and flood related problems caused by the combination of population growth, climate and land use change. Further, this study contributes to the

understanding of Addis Ababa 40/60 condominiums have most of rooftop RWH system components that enable the practice for supplementary water supply source.

5.3. Recommendation

From the study, the following five points are recommended for Academics community, Government Institutions under Addis Ababa City Administration that has responsibility toward the subject matter, practitioners and the residents itself.

1. Addis Ababa population growth and development directly lead to additional water supply need. Contrary to that, the city can't meet current demand following the same practice. Therefore, Addis Ababa City Administration should enforce all buildings to consider rainwater harvesting as supplementary water supply sources to relatively simplify the city water supply challenges.
2. Currently, Addis Ababa corridor development project has introducing surface runoff RWH harvesting components such as rain garden; ERA also recommends application of WSUD components for urban and rural streets (Drainage Design Manual, 2013, p2-32). Thus, Addis Ababa City Road Authority and Addis Ababa Planning Commission should change the current street storm water conveyance gray infrastructure practice to green infrastructure that can helps storm water treatment and infiltration.
3. In order to help the practice of WSUD for surface runoff RWH and treatment, further research should explore the Addis Ababa hydrological soil group types and field verified rate of infiltration by academic community.
4. Addis Ababa City Housing Development Agency should organize the existing multi-story condominium housing occupants and able they harvest rainwater to bridge their water supply demand deficits. Additionally, the agency should include rainwater harvesting as additional water supply source to its currently under construction and future projects.
5. Urban planners, Architects, Engineers and other professionals' who participates in planning and designing urban settlements should include rainwater harvesting system to their future development design.

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APPENDIX

A. INTERVIEW QUESTIONNAIRES

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Addis Ababa University
አዲስ አበባ ዩኒቨርሲቲ

Building Ethiopia Since 1954

Dear Sir/Madam

I am currently undertaking a Master of Science Degree in Urban Design and Development at Ethiopian Institute of Architecture, Building Construction and City Development (EiABC), Addis Ababa University. In fulfilment of this study's, I am required to research a topic area and produce thesis. The topic I have chosen is 'Potential of on-spot Rainwater Harvesting for Bridging water supply challenges of High occupancy Mixed-use buildings of Addis Ababa' and I am investigating the following:

1. Current water supply and usage,
2. Actual water demands

I would be very grateful if you could complete the attached questionnaire and return it in the addressed, prepaid envelope provided. Needless to say, the information provided will be treated with strict confidence and individual firms will not be identified. Equally, a copy of the summary report will be available to the co-operating firms and on the university website.

Yours faithfully,
Ashenafi Belina

Interview Questioner

1. Socio-demographic

1.1. In what age group are you?

- 17 and under
- 18 - 29
- 30 - 39
- 40 - 49
- 50 - 59
- 60

1.2. What is your education level?

- High school
- Collage diploma
- First degree
- Second degree and above

1.3. Household/Family size: _____

Male: _____

Female: _____

2. House Characteristics

2.1. Ownership:

- Owned
- Rented

2.2. If it is rented how much money is the rent for the dwelling per month?
(_____)

2.3. House type:

	Residential	Commercial (Specify)
<input type="radio"/>	One Bedroom	_____
<input type="radio"/>	Two Bedroom	_____
<input type="radio"/>	Three Bedroom	_____
<input type="radio"/>	Four Bedroom	_____

2.4. Number of Appliance:

Water Closet: _____

Shower: _____

Handwash: _____

Laundry: _____

2.5. Do you have a garden?

- Yes (Area _____ m²)
- No

2.6. Is the garden watered daily?

Yes

No (Specify: _____)

3. Indicators of water use activities

Interview questions	Answers
How many times per week does your family do laundry?	
How many times per week do you take a shower or bath?	
How many times per day do you wash your face, hands and feet?	
How many times per day do you use toilet?	
How many times per day does your family cook?	
How many times per day does your family dishwash?	
How many times per week does your family water your vegetable and garden land?	
How many times per week does your family clean the house or yard?	
How many times per week does your family wash a car?	
Other activities you use water:	

4. Water demand for water use activities

Interview questions	Answers
How many liters of water is your family demand for one time laundry?	
How many liters of water is your demand for one time of taking a shower or bath?	
How many liters of water is your demand for one time of washing your face, hands and feet?	
How many liters of water is your demand for one time use of toilet?	
How many liters of water your family demand for one time cooking?	
How many liters of water your family demand for one time dishwashing?	
How many liters of water your family demand vegetable/gardening?	
How many liters of water your family demand for cleaning the house or yard?	
How many liters of water your family demand for washing a car?	
Other activities you use water:	

Thank You!

WATER SENSITIVE URBAN DESIGN FOR SUPPLEMENTARY WATER SUPPLY AND FLOOD REDUCTION IN ADDIS ABABA HIGH OCCUPANCY BUILDING; THE CASE OF CROWN HOTEL 40/60 CONDOMINIUM

Ashenafi Belina

Abstract

Addis Ababa City constructed hundreds of thousand housing units through its Integrated Housing Development Program (IHDP). Thus, the city is facing water stress as water demand is increasing due to expansion of the city, population growth and economic development. Crown Hotel site 40/60 condominium is one of IHDP for higher middle-income residents. The site has a drainage system that doesn't cover the whole catchment that the compound is located in. As a result, stormwater from the compound and upper catchment area, which have traditional grey drainage systems, flows to the lower catchment area, which lacks sustainable drainage causes flooding, despite the fact that the condominium property is suited for rainwater harvesting (RWH). Therefore, this paper aims to propose Water Sensitive Urban Design (WSUD) for supplementary water supply and stormwater management through rooftop and surface runoff RWH. The rooftop RWH potential is calculated using roof catchment size, roof material runoff coefficient and rainfall depth of the site interpolated from fifteen rain gauge stations daily recorded rainfall data. Infiltration trench and basin are proposed for surface runoff harvesting based on the suitability criteria. The study site catchment hydrology is analyzed using rational method. The size of infiltration trench and basin is determined from their respective CDA design storm. The total RWH potential from all fourteen buildings are 16,382.8 cubic meters annually. The proposed infiltration components sizes are 14.13m² for trench and 22.7m² for basin. Thus, the proposed infiltration trench can harvest 8,565.9m³ and infiltration basin has a potentials harvest to 13945.38 m³ of storm water annually.

Key words:

Water Sensitive Urban Design, rooftop rainwater harvesting, surface runoff, stormwater

1. Introduction

The gradual increasing water shortage has raised the need to develop efficient water resource management initiatives (Ameen, et al, 2020). Water Sensitive Urban Design (WSUD) is among one of initiatives to change the conventional means by which urban areas are planned and built introduced in Australia in 1994 (Wong). WSUD aims to manage the water cycle by producing qualitative and quantitative impacts on land, water, aesthetic values and biodiversity as well as

maintaining economic endurance. WSUD focuses on sustainability of environment and water cycle in urban development or even in redevelopment of urban structures (Tennessee Water Resources Symposium, 2011). It incorporates rainwater into the landscape, conserves water quality and natural system and reduces runoff and peak flows (Ameen, et al, 2020).

Ethiopia's mass-scale subsidized housing delivery program has driven the rapid expansion of middle-income, mid-rise settlements on the outskirts of Addis Ababa, requiring the provision of infrastructure to newly developed areas (Liza Rose, et al, 2021). While these housing units have significantly improved the quality of life of low-income residents that previously resided in inner city slums (UTAFITI SERA Policy Brief, 2017); water demand is rising due to population growth and economic developments (Abraha, et al, 2022). The city water scarcity problem is not due to lack of resource; it is due to lack of production; Addis Ababa has a potential to produce 52,566,362m³/year water from rooftop RWH (Kidist and Kumar, 2015).

Addis Ababa city water sources are not secured as the sources lie outside the city boundary and there is a political boundary between Addis Ababa and Surrounding Oromia Region. Although the 10th Addis Ababa City Master Plan proposed ways of diversifying water sources such as harvesting rainwater and reusing grey water, its implementation is slow, and the city is relying on surface and boreholes water sources (Addis Ababa Water resilient profile, p.60). Failure of any of these water sources would result in a crisis (World Bank Group, 2015).

To address these challenges, broader water management perspectives like Integrated Water Resources Management (IWRM), Sustainable Urban Water Management (SUWM) and Water Sensitive Urban Design (WSUD) have emerged. These frameworks promote a holistic approach that considers all aspects of the urban water cycle, from water supply and sanitation to stormwater management. Rainwater harvesting and infiltration practices are key components of these frameworks, offering a sustainable and localized solution for improving water security.

Crown Hotel site 40/60 condominium is among the earliest project of its type that constructed under IHDP for higher middle-income residents. This compound is fully occupied and relatively well developed than its kind projects constructed afterward. It has a drainage system that is connected to the nearby municipal drain system with in and adjacent to the compound. However, the system doesn't cover the whole catchment that the compound is located in. As a result, stormwater from the compound and upper catchment area, which have traditional grey drainage systems, flows to the lower catchment area, which lacks sustainable drainage. This causes

flooding, despite the fact that the condominium property is suited for rainwater harvesting (RWH), which might provide residents with water while reducing runoff from impermeable surfaces such as rooftops and pavements.

Therefore, this paper aims to propose Water Sensitive Urban Design (WSUD) for supplementary water supply and stormwater management in Addis Ababa 40/60 Condominium located around Crown Hotel.

2. Literature Review

Water Sensitive Urban Design (WSUD) is among one of initiatives to change the conventional means by which urban areas are planned and built. It was introduced in Australia in 1994 (Wong). WSUD aims to manage the water cycle by producing qualitative and quantitative impacts on land, water, aesthetic values and biodiversity as well as maintaining economic endurance. WSUD focuses on sustainability of environment and water cycle in urban development or even in redevelopment of urban structures (Tennessee Water Resources Symposium, 2011). The objective of WSUD is to incorporate rainwater into the landscape, conserve water quality and natural system and reduce runoff and peak flows (Ameen, et al, 2020).

Rooftops, sidewalks, roadways, and other impervious surfaces of an urban center, on streams and rivers have two major impacts. First, as drainage areas become increasingly impervious, stormwater runoff volumes, flows, and velocities increase, while base groundwater flows decrease. Small annual storm events that would be captured by the plants and soils of an undeveloped landscape are delivered quickly and efficiently to the receiving pipe network and streams in a city. Second, human activities in the city generate increased pollutant loads, ranging from heavy automobile traffic to use of various chemicals. These pollutants, as well as the deposition of atmospheric pollution, build up on impervious surfaces during dry weather, and rain and snow events wash these pollutants into sewer pipes, streams, and rivers (Center for Watershed Protection, 2012).

The components of a WSUD system include elements for collection, treatment, storage, distribution, and disposal of the stormwater. The many design decisions include the size, type, number and location of components, and how they are connected. These need to satisfy a number of practical constraints including cost, available land, and planning and other legal restrictions.

Multiple spatial scales are also possible, including individual allotments, clusters of allotments, and precinct scale (Graeme, et al.).

Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops, land surfaces, road surfaces, or rock catchments using simple techniques such as pots, tanks, and cisterns, as well as more complex techniques such as underground check dams (Appan 1999; Prinz 1995; Zhu et al. 2004). Rainwater harvesting can also mean collecting rainwater before it infiltrates into the ground and becomes underground water. Harvested rainwater is a renewable source of clean water that is ideal for domestic and landscape uses. Water harvesting systems provide flexible solutions that can effectively meet the needs of new and existing water demand for domestic and agricultural uses (Fayez, et, al. 2021).

3. Material and Methods

3.2. Study area description

Addis Ababa located between, 8°50' N to 9°5' N and 38°38' E to 38°54'E; the city altitude ranges from 2050m to 3040m above sea level and average annual rainfall is 1184mm. Addis Ababa, the climate is warm and temperate. Summers are much rainier (June to September) than winters and the average annual rainfall is 1184mm. The average maximum and minimum temperatures range between 22.9oC and 10.2oC. The average humidity of the city is 57.67% (Feyissa et al, 2018; and Metaferiya, 2017).

40/60 Condominium is one of IHDP schemes that intend for higher middle income residents of Addis Ababa. The study site, Crown Hotel 40/60 condominium is among the earliest project of its kind next to Sengatera site. It located south west of Addis Ababa. The study site, Crown Hotel 40/60 condominium located south west of Addis Ababa. It is among the earliest project of its kind next to Sengatera site. It has fourteen buildings; each has commercial space from ground to second floors and residential housing units from third to eighth floors. The basement floor of the buildings serves car parking area, storage and placement of the buildings underground water reservoir. Unlike other 40/60 typologies, these site residential housing units are two-bed, three-bed and four-bed housing types..

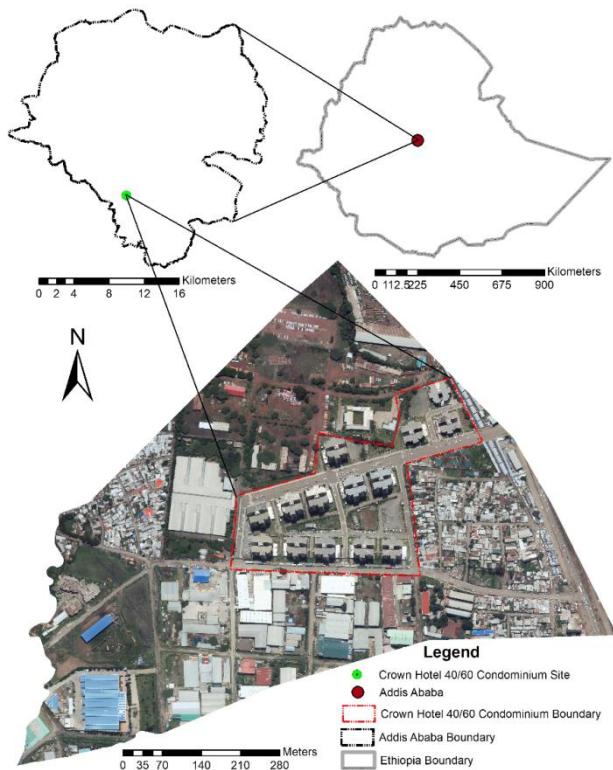


Figure 3.1 Location map of study area

3.2. Research design

Both qualitative and quantitative research types employed to collect and analyze relevant data for the study. Both primary and secondary relevant data for the study were obtained using field observation, desk study and intensive review of different documents from governmental organizations, official reports, books, magazines, journals, and online sources, published and unpublished previous researches.

3.2. Data sets

3.3.1. Catchment

The study site catchment slope is analyzed from Nortec contour using GIS 3D, and Spatial Analyst tools. Roof catchment materials, size and rainwater drainage system are determined from each buildings Architectural drawing. As well as the study site sub catchment area is converted to Arc GIS shapfiles from the sites' Neighborhood Design and the catchment land use and soil properties were determined through field observation. The attributes of catchment land use are surface cover types and their area.

3.3.2. Runoff Coefficient

The cumulative average runoff coefficient of the study site is calculated using the combination of (Pecey Arnold and Cullis Adran, 1989, Federal Highway Administration, HEC No. 19, 1984) and ERA (Ethiopian Road Authority) Drainage design manual (2013) runoff coefficient value of different surfaces covers.

3.3.3. Rainfall data

To identify the mean monthly rainwater depth of study site, monthly rainfall data obtained from National Meteorological Agency were interpolated for each month by Inverse Distance Weighting (IDW) method using ArcGIS spatial analyst tool; the interpolated each month's monthly rainfall distribution raster map is reclassified in to five equal intervals and the average result of rainfall amounts is used as monthly rainfall depth.

3.3.4. Monthly rooftop rainwater harvest potential

The volume of monthly rainwater that could be harvested from roof were calculated using (Eslamian and Eslamian, 2021) equation by interpolating monthly rainfall data, the total roof area, and a runoff coefficient.

$$VR = (R \times A \times C) / 1000$$

Where;

VR = Monthly volume of rainwater that could be harvested (m³),

R = Average monthly rainfall in each rainfall zone (m/y),

A= Roof area (m²),

C =Runoff coefficient

3.3.5. Rainfall intensity

Rainfall intensity is the rate of rainfall upon a watershed, usually expressed in centimeters per hour. ERA has categorized Ethiopia in to eight rainfall regions, and Addis Ababa located in A2 rainfall region. Thus, ERAs' A2 region IDF rainfall intensity curve is used to calculate the catchments' peak flood.

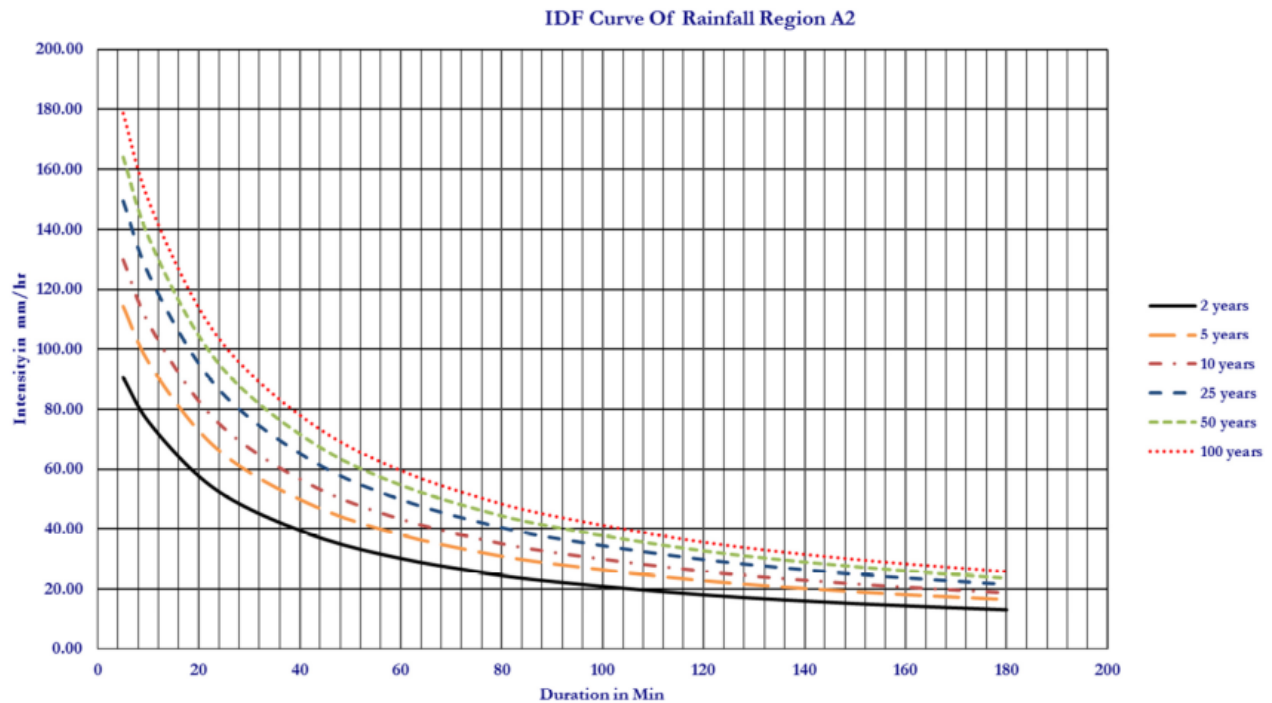


Figure 3.2 Addis Ababa region IDF curve of rainfall
Source (ERA drainage design manual, 2013)

3.3.6. Peak Flood

The study sites' peak flood is analyzed using ration methods of hydrology analysis. The method can provide satisfactory estimates of small catchments peak discharge.

3.6.8. WSUD component Proposal

Proposed WSUD components are Rooftop RWH for supplementary water supply and Infiltration trench and basin for stormwater management. Infiltration basin and trench are components of WSUD that infiltrates surface runoff water to ground soil. The surface area required for both infiltration types design is calculated using design storm result of hydrology analysis and soil infiltration rate, maximum drawn down time, stone reservoir porosity and time to fill infiltration

facility normally 2 hours from different literatures. The sizing of infiltration components and placement in the catchment is done based on the feasibility of the site.

Generally accepted feasibility criteria for Infiltration basin and trench are derived from reviewed literature. The criterias followed in this study are;

Infiltration facility should not be hydraulically connected to structure foundations or pavement, in order to avoid harmful seepage. Thus, there should be setbacks in between. Setbacks to structures vary based on the size of the infiltration practice; typical setbacks from buildings are (Center for Watershed Protection, 2012):

- 76.25 to 762.5m² = 1.5m if down-gradient from building; 7.6m if up-gradient.
- 762.5 to 6100m² = 3m if down-gradient from building; 15.2m if up-gradient.
- 6100 to 30500m² = 7.6m if down-gradient from building; 30.5m if up-gradient.

The maximum Contributing Drainage Area (CDA) to an individual infiltration practice should be less than 2 acres and as close to 100% impervious as possible. Site Topography, infiltration shall not be located on slopes greater than 6%. Every infiltration system shall have pretreatment mechanisms to protect the long-term integrity of the infiltration rate. One of the following techniques must be installed to pretreat 100% of the inflow in every facility (Center for Watershed Protection, 2012):

- Grass filter strip (minimum 6.1m only if sheet flow is established and maintained)
- Gravel diaphragm (minimum 0.3m deep and 0.6m wide and only if sheet flow is established and maintained)
- If the basin serves a CDA greater than 6,100m², a forebay or sand filter cell must be used for pretreatment.
- Forebay (minimum 25% of the design storm volume)

4. Results and Discussion

4.1. Potential of rooftop RWH to supplement the municipal water supply

The potential of rainwater harvested from rooftop is calculated by multiplying the rooftop surface area with runoff coefficient of the roof material and average interpolated mean monthly rainfall depth of the site in millimeter. The studied building's roof catchment area is 1265.01m² and the roof surface material is concrete. Thus, 0.85 runoff coefficient is used. Table 4.4 below shows, the monthly RWH potential in cubic meter.

Table 4.1 Rooftop monthly RWH potential

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean rainfall	10.4	18.0	66.7	81.4	76.6	127.1	250.2	275.4	160.8	30.7	9.6	4.6
RWH potential	11.2	19.4	71.7	87.5	82.4	136.7	269.0	296.1	172.8	33.0	10.3	4.9

The study building has a potential to harvest 1190.2m³ of rainwater from rooftop annually. This amount can cover about 10.3% of the dwellers annual water demand of each building (Ashenafi, 2024). Comparing this with related previous studies, (Dagnachew, et al, 2018) study on eleven categories of public institutions in Addis Ababa have potential, six of them can replace their monthly consumption of water during July and august months from rooftop RWH and the overall annual potentials can replace 2.3% of city level domestic water supply from the large public institutions through rooftop RWH. (Yalemzewd, et al, 2020), the annually rooftop RWH potential of Tulu-Dimitu condominium can cover 18.13% of water consumption of toilet flushing's. According to (Hayysam and Marwa, 2015) proposed rooftop rainwater harvesting system, Lebanon could harvest around 23 million cubic meter of rainwater a year and it can cover around 70 % of the deficit in the domestic water supply estimated at 33 million cubic meters.

Crown Hotel 40/60 condominium buildings water supply is indirect supply system. The municipal water mains connected to underground water reservoir placed in basement floors of the buildings, and the water pumped to elevated water tanker on the roof top. The water distribution line of each housing units connected to elevated water tank and the fixtures supplied via gravity. The storage capacity of underground tank is 30m³ and elevated tank is 20m³.

The widely common reasons for impracticalities of RWH are related to the cost and space needed for the construction of water storage tanks (Hayssam and Marwa, 2015). However, the study buildings have not such problems. Additionally, the building's has concrete gutter that and PVC downpipe that drains rainwater from rooftop to concrete open channel surrounding the buildings, then flow to street side ditch and municipal drainage system with surface runoff rainwater.

The building's existing rooftop concrete gutter, downpipe, underground water tank and pumps are the component that enables to implement RWH with few additional components. These required additional components are, first flush, mesh cover for roof gutter to filter debris, dust and bird drops, as well as, connecting downpipe to underground water tank.

4.5. Stormwater infiltration trench and basin for flood reduction

4.5.1. Catchment Characteristics

Crown hotel 40/60 condominium site catchment total area is 7.9 hectares. It divided to three sub catchments by the nearby street. Each sub catchment surface runoff drains to these streets'

drainage. The site has occupied by different land uses (See figure 4.3). The catchment soil type is well drained black soil.

4.5.2. Hydrology analysis

Since the catchment area is less than 50 hectares, a rational method of hydrology analysis is used as follows;

A. Rainfall intensity

The rainfall intensity from the IDF curve of Addis Ababa, for 90 minutes time of concentration, the catchment rainfall intensity for different rate of return is:

$$I_2 = 22\text{mm/hr}; I_5 = 29\text{mm/hr}; I_{10} = 32\text{mm/hr}; I_{25} = 38\text{mm/hr}; I_{50} = 40\text{mm/hr} \text{ and } I_{100} = 43\text{mm/hr}$$

B. Runoff coefficient

Each sub-catchment's land use and runoff coefficient is listed in table 4.5 and 4.6 below depending on the slope, permeability of the soil and vegetation cover and the catchment average runoff coefficient is calculated by multiplying each sub-catchment area with runoff coefficient and dividing by the summation of each sub-catchment's area.

Table 4.2 Crown hotel 40/60 site pervious catchment

Pervious surface	Soil type	Slope (%)	Runoff coefficient				Area (m ²)
			Cv	Cp	Cs	Cv+Cp+Cs	
Grassland	Purely drained	< 3.5	0.15	0.15	0.05	0.35	15245.3
Barren	Sand and gravel	< 3.5	0.3	0.1	0.05	0.45	2045.4

The surface and soil properties are identified through field observation, slope is analyzed using GIS and the runoff coefficient is determined from ERA Drainage Design manual, 2013.

Table 4.3 Crown hotel 40/60 impervious catchment

Impervious surface	Runoff coefficient	Area (m ²)
Asphalt	0.8	20862.2
Cobble stone	0.75	12701.9
Concrete	0.85	26594.2
Tile	0.85	1507.4

The average overland flow runoff coefficient is (C_{avg}):

$$C_{avg} = \frac{(0.35*15245.3+0.45*2045.4+0.8*20862.2+0.75*12701.9+0.85*26594.2+0.85*1507.4)}{(78956.4)} = \mathbf{0.714}$$

D. Peak flood

The catchment peak flood for different rate of return period is calculated in table 4.7 below.

Using the equation:

$$Q = 0.278 C C_f I A$$

Where:

Q = Maximum rate of runoff m³/s

C = Runoff coefficient

C_f = Frequency factor

I = average rainfall intensity for a duration equal to the time of concentration, for a selected return period, mm/hr

A = catchment area tributary to the design location, (km²)

Table 4.4 Catchment peak flood result

	2 Years	5 Years	10 Years	25 Years	50 Years	100 Years
I (mm/hr)	22	29	32	38	40	43
C	0.714	0.714	0.714	0.714	0.714	0.714
C _f	1	1	1	1.1	1.2	1.25
A (km ²)	7.9	7.9	7.9	7.9	7.9	7.9
Q (m ³ /s)	34.50	45.47	50.18	65.55	75.27	84.28

4.5.3. Sizing and placement of Infiltration component

(ERA Drainage Design Manual, 2013) recommends two years ARI for Sediment basins and related structure design. Thus, the size of two years rate of return period is selected. Based on feasibility criteria discussed in chapter three; two potential places are identified, one for each infiltration basin and trench (See figure 4.4). Both proposed infiltration components are placed on the lowest point of their CDA and the runoff conveyed to the components through open channel. The infiltration trench CDA is 10,138.36m² and the infiltration basin CDA is 17,661.7m².

According to District of Columbia storm water management guidebook, the recommended maximum depth of micro infiltration basin and trench are, 0.3 meter and 0.9 meter respectively. The surface area required equations for both infiltration types design is (Center for Watershed Protection, 2012):

For Infiltration Basins

$$SA = DesignStorm / (d + 1/2 i * t_f)$$

For Infiltration Trenches

$$SA = DesignStorm / (n_r * d + 1/2 i * t_f)$$

Where:

SA = Surface area (sq. meter)

i = Field-verified infiltration rate for the native soils (m/day)

n_r = Available porosity of the stone reservoir (assume 0.35)

d = Infiltration depth (0.3m meter for basin and 0.9m for trench.)

t_f = Time to fill the infiltration facility (days – typically 2 hours, or 0.083 days)

The study catchment soil type is black cotton. As (Donny H. and Evi N. Cahya, 2020) such types soil has a field verified infiltration rate of 1.34. Thus, the value 1.34 is used as an infiltration rate of the study catchment soil.

The design storm of infiltration trench and basin CDA are $4.4\text{m}^3/\text{s}$ and $7.13\text{m}^3/\text{s}$ respectively. Using the equations above, the surface area of infiltration is trench 14.72m^2 .and infiltration basin is 22.7m^2 .



Figure 4.1 Proposed Infiltration trench and basin

4.5.4. Surface runoff Harvesting potential

Crown Hotel 40/60 condominium site generates $62,401.34\text{m}^3$ of floods annually, Rooftops RWH system potential is $16,662.8\text{m}^3$, Surface runoff harvesting potentials using infiltration trench and basin are respectively $8,565.9\text{m}^3$ and 13945.38m^3 .

In general, 40/60 saving housings in Addis Ababa has a potential for RWH system; they have a good rooftop drainage system that can enable to rooftop RWH. Their indirect water supply system with underground and rooftop elevated water tank is also an advantage to collect, store and resupply for domestic consumption.

If both surface and roof top RWH system are implemented in these compounds, huge amount of water can be collected for domestic consumption that can ease the pressure from AAWSA as well as surface runoff RWH will increase the ground water table of Addis Ababa while reducing the storm water.

5. Conclusion and Recommendation

Rooftop and Surface runoff RWH potential of Crown Hotel 40/60 Condominium sites is studied for supplementary water supply and flood reduction. The rooftop RWH potential is calculated using roof catchment size, roof material runoff coefficient and rainfall depth of the site interpolated from fifteen rain gauge stations daily recorded rainfall data. Infiltration trench and basin are proposed for surface runoff harvesting based on the suitability criteria. The study site catchment hydrology is analyzed using rational method. The size of infiltration trench and basin is determined from their respective CDA design storm.

The study result shows, each study site buildings have rooftop RWH potential of 1170.2 cubic meters annually. The total RWH potential from all fourteen buildings are 16,382.8 cubic meters annually; this volume can cover substantial amount of the buildings annual water demand. As well as, it reduces the stress from AAWSA; the sole water supplier authority in the city. Based on the suitability criteria, for infiltration trench and basin; two CDA are identified for each infiltration components. The proposed infiltration components sizes are 14.13m² for trench and 22.7m² for basin. Thus, the proposed infiltration trench can harvest 8,565.9m³ and infiltration basin has a potentials harvest to 13945.38 m³ of storm water annually.

Both surface and roof top RWH systems are a potential to reduce 63 percentage of flood generated from the study site while supplementing the existing water supply system. Rooftop RWH and Infiltration trench and basins are WSUD components used for supplement water supply and stormwater management. Addis Ababa 40/60 condominiums have a potential for both RWH systems. Considering these as additional sources of water supply will reduce the current stress from AAWSA and it reduced the substantial amount of the surface runoff generation while

increasing the ground water table as well as reducing the peak floods from traditional drainage system.

Addis Ababa City Administration should consider WSUD; rooftop RWH for supplementary water supply and surface runoff RWH for flood management to encounter the city water supply challenges and flood related problems caused by the combination of population growth, climate and land use change. Further research should explore the Addis Ababa hydrological soil group types and field verified rate of infiltration for surface runoff RWH system.

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