INTEGRATED WATER RESOURCE MANAGEMENT FOR SUSTAINABLE CAMPUS DEVELOPMENT

FINAL YEAR PROJECT UG 2020

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This is to certify that the
Final Year Project Titled

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has been accepted towards the requirements
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This thesis is dedicated to our parents.

For their love, support, and prayers throughout our lives.

Abstract

Water scarcity is a major global issue that requires efficient water management strategies. The goal of this project is to create environmentally friendly rainwater harvesting methods for the NUST H-12 campus in Islamabad, Pakistan. In order to maximise water capture, storage, and quality, our goals also included assessing current rainwater harvesting models, testing water quality, conducting resistivity studies, and developing novel water harvesting methods.

Three water harvesting structures systems that are currently in use were evaluated: Volleyball Ground Bore, NICE Backyard Bore, and NICE Ground Bore. The Volleyball Ground Bore appears to be the most efficient technology available at the moment, as it showed the maximum efficiency in both water infiltration and storage. Enhancing infiltration rates and boosting storage capacity were two suggestions for improvement.

World Health Organisation (WHO) requirements were compared to harvested rainwater parameters, including TDS, turbidity, alkalinity, pH, EC, nitrates, hardness, and chlorides, through comprehensive water quality testing. The water does not require a lot of filtering to meet WHO guidelines for non-potable uses, such irrigation and toilet flushing.

The ideal locations for new infrastructure were identified by resistivity investigations conducted at four candidate sites. These measurements also helped with the placement of bio retention zones, percolation pits, and roof water harvesting systems. To make sure systems could manage peak rainfall events, we used Intensity-Duration-Frequency (IDF) curves to compute design discharges and choose suitable pipe diameters.

A novel self-backwashing filtering system was created to sustainably maintain water quality. With its low maintenance needs and self-cleaning capacity, this energy-efficient system ensures continual filtering with little need for human interaction.

The suggested harvesting locations could greatly lessen flash flooding and increase water availability during dry spells, according to simulations of rainfall runoff. Rainwater collecting has the ability to alleviate water scarcity issues on campus; the total annual water gathered from roof water harvesting was estimated to be about 37,637,011 litres.

This study emphasises the significance of combining cutting-edge technologies and strategic planning in sustainable water management and offers a repeatable model for cities experiencing comparable difficulties.

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CHAPTER 1

INTRODUCTION

1.1 Background

On a global scale, the issues surrounding water scarcity and mismanagement of rainwater transcend local boundaries, becoming a shared concern for humanity. Due to increasing urbanization worldwide, coupled with shifting climatic patterns, has led to a global imperative to rethink how we manage water in urban environments.(Sharma, 2017) Across the planet, impermeable surfaces are proliferating in urban areas, altering the natural flow of rainwater. This phenomenon is not confined to specific regions; it's a widespread transformation impacting cities on every continent. The consequences are felt universally — groundwater tables are depleting, and the uncontrolled runoff is causing floods in downstream areas.

Over 50% of Punjab's irrigated areas face a decline in groundwater levels below 6 meters, leading to higher pumping costs and poorer water quality. Despite active efforts, 21% of these farming lands continue to grapple with varying levels of soil salinity. (Qureshi, 2020). This poses challenges for farmers, impacting both their expenses and crop health. Ongoing collaboration is crucial to finding effective and sustainable solutions for maintaining water and soil quality in Punjab's agriculture.

The world is rapidly urbanizing, with the global urban population projected to reach 6.7 billion (68.4%) by 2050. Urban water scarcity, where demand exceeds availability, poses a significant threat to water security, impacting health, urban environments, and socioeconomic development. Population growth, urbanization, and climate change are expected to increase water demand by 50–80% over the next three decades. (He et al., 2021)

Water demand and supply for 118 nations from 1990 to 2025. Considering limitations in country-level information, the study finds places with increasing water shortages. According to the predictions, a quarter of the world's population, or one-third of the population in developing nations, may face acute water scarcity in the first quarter of the next century. The often-ignored issue of falling water levels in semiarid parts of Asia and the Middle East, which include important breadbaskets like the Punjab and North China Plain, is a particularly noteworthy worry.(Seckler et al., 1999) This emphasizes the urgent need for professionals and policymakers to address the issue of groundwater depletion, recognizing it as a significant threat to global food security in the coming century.

The water crisis affects 1.2 billion people lacking safe domestic water and 900 million impoverished individuals in rural areas. Lack of safe water contributes to 2.18 million annual deaths, with 75% being children under five. Poverty and malnutrition are exacerbated, creating a vicious cycle. Water scarcity is challenging to define universally, influenced by factors like infrastructure, spatial scales, and water quality. Understanding water scarcity is crucial for effective policy. (Liu et al., 2017)

Over the past 50 years, global groundwater withdrawals have reached 750–800 km3/year, resulting in economic gains but also severe depletion issues. Groundwater depletion is a natural consequence, impacting well yields, pumping costs, water quality, ecosystems, and causing irreversible land subsidence. Theis (1940) noted that plumage initially comes from water in storage, leading to decreased discharge and/or increased recharge over time. Excessive depletion is notable in North Africa, the Middle East, South and Central Asia, North China, North America, and Australia. Approximately 700–800 km3 of groundwater was depleted from U.S. aquifers in the 20th century, with the High Plains aquifer system experiencing a 6% reduction in predevelopment water volume. In some areas, irrigation with groundwater has become impossible or cost prohibitive. Depleting easily recoverable freshwater can result in inferior water quality due to induced leakage from saline or contaminated sources. Coastal areas, hosting major cities, face reduced fresh groundwater volumes due to seawater intrusion caused by aquifer head declines. The ongoing global trend of groundwater depletion requires objective analysis and proactive management strategies. (Scanlon et al., 2023)

In the Indus Basin, droughts and famines historically occurred every 7 to 8 years during the 19th and first half of the 20th century. Baluchistan and Sindh provinces in hyper-arid climates experience higher drought frequency than Punjab and NWFP. Pakistan faces challenges with limited water resources, experiencing a drastic reduction in annual water availability per capita from 5600 m3 in 1947 to 1200 m3 in 2001. Reduced rainfall necessitates modern water application, conservation, and management strategies. The paper critically discusses existing institutional arrangements for disaster management in Pakistan, highlighting constraints and limitations. Recommendations for improvements are presented. Additionally, technological options to address water-related challenges and minimize drought impacts are reviewed. The document aims to assist policymakers and donors in developing long-term, effective drought management strategies in the country. (Pomee & Hertig, 2022)

Moreover, as climate change continues to reshape weather patterns globally, the need for adaptable, technology-driven solutions becomes even more critical. The IRHS, by marrying advanced engineering with environmental consciousness, seeks to contribute to a collective global effort to build resilient and sustainable urban water systems. In essence, this project transcends local boundaries, envisioning a future where cities worldwide can harness the power of rainwater to address water scarcity challenges and foster ecological balance on a global scale

1.2 Problem Statement

In the face of escalating global water scarcity, diminishing groundwater reserves, heightened vulnerability to droughts, and the growing demand for water in agricultural irrigation, urgent attention is required to address these critical issues. Conventional water supply systems are struggling to cope with the rising challenges, necessitating innovative approaches to ensure sustainable water management.

Additionally, environmental conservation remains a pivotal concern, highlighting the need for comprehensive solutions that not only alleviate water scarcity but also contribute to the preservation of ecosystems. This study aims to tackle these multifaceted challenges through an in-depth exploration of advanced technologies in rainwater harvesting and greywater reuse within urban areas, offering a holistic approach to water resource management.

1.3 Objective

The main objective of the project is to establish a comprehensive and sustainable integrated water management system for the NUST H-12 campus. The specific objectives for the study are:

Identification of Potential Catchment Sites around NUST H-12.

Identification and Implementation of Appropriate Rainwater Harvesting (RWH) Models and Recharge Wells in H-12.

Filter Design to filter out pollutants in water coming from porous pavements.

1.4 Scope

The focus of this thesis revolves around the comprehensive examination and implementation of water management strategies within the NUST H-12 campus. The selected area for testing, NUST H-12, serves as an ideal microcosm for studying water management due to its distinct geographic and environmental characteristics.

The land use data employed is sourced from SCEE-NICE, and the study involves the application of water harvesting models on identified catchment areas within the campus. Subsequent testing and analysis will be conducted to assess the effectiveness of the implemented water harvesting strategies.

The undertaken research spans from January 2023 to December 2023, utilizing monthly climate data obtained from the Computerized Data Processing Center of the Pakistan Meteorological Department. The data encompasses crucial climate parameters such as rainfall (precipitation), minimum and maximum temperatures, wind speed, atmospheric pressure, and relative humidity in Islamabad, the capital of Pakistan.

1.5 Significance

The significance of the integrated water harvesting models implemented in this project is multifaceted, addressing critical challenges and contributing to sustainable water management.

By harnessing innovative water harvesting techniques, the project directly confronts the issue of water scarcity. The models aim to optimize water retention, minimize runoff, and enhance overall water availability, offering a tangible solution to regions grappling with water shortages.

The implemented models specifically target groundwater recharge, utilizing strategies such as recharge wells and permeable road materials. This not only replenishes depleted groundwater tables but also ensures a sustainable and long-term approach to managing this vital water resource.

Drought-prone regions stand to benefit significantly from the project's focus on water harvesting. By capturing and storing rainwater, the models provide a reliable alternative water source during periods of drought, offering resilience to communities and ecosystems vulnerable to water scarcity.

The project positively impacts agricultural practices by facilitating efficient water usage through harvested grey water and optimized irrigation methods. This directly contributes to increased agricultural productivity, supporting food security and livelihoods in regions dependent on rain-fed agriculture.

Implementing water harvesting models aligns with environmental conservation efforts. By reducing reliance on conventional water sources and minimizing the environmental impact of runoff, the project contributes to preserving ecosystems, protecting biodiversity, and maintaining the ecological balance.

CHAPTER 2

LITRATURE REVIEW

2.1 Introduction to Water Harvesting in Urban Landscapes

In the contemporary era, a significant global challenge arises from water scarcity, primarily attributed to the exponential growth of the world population and the impacts of global climate changes. Cities accommodate over 53% of the world's population, with more than 75% residing in North America, Europe, and Oceania. The combination of growing urban populations and climate change exacerbates the demand on water supplies in these regions. (Nachshon et al., 2016). The number of urban residents without access to improved water sources rose from 113 million in 1990 to 173 million in 2000. In developing countries, like India, the urban population is projected to increase significantly by 2050, exacerbating water challenges for cities, with only 20% currently meeting health and safety standards. (Albalawneh et al., 2015).

Silvia and Marcos aimed for self-sufficient urban landscape irrigation through integrated rainwater harvesting, treatment, storage, and a photovoltaic system. The automatic irrigation system cut water consumption by 64%, with rainwater meeting 60% of the demand. The photovoltaic system supplied energy needs and generated a surplus of 819 kW h. Economic feasibility was initially challenging, but sensitivity analysis revealed viability, especially in scenarios with rising water prices and emphasis on green technologies. (e Silva et al., 2014). However, there is a pressing need for a more environmentally friendly and cost-effective model.

In urban areas, Rainwater Harvesting (RWH) involves concentrating, collecting, storing, and treating rainwater from impervious building surfaces like rooftops, terraces, and courtyards for use on the site. The goal of the many civic applications of collected rainwater is to reduce the amount of drinking water that is obtained from centralized sources. These applications include washing clothes, watering gardens, flushing toilets, cleaning terraces, and doing outside tasks like washing cars. (GhaffarianHoseini et al., 2016) highlight the major water saving advantages related to RWH implementation by estimating that these uses can account for 80–90% of total household water use globally. As a result, the implementation of RWH systems improves cities' water self-sufficiency and may postpone the need to build new, centralized water infrastructure. (Steffen et al., 2013)

There are other factors besides water scarcity and the requirement to supplement water supplies that are driving towns to build more Rainwater Harvesting (RWH) systems. Research and grey literature from the last 20 years suggest that RWH belongs to the larger group of detention-based LID (low impact development) or Sustainable Drainage Systems (SUDS) methodologies. When appropriately designed, RWH, along with other at-source technologies, can serve as a complementary measure to decrease the frequency, peaks, and volumes of urban runoff. Growing urbanization's effects on stormwater drainage systems may be lessened by the increased usage of tank-based RWH systems for urban catchments (Brodie, 2008; Burns et al., 2015), which may also help to lessen environmental effects on receiving water bodies. (Hamel & Fletcher, 2014)

(Burns et al., 2012) The installation of rainwater storage facilities within the allotted scale has been shown in Australian studies to be able to recover the runoff from rainfall response of impermeable roofs to levels that are like those that existed before development. and lessen disruptions to watershed water quality regimes. (Burns et al., 2012) By building up storage capacity in the tank for impending rain events, the incorporation of multiple-usage needs enables a relatively constant consumption of water, optimizing rainfall capture. (Domènech & Saurí, 2011; Gardner & Vieritz, 2010) The system's efficiency for reducing stormwater runoff and conserving water may be significantly increased by matching demands to local rainfall patterns. (Zhang et al., 2009)

2.2 Global Context of Water Scarcity: Implications for H-12 Sector, Islamabad

2.2.1 Understanding Global Water Scarcity

The global hydrological cycle consistently provides more freshwater annually than required to sustain the current world population. However, due to uneven distribution in both time and space, a significant portion remains inaccessible for human use. About half of the annual runoff rapidly flows off the land in floods, while one-fifth is too remote for practical utilization. This leaves only approximately 31% of the annual runoff accessible for controlled human use. Despite optimistic projections of dam construction indicating a potential 10% increase, the challenges of meeting water demand persist, especially with a projected population growth of 30–35% in the next 30 years.(Postel, 2000) Postel found that humans currently utilize half of the accessible runoff for agriculture, urban areas, industries, and other purposes. This includes direct withdrawals and indirect uses like pollution dilution. Despite optimistic estimates regarding dam construction and conservative projections for increased human demands, the study suggests that human appropriation of accessible runoff could rise to 70% by 2025.(Postel, 2000)

Numerous studies have assessed global water scarcity patterns, revealing significant increases influenced by climate change and human activities. (Kummu et al., 2010) Variability in trends is evident across regions. Past research has delved into the impacts of climate factors like El Niño-Southern Oscillation and inter-annual variability, while human activities such as population growth, food demand, and land use changes also contribute significantly. (Veldkamp et al., 2015) Factors like population and GDP growth have been linked to rising water scarcity (Fant et al., 2016; Mekonnen & Hoekstra, 2016) Human interventions, including land use changes and reservoir regulations, contribute to the emergence of water scarcity hotspots. (Veldkamp et al., 2017) However, previous studies often focused on individual factors, underscoring the need for a comprehensive assessment of the combined effects of changes in water withdrawal and water availability patterns on global, regional, and local water scarcity evolution.

Pakistan holds the third position on the IMF's water scarcity index, indicating a significant challenge as the nation faces an imminent "severe water shortage" by 2025, as reported by PCRWR (Pakistan Academy of Science and Council of Research in Water Resources). (Verbeek & Osorio Rodarte, 2015) The historical susceptibility of the Indus basin to droughts dates back to the 19th century. (Anjum, 2012; Qureshi & Ashraf, 2019; Sarwar, 2008) The nation's heavy reliance on agriculture, coupled with population growth and urbanization, poses a threat to water security, exacerbated by climate change and pollution. (Aijaz & Akhter, 2020) Urgent action is imperative to prevent adverse consequences and increasing inequality, particularly impacting vulnerable groups in society.

Pakistan's evolving climatic conditions, marked by heightened heat waves of sun, and droughts, floods, intensify challenges of insecurity of food, disproportionately affecting impoverished communities that heavily rely on agriculture and natural resources for sustenance. (Jamil, 2019) The escalating competition for water resources, compounded by climate change, population growth, and rapid urbanization, poses life-threatening consequences for the majority of the population. Addressing water scarcity is paramount not only for preserving natural resources but also for fostering sustainable development and safeguarding the well-being of communities. (Jamil, 2019)

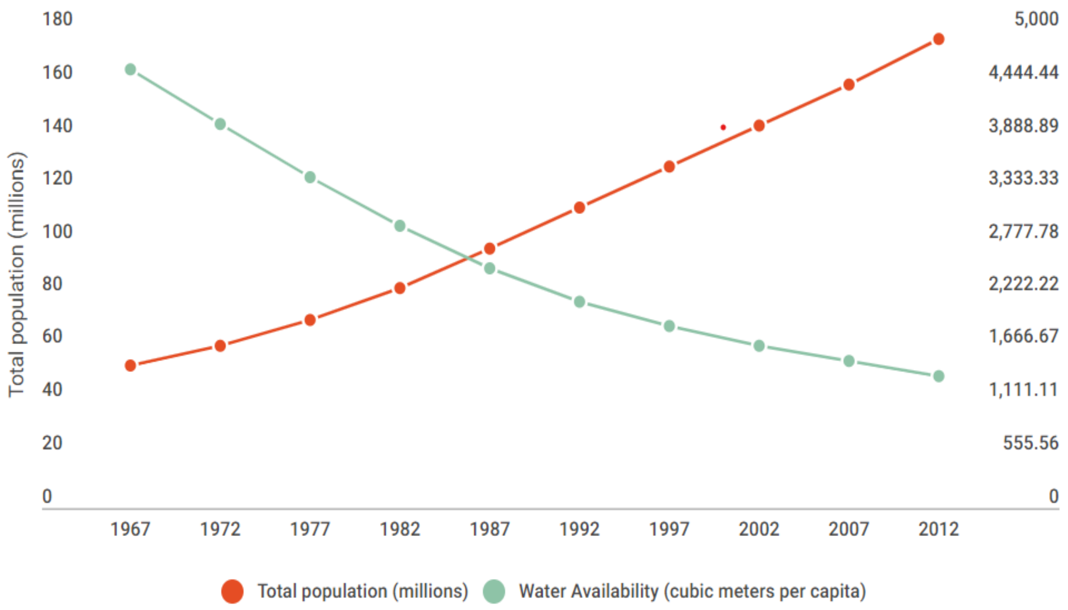

Figure 1: Per Capita Water with Population Relation

2.2.2 Bridging the Global Challenge to Local Realities

Pakistan is confronted with rapid climate change, leading to extreme vulnerability in the country's water resources. Water scarcity is a prominent challenge in developed cities, particularly affecting the capital, Islamabad. The city has experienced significant population migration over the last decade, resulting in a staggering increase in water demand, growing at a rate of 5.7% annually. According to the Capital Development Authority (CDA), the city faces an annual water shortage of 481 million liters/day against an average demand of 800 million liters/day. Key water sources include Simly Dam, Khanpur Dam, tube wells, and bores, contributing a collective 381 million liters/day. However, acute water shortages occur during summer and pre-monsoon periods, exacerbated by events like the drying of Simly and Khanpur dams in June

2017, leading to a reduction in water supply from 109 million liters/day to 86 million liters/day. (Rashid et al., 2018)

(Jo-Ellen Parry, 2016)

Unplanned domestic water supply lines further exacerbate the issue through water leakages. Inadequate rules and regulations, coupled with a lack of awareness, hamper effective monitoring of water usage, ultimately straining supply and increasing demand. A UN-Habitat report highlights an alarming depletion rate of 1.7 meters/year in Islamabad's groundwater level, with observations of a 20-meter drop in various sectors. This decline is attributed to heightened water extraction and reduced water percolation due to urbanization and population growth in the city. (Rashid et al., 2018)

2.3 Sustainable Stormwater Management with Porous Concrete Pavement

The construction of paved roadways becomes essential for economic growth as metropolitan areas increase in size and population. While paved roads enhance the efficiency of transportation, offering time and cost savings, and improved safety and comfort, they contribute to environmental challenges globally, covering about 3% of the Earth's surface. (Sinha et al., 2002) Because of the widespread paving, natural processes like hydrological renewal are hampered, leading to runoff and water pollution. Additionally, the sun absorption by pavements raises metropolitan temperatures. [(Rodriguez-Hernandez et al., 2016; Sinha et al., 2002) The surge in motor vehicle usage, with approximately 132 vehicles per 1000 persons worldwide, further exacerbates environmental issues by emitting gasses into the air.

In response to these challenges, Sustainable Urban Drainage Systems (SUDS) have emerged as a crucial approach for stormwater management in urban areas. Among various SUDS alternatives, permeable pavements have gained prominence due to their versatility and ease of implementation. They offer an environmentally friendly alternative to conventional road development, mitigating issues associated with impermeable surfaces. Permeable pavements utilize diverse surface materials such as pavers, grass, or porous materials like concrete and asphalt. Particularly, pervious concrete (PC) stands out as an effective solution for reducing both water and air environmental impacts. PC, a specialized type of concrete used in pavement technology, features a granular skeleton coated with a cementitious binder, maintaining a high air void content (AV) typically ranging from 15% to 30%. The permeability rates that this design permits range from 1.0 to 47.7 mm/s, making it easier for rainfall to collect and then seep into the earth. (Rangelov et al., 2016) (Brake et al., 2016) (Giustozzi, 2016) (Tennis et al., 2004)

Throughout their operational life, PC (permeable concrete) pavements must have sufficient permeability to handle rainstorm events, with a restricted connected percentage of total voids. (Vardanega, 2014). While certain studies have reported air void contents exceeding 40% (Ghashghaei & Hassani, 2016; Ramadhansyah et al., 2014) the proportion of interconnected air voids is often constrained to not surpass 30% (Agar-Ozbek et al., 2013; Shen et al., 2013) This limitation is attributed to the compaction level employed during pavement construction, mainly utilizing the Proctor hammer with variations in casting layers and blows, and the use of multiple aggregate sizes in the mixture. (Crouch et al., 2007) (Ibrahim et al., 2014; Sumanasooriya et al., 2012) On the other hand, by adding fibers and super plasticizers and using a rodding compaction technique, researchers have been able to obtain air voids as low as 10%, leading to permeability rates of 0.70 mm/s. (Wu et al., 2011)

The permeability of porous mixed surfaces has been measured directly using a variety of techniques, including as permeameters, rainfall simulators, and single- and double-ring infiltrometers. (Andrés-Valeri et al., 2016; Dougherty et al., 2011; Li et al., 2013; Ranieri et al., 2012; Rodriguez-Hernandez et al., 2016) Permeability values, depending on the parameters of the combination, range from 0.30 mm/s to 47.7 mm/s, according to a survey of the literature. (Yang & Jiang, 2003) With a maximum air void ratio of 42%, a permeability of 17.4 mm/s was obtained. (Ibrahim et al., 2014) Furthermore, the applied compaction energy has a major effect on the intrinsic porosity of PC mixes; a higher compaction energy results in a smaller air void content. (Zaetang et al., 2013)

2.4 Sustainable Stormwater Management with Bioretention Area

Bioretention facilities, including rain gardens, play a crucial role in stormwater retention and treatment, contributing to urban vegetation. These facilities engage in active processes such as organic complexation, ion exchange, decomposition, adsorption , volatilization, infiltration, and filtration. (Clar et al., 2004)). Retention of metals in soil is influenced by cation exchange, co-precipitation, organic complexation, and plant uptake, with plants contributing to the interaction between roots, the rhizosphere, and the soil, enhancing infiltration, soil texture, and preventing clogging.(Gregory, 2006) Over 90% of lead, zinc, and copper have been removed in the bioretention facilities, according to studies incorporating experimental and event-based field testing; plant absorption accounts for around 5% of the removal by mass. On the contrary hand, the mulch layer helped remove 34% of zinc, 10% of lead, as well as 20% of copper. (Davis et al., 2001) Field testing on existing bioretention sites revealed performance that varied widely, from more than 90 percent in well-developed facilities with dense vegetation to 42 percent to 70 percent in less developed ones. (Davis et al., 2003)

In situ infiltration techniques have been recommended as a treatment for urban snowmelt with high levels of soluble contaminants. (Oberts, 2003) For infiltration to efficiently absorb soluble contaminants, it must have the soil's ion-exchange capability or specially designed infiltration medium. (Oberts, 2003) Achieving sufficient rates of infiltration is crucial for successful meltwater infiltration, with literature recommending a minimum rate of 1.3 cm/h and clay contents below 30% (Caraco & Claytor, 1997). In the field, additions of 1–2% clay to the top soil (“claying”) have been practised by farmers to overcome water repellency. (McKissock et al., 2000) The amount of water in the soil prior to freezing is important because too much water in the soil after freezing might cause concrete frost, which is an impermeable layer of the soil with almost no infiltration. Granular or porous frost, on the other hand, can preserve and even surpass the unfrozen soil's ability to infiltrate. (Granger et al., 1984; Kane, 1980)

As adjustments to cold environment BMPs (best management practices), the incorporation of biological features into meltwater treatment systems has been suggested. Examples of these elements are vegetated swales with plant roots to assist infiltration and vegetated cover to encourage sheet flow. (Caraco & Claytor, 1997; Oberts, 2003) Based on these results, it appears that bioretention has a great deal of promise for usage as a snowbank and for storing contaminants from meltwater. Because of the varied flora, there is more penetration, and because plant roots are active in the winter, there is a chance that pollutants will be adsorbed. By keeping contaminants from the snowmelt and minimizing clogging, the mulch layer acts as a disposable treatment layer.(Muthanna et al., 2007).

2.5 Current Water Dynamics in Islamabad

The meteorological model computes the necessary precipitation input for a sub-basin element, employing both point and gridded precipitation data. For this study, point precipitation data was utilized, specifically from five rain gauges in the study area: Bokra, Golra, PMD, RAMC, and Saidpur. The Thiessen Polygon method was applied, dividing the focused watershed into five polygons. Depth weights for rain gauges across 11 sub-basins were determined using ArcGIS. (Ali et al., 2011)

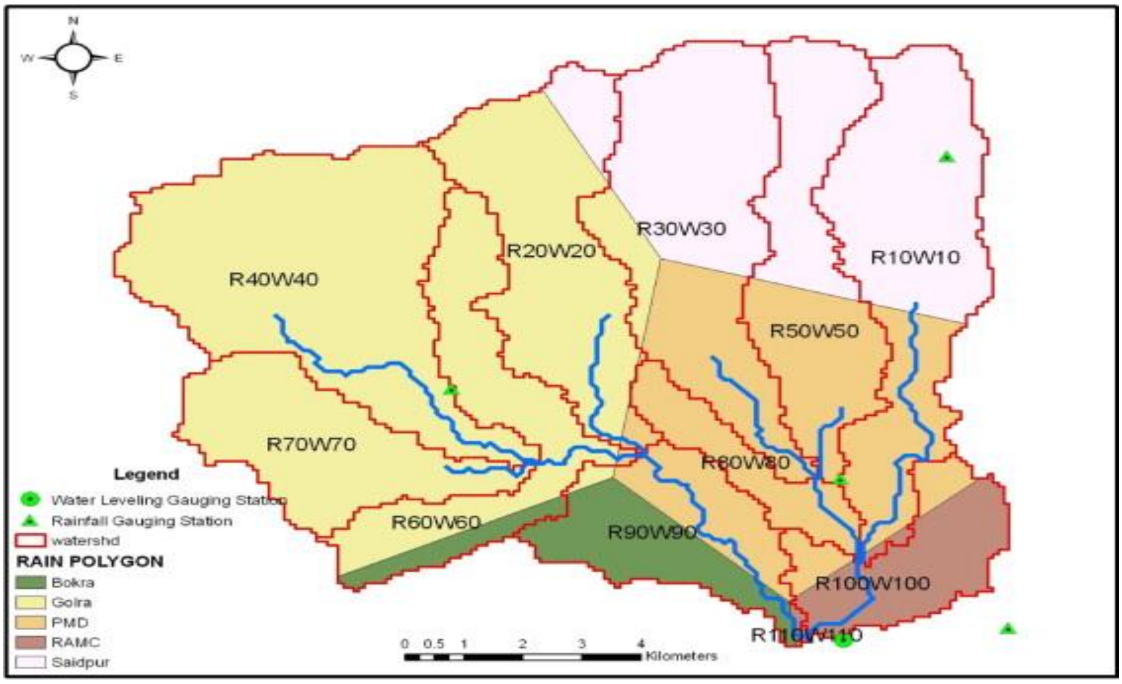

Figure 2: Catchment Area in Islamabad (Ali et al., 2011)

The impact of Rainwater Harvesting (RWH) on energy consumption is subject to debate. Although some contend that RWH systems frequently require more energy for operation than the water supply that they replace, (Ward et al., 2012) refute this, saying that it really depends on the situation. Technological advancements in pump design and low- or no-energy RWH systems are seen as mitigating factors. Even the possibility of lower energy use with RWH systems was discovered. Certain initiatives also look at recovering thermal energy and cooling buildings using collected rainwater. (Albalawneh et al., 2015)

2.6 Advancements in Harvesting and Greywater Reuse Techniques

Water resources are facing escalating exploitation and pollution, and there is a projected escalation in global water stress in the coming years. (Matos et al., 2010; Santos et al., 2012; Zavala) There is a rising interest in investigating other water sources, such as rainfall and recycled wastewater, due to the increasing demands on water resources brought about by rapid industrialization, urbanization, and agricultural production in developing nations. (Antunes et al., 2016; Bixio et al., 2006; Chu et al., 2004; Revitt et al., 2011) Rainwater harvesting, or RWH, is a well-known and widely used practice in Asia and Africa. In several European nations, it has improved significantly. Regulations and incentives are in place globally to encourage the use of rainwater.(Domènech & Saurí, 2011) The amount and intensity of rainfall have a major impact on whether rainwater collection is viable in a given location. Relying exclusively on rainwater gathering may not be adequate in areas with low precipitation rates to fulfill the water supply demands of both urban and rural populations.(Zavala) However, because of its many advantages and affordability, rainwater collecting works well as a backup water supply.(Imteaz et al., 2011; Liuzzo et al., 2016; Thulo Ram Gurung, 2014)

On the other hand, cities in arid and semiarid countries with booming economies are becoming more interested in GWR (greywater reuse) because of the shortage of freshwater, the increase in water demand brought on by population development, and the speed at which industry is developing. Reusing greywater offers a viable way to mitigate the effects of climate change-induced water scarcity and lessen the strain on current water supplies in these regions. Reusing and treating greywater provides a substitute for potable water in homes, with the potential to cut down on water use per person by as much as 50%.(Gross et al., 2007; Revitt et al., 2011; Winward et al., 2008; Zavala et al., 2014) In Mexico and several other Latin American nations, greywater makes up more than 70% of all wastewater volume, making it a substantial component of household wastewater (Zavala et al., 2014). Greywater reuse has been actively pushed and sponsored by many nations globally, including Japan, the USA (Arizona, Texas, and California), Australia, China, Korea, Spain, and Cyprus. To promote greywater reuse, authorities in these nations have used a variety of tools, including policies, laws that must be followed, incentive programs, and subsidies.(Oron et al., 2014) Greywater has been treated using a variety of techniques, including membrane filtration and screening, coagulation-flocculation as well as ion exchange resins, physical systems, and biological systems, such as constructed wetlands, membrane bioreactors, rotating biological reactors, and sequencing batch reactors. Physical treatment systems are frequently employed in conjunction with other techniques or disinfection procedures in order to obtain the desired microbiological quality. Relying alone on these systems may not be sufficient.(Barışçı & Turkay, 2016) GWR for flushing toilets may be financially feasible in some circumstances, even for end users. These circumstances include the population serviced, the treatment technology selected, and the current cost of water.(Ghisi & de Oliveira, 2007; Penn et al., 2013).

CHAPTER 3

METHODOLOGY

3.1 Overview of Flow Chart

This segment presents a graphical depiction of the fundamental water harvesting cycle at the NUST H-12 campus. The flow chart delineated the sequential stages of rainwater collection, treatment processes, and utilization, refraining from specific assumptions about the employed techniques. Our approach involved adhering to the illustrated flow chart for the development and implementation of water harvesting techniques on our campus. Initially, the focus was on the meticulous collection of rainwater through various harvesting methods. Subsequently, the second phase entailed the filtration of water and its diverse applications based on its composition. Finally, any surplus water underwent a recharging process to counteract the depletion of underground water resources.

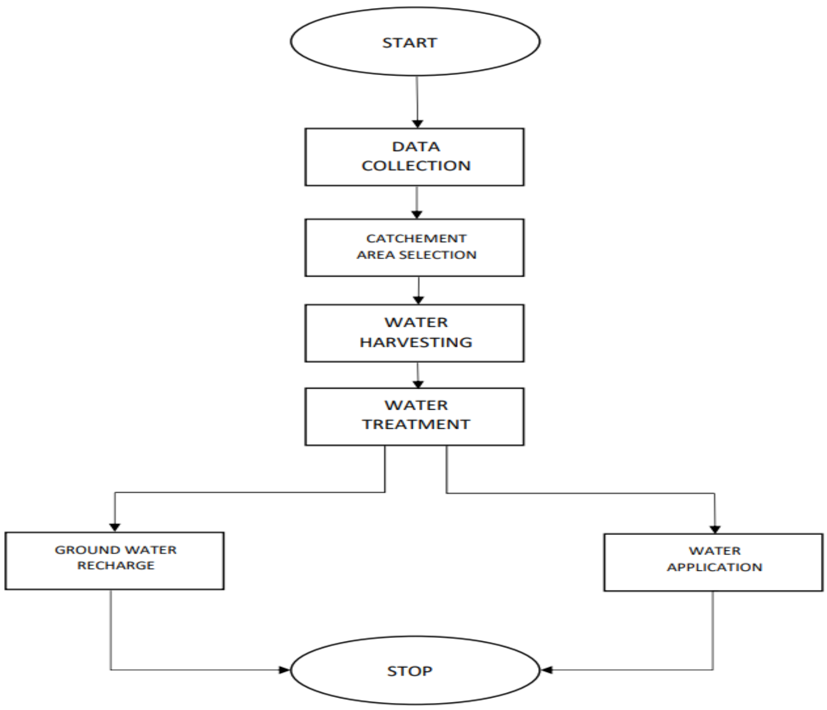

Figure 3: Flow Chart for Hydraulic Cycle within this Project

3.2 Hydrological Data Acquisition

3.2.1 Data Sources

The foundation of the Sustainable Water Harvesting Project at NUST University was rooted in precise hydrological and terrain data obtained from authoritative sources such as the Pakistan Council of Research in Water Resources (PCRWR) and Pakistan Meteorological Department (PMD), along with some available satellites data such as ALOS Pulsar and sentinel 2SA satellite. The precipitation data was taken from existing research of Engr. Syed Adnan Shah as he provided the data in his thesis "Development of Intensity-Duration-Frequency (IDF) Curves for Islamabad and Abbottabad under Varying Climatic Conditions". This data, including precipitation patterns, formed the basis for informed decision-making in water resource management at NUST.

3.2.2 Advanced Data Analytics for Informed Decision-Making

The cornerstone of the Sustainable Water Harvesting Project at NUST University lay in the judicious utilization of precise hydrological data obtained from previous mentioned sources. This foundational data, encompassing precipitation patterns and hydrological information, formed the bedrock for our strategic decision-making in water resource management at NUST.

To extract actionable insights from this data, we employed an advanced data analytics methodology. This involved the application of statistical models and predictive analytics to discern meaningful patterns and trends. By leveraging the power of data analytics, our objective was to inform decision-making processes throughout the various stages of water resource management. This analytical approach aided in the identification of optimal water harvesting techniques based on the specific characteristics of the terrain at NUST.

The advanced analytics methodology extended beyond mere data interpretation; it served as a proactive tool for predictive modelling. By anticipating future water availability and usage patterns, we could tailor our water harvesting strategies to align with the dynamic needs of the campus. This forward-looking approach enabled us to make informed decisions on the type of water harvesting techniques best suited to the unique hydrological features of the NUST H-12 campus.

In essence, the utilization of advanced data analytics not only formed the basis for strategic decision-making but also empowered the Sustainable Water Harvesting Project with a dynamic and adaptive framework. This methodology ensured that our water management strategies at NUST were not only data-driven but also forward-thinking, contributing to the long-term sustainability and resilience of the university's water resources.

3.3 Data Utilization Methods

3.3.1 Mapping Techniques

In the realm of water resource management, our strategy began with the accusation of terrain and land use data which we obtained from ALOS Pulsar and sentinel 2SA satellite, respectively. This dataset became the bedrock for our advanced geospatial analysis, facilitating the identification and selection of prime areas with the utmost potential for water collection. Our meticulous mapping approach ensured not just accuracy but strategic ingenuity in the placement of water harvesting infrastructure. Through a flexible application of geospatial mapping techniques at NUST, we steered clear of rigid assumptions, allowing for a nuanced visual representation of the campus topography and hydrological features.

We employed sophisticated processing tools like Infraworks and Arc-GIS. This technological synergy enabled a granular analysis, fine-tuning and optimizing our water management strategies. This comprehensive mapping methodology transcended conventional approaches, empowering us with a true-to-life depiction of the campus terrain. This accuracy, in turn, equipped us to make judicious decisions, ensuring the sustainable and efficient utilization of water resources at NUST.

3.3.2 Optimization Strategies

Guided by the insights derived from data analytics, our approach involved the meticulous selection of areas with the highest potential for water collection. The execution of water harvesting unfolded through the strategic optimization of existing infrastructure, capitalizing on pre-dug boreholes, and thoughtfully positioned recharge wells to ensure the utmost efficiency in water collection.

3.3.3 Efficiency Measures: Leveraging Existing Infrastructure for Sustainable Water Harvesting

The essence of efficient water harvesting lay in the astute optimization of existing infrastructure. Our project was designed to leverage pre-existing boreholes, minimizing the necessity for additional drilling. By capitalizing on the university's established infrastructure, we not only enhanced operational efficiency but also underscored our commitment to sustainable water management practices.

3.4 Study Area and Methodology

3.4.1 Geographic Focus: NUST H-12 Campus as the Epicentre

Our research's geographical focus centred on the National University of Science and Technology (NUST) H-12 campus. This deliberate choice served as the canvas for our in-depth exploration into water harvesting methodologies. The upcoming stages of our project saw the development and demonstration of a comprehensive model, meticulously crafted within the framework of Arc-GIS. This modelling exercise was not just an academic endeavour; it was a strategic tool designed to enhance comprehension and strategic decision-making regarding water resource management throughout the entire NUST H-12 campus.

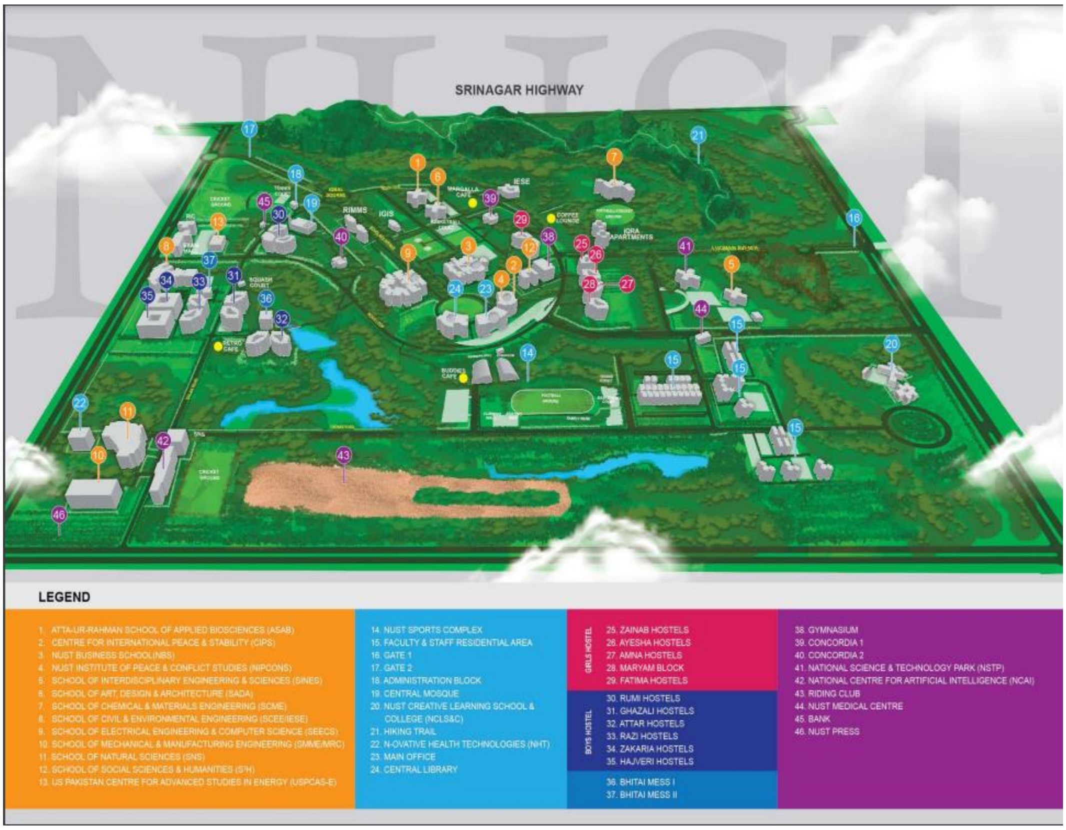

Figure 4: NUST H-12 Topographical Representation from www.nust.edu.pk

3.4.2 Methodological Blueprint: Guiding Water Harvesting Implementation

Our methodology, designed for the Sustainable Water Harvesting Project at NUST University, offered a comprehensive and systematic approach to the implementation of water harvesting techniques within the NUST H-12 campus. Rather than delving into specific assumptions, our methodology adhered to general principles, emphasizing data-driven decision-making, strategic infrastructure placement, stakeholder engagement, and effective monitoring strategies. This methodological blueprint served as a strategic guide, aligning our efforts with sustainability goals and environmental initiatives. By prioritizing principles over assumptions, we aimed to foster adaptability and responsiveness throughout the water harvesting process. The flexibility inherent in our approach ensured that our strategies remained attuned to the dynamic needs of NUST H-12.

In summary, our methodology provided a roadmap for the seamless integration of water harvesting techniques, emphasizing principles that were universally applicable and ensuring the enduring success of our sustainability endeavours.

3.5 Analysis of Existing Rain Water Harvesting Models in NUST

We conducted a thorough evaluation of the various rainwater harvesting models implemented at NUST. This evaluation aimed to comprehensively analyze the effectiveness, efficiency, and sustainability of these models. By doing so, we sought to identify best practices and areas for improvement to optimize the overall system.

The comparative analysis was detailed and multifaceted, encompassing several key parameters. These included the methods used for rainwater collection, the solutions in place for storage, the processes involved in treating the harvested water, and the level of integration with the broader water management system of the campus.

Through this detailed analysis, we aimed to understand how each model performed under different conditions and to pinpoint which practices contributed most to their success. This approach enabled us to make informed recommendations for enhancing the rainwater harvesting infrastructure at NUST, ensuring that it meets the highest standards of sustainability and operational efficiency.

3.6 Rain Water Quality Testing

To ensure the harvested rainwater met safety and usability standards, we conducted comprehensive water quality testing. This testing included various parameters such as pH, turbidity, microbial content, and chemical contaminants. The findings provided crucial insights into the suitability of rainwater for various applications and informed the necessary treatment processes required to meet health and safety standards.

Our methodology involved collecting rainwater samples from different harvesting points across the campus and analysing them in a laboratory setting. The pH levels were measured to determine the acidity or alkalinity of the water, while turbidity tests assessed the clarity and presence of suspended particles. Microbial content analysis was conducted to detect any harmful bacteria or pathogens, and chemical tests were performed to identify potential contaminants such as heavy metals and pesticides.

The results of these tests revealed the overall quality of the harvested rainwater and its potential uses. For instance, rainwater with low turbidity and minimal microbial content was deemed suitable for non-potable uses such as irrigation and toilet flushing. In cases where chemical contaminants were detected, specific treatment processes were recommended to ensure the water met the required safety standards for its intended use.

Overall, the comprehensive water quality testing provided essential data that guided the development of effective treatment protocols, ensuring that the harvested rainwater could be safely utilized across various applications within the campus.

3.7 Resistivity Survey of Selected Sites in NUST

We conducted a resistivity survey of selected sites within NUST to evaluate the subsurface characteristics and determine the suitability for rainwater harvesting infrastructure. This survey aimed to identify areas with optimal conditions for installing components of the rainwater collection system.

The resistivity survey involved using electrical resistivity methods to map the subsurface features. By sending electrical currents through the ground and measuring the resistance encountered, we were able to create detailed profiles of the subsurface composition. This information was crucial for identifying areas with favourable soil conditions and avoiding locations with potential issues such as high levels of rock or impermeable layers.

The findings from the resistivity survey provided valuable insights into the geotechnical properties of the selected sites. These insights informed the design and placement of the rainwater harvesting systems, ensuring that the infrastructure would be both effective and sustainable. By selecting sites with suitable soil conditions, we aimed to enhance the efficiency of water infiltration and storage, thereby improving the overall performance of the rainwater harvesting system.

The resistivity survey was a key component of our comprehensive approach to developing a sustainable rainwater harvesting model at NUST. It ensured that the chosen sites would support the long-term functionality and durability of the system, contributing to the campus's broader water management strategy.

3.8 Developing a Sustainable Roof Water Harvesting Technique

We focused on developing a sustainable technique for harvesting rainwater from roofs, covering the design, implementation, and optimization of roof-based water collection systems. By incorporating principles of sustainability and efficiency, we aimed to create a model that could be replicated across different buildings within the campus.

We evaluated various materials for gutters, downspouts, and storage tanks to ensure durability, cost-effectiveness, and environmental friendliness. Materials were chosen based on their ability to withstand local weather conditions and their minimal environmental impact. The design phase involved creating blueprints for the water collection system that maximized efficiency and minimized waste, including strategically placing collection points to capture the maximum amount of rainwater and designing the system to integrate seamlessly with the existing building infrastructure.

Efficient methods for transporting rainwater from collection points to storage tanks were devised, optimizing the slope and layout of gutters and downspouts to ensure smooth water flow and minimize potential blockages. To ensure the quality of collected rainwater, we implemented multi-stage filtration processes, starting with initial debris filters to remove large particles, followed by finer filters to eliminate smaller contaminants. Advanced filtration systems, such as UV sterilization, were also considered to address microbial content.

Various storage options were analysed, including above ground and underground tanks. We focused on selecting tanks that were not only capable of storing large volumes of water but also designed to prevent contamination and minimize evaporation losses.

Throughout the process, we highlighted the potential for scalability and long-term sustainability. The techniques and systems developed were designed to be adaptable, allowing for easy implementation across different buildings with varying architectural styles and sizes. This adaptability ensures that the rainwater harvesting model can be expanded campus-wide, contributing significantly to water conservation efforts and promoting sustainable practices.

By addressing these key components, we aimed to create a robust, efficient, and sustainable rainwater harvesting system that could serve as a model for other institutions looking to implement similar initiatives.

3.9 Stakeholder Collaboration and Alignment

Effective collaboration with pivotal stakeholders, including PCRWR, PMD, SCEE-NICE and Works Directorate NUST, stood as a cornerstone for the successful realization of our water harvesting project at NUST University. Our commitment extended to continuous engagement with university officials, students, and the local community. This ongoing dialogue was meticulously curated to ensure a seamless alignment with institutional sustainability goals and broader environmental initiatives. By fostering a collaborative spirit, we aimed to integrate diverse perspectives, expertise, and resources for the collective advancement of our water management endeavours.

3.10 Technological Innovation for Future Sustainability

The Sustainable Water Harvesting Project was more than a response to immediate needs; it positioned the university at the forefront of water management innovation. The insights garnered functioned as a detailed blueprint, steering not only our project but also offering practical guidance for similar initiatives. This initiative actively promoted a culture of sustainable water use within the university, emphasizing efficient technologies such as advanced water harvesting methods and the effective use of recharge wells. These implementations optimized water utilization, paving the way for future advancements in water resource management.

The acquired knowledge became a valuable resource, influencing not only our practices but also serving as a knowledge hub for institutions undertaking similar journeys. Our commitment to technological innovation underscored a proactive stance, ensuring the perpetual environmental sustainability of NUST University. By championing modern, eco-friendly practices, we set the stage for a broader impact in the academic community and contributed to a collective movement for responsible and resource-conscious water management strategies.

CHAPTER 4

RESULTS

4.1 Overview

This chapter presents the comprehensive results of our study on sustainable water harvesting at NUST, including the evaluation of existing rainwater harvesting models, detailed water quality testing, resistivity surveys of selected sites, and the development of innovative water harvesting techniques. We also provide thorough recommendations for the implementation of these techniques across various sites within the NUST campus.

4.2 Evaluation of Existing Rainwater Harvesting Models

To assess the effectiveness of the existing rainwater harvesting models, we collected and analysed data from three specific locations: NICE Ground Bore, NICE Backyard Bore, and the Volleyball Ground. Water levels were measured during various rainfall events to determine the performance and efficiency of these systems.

4.2.1 NICE Ground Bore

The NICE Ground Bore demonstrated stable water levels throughout the observation period. The data collected showed minimal fluctuation in water levels, indicating a consistent rate of infiltration and storage.

This stability suggests that the ground bore is effectively capturing and storing rainwater, providing a reliable source of water for non-potable uses. However, the relatively low fluctuation may also indicate limited capacity for additional water during heavy rainfall events, suggesting potential areas for improvement in expanding storage capacity or enhancing infiltration rates.

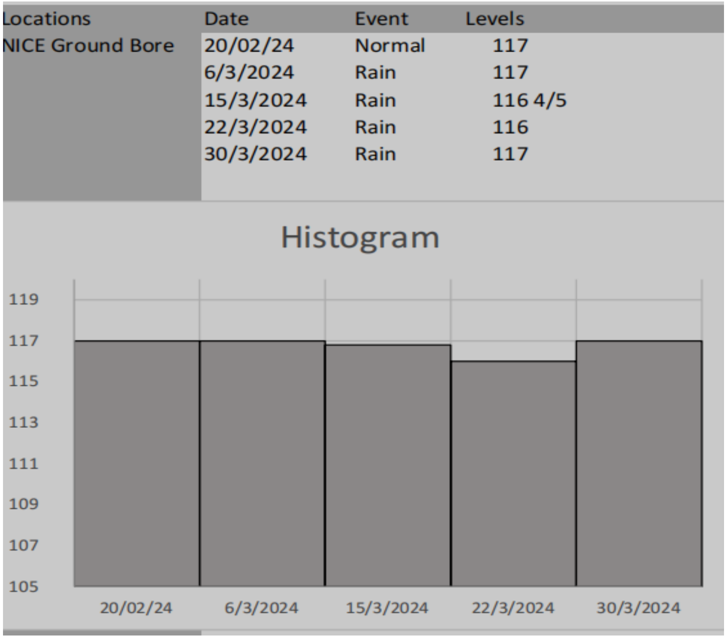

Figure 5: Water Level at NICE Ground Borehole

4.2.2 NICE Backyard Bore

The NICE Backyard rainwater harvesting system also demonstrated fluctuations in water levels, although to a lesser extent than the NICE Backyard Bore. The data indicates that this system is capable of effectively capturing and storing rainwater but may have a more moderate capacity compared to the backyard bore.

This system's performance suggests it is well-suited for areas where moderate rainfall is expected, providing a balanced approach to rainwater harvesting that

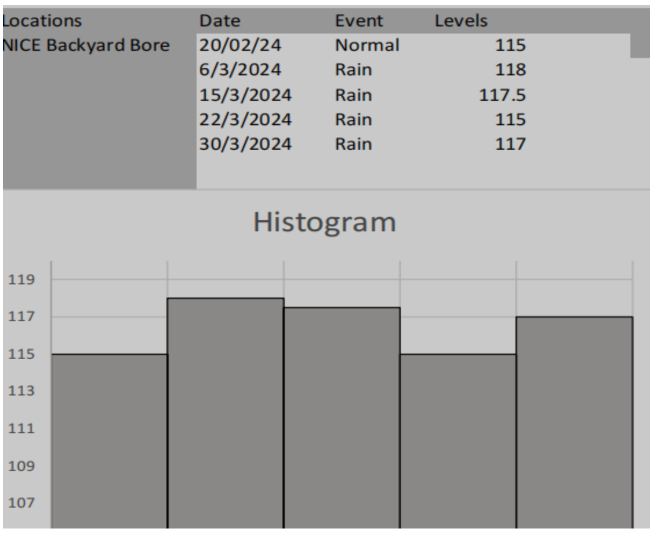

Figure 6: Water Level at NICE Backyard Borehole

combines efficiency with stability. Potential improvements could include increasing storage capacity or optimizing the system to handle larger volumes of rainwater.

4.2.3 NICE Volleyball Ground

The Volleyball Ground Bore showed significant variations in water levels during different rainfall events, indicating a higher efficiency in water infiltration and storage compared to the NICE Ground Bore. This variability highlights the system's responsiveness to rainfall and its ability to adapt to varying volumes of water.

The higher fluctuation suggests that the backyard bore is more effective at capturing large volumes of rainwater quickly, which can be particularly beneficial during periods of heavy rainfall. However, this also means the system may require more frequent monitoring and maintenance to ensure it continues to function effectively.

Locations	Date	Event	Levels
Volley Ball	20/02/24	Normal	120
	6/3/2024	Rain	95
	15/3/2024	Rain	88
	22/3/2024	Rain	82
	30/3/2024	Rain	85

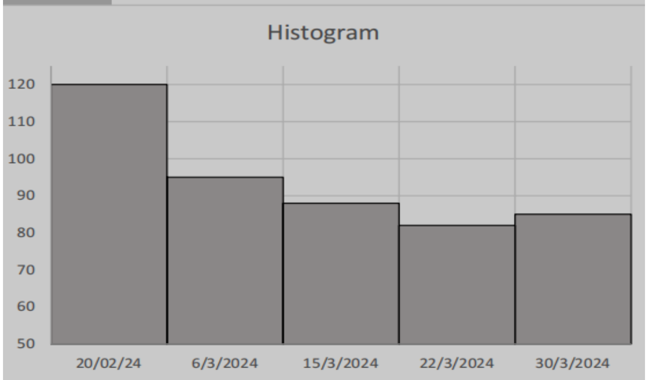

Figure 7: Water Level at NICE Volleyball Ground Borehole

4.3 Water Quality Testing

Comprehensive water quality testing was conducted to ensure the harvested rainwater met safety and usability standards. This testing included various parameters such as Total Dissolved Solids (TDS), turbidity, alkalinity, pH, electrical conductivity (EC), nitrates, hardness, and chlorides. These parameters were carefully measured and compared against the thresholds provided by the World Health Organization (WHO).

The water quality testing results demonstrate that the harvested rainwater is suitable for various non-potable uses, such as irrigation and toilet flushing, without the need for extensive filtration. The values for all tested parameters are within the acceptable ranges specified by the WHO, confirming the effectiveness of the rainwater harvesting system in maintaining water quality.

Testing	Values	Threshold
TDS	122.36	<1000
Turbidity	94.36	<150
Alkanity	106.04	<200
pH	6.82	6.5-7.5
EC	247.40	<4000
Nitrates	1.68	<50
Hardness	108.00	<500
Chlorides	14.01	<250

Figure 8: Water Quality Concentrations and Comparison

4.4 Resistivity Survey of Selected Sites

To identify optimal locations for installing rainwater harvesting systems, we conducted resistivity surveys at four potential sites within NUST. These surveys provided valuable insights into the subsurface characteristics of each site, helping to determine their suitability for rainwater harvesting infrastructure.

4.4.1 Site Suitability Map

The site suitability map below shows the areas within NUST that were identified as suitable for rainwater harvesting based on the resistivity surveys.

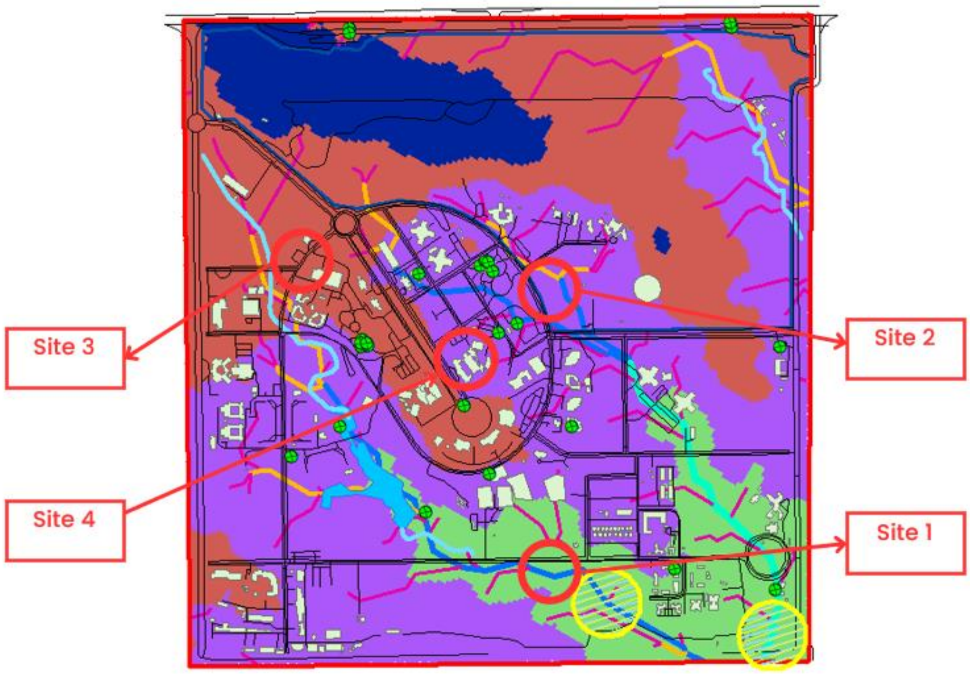

Figure 9: Site Suitability Map of NUST

4.4.2 Site 1: Near Sports Complex

We proposed a bio retention area for Site 1, near the Sports Complex, due to its potential as a catchment area and the convergence of all NUST streams. The absence of nearby built structures and signs of life further support its suitability for this purpose.

The resistivity analysis for Site 1 revealed that the site has a medium yield for groundwater, indicating moderate potential for water storage and recharge. The geological composition consists of alluvium and Murree/Kamrial Formation, which are conducive to water infiltration. A test well should be drilled to a depth of 300 feet to optimize water extraction and storage.

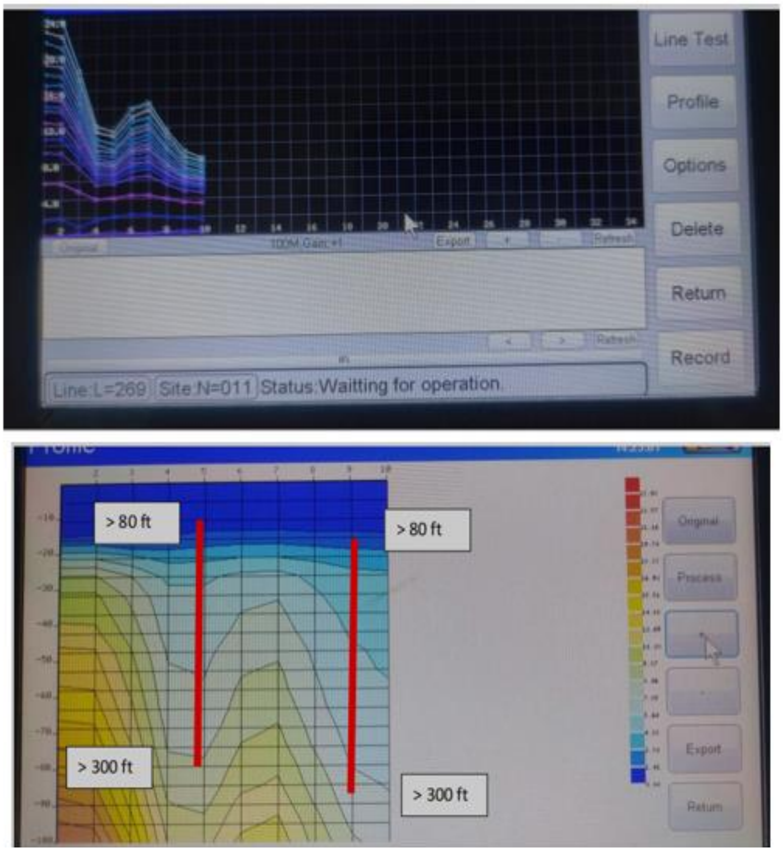

Figure 10: Terameter Display of Site 1

4.4.3 Site 2: Near SCME Ground

For Site 2, near the SCME Ground, we proposed the use of percolation pits. These pits are effective for water penetration, cover a large catchment area, and feed boreholes efficiently. The resistivity analysis for Site 2 revealed that the site has a low yield for groundwater, indicating limited potential for water storage. The geological composition is similar to Site 1, consisting of alluvium and Murree/Kamrial Formation. A test well should be drilled to a depth of 250 feet to optimize water extraction and storage.

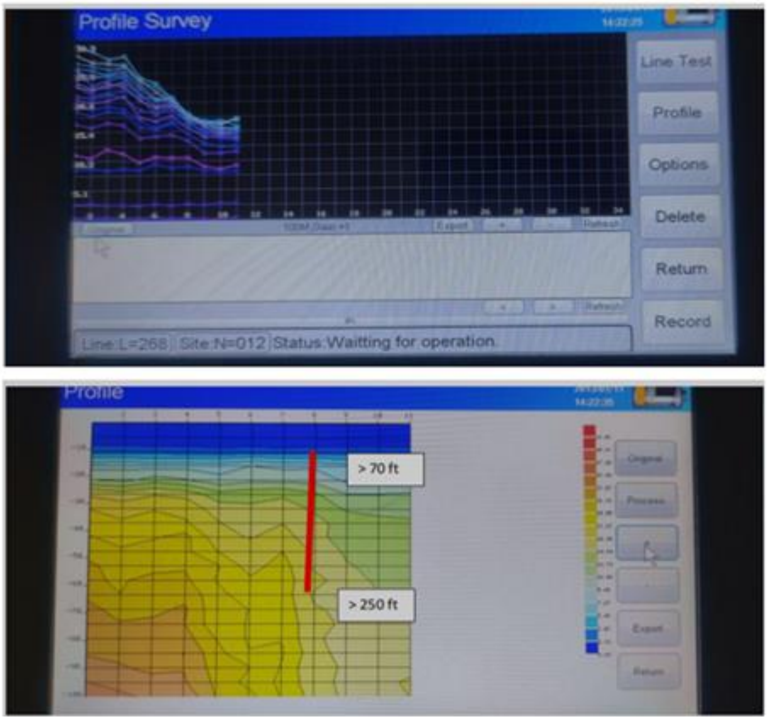

Figure 11: Terameter Display of Site 2

4.4.4 Site 3: Near NICE Volleyball Ground

No resistivity analysis was conducted for Site 3 due to the presence of a pre-existing dead borehole. This site will utilize the existing infrastructure for water storage and recharge, making it a cost-effective option for rainwater harvesting.

4.4.5 Site 4: NUST Business School

For Site 4, located at the NUST Business School, we proposed roof water harvesting due to the large roof catchment area. This method provides good water recharge capability and effective utilization of rainwater.

The resistivity analysis for Site 4 revealed that the site has a low yield for groundwater, indicating limited potential for water storage. The geological composition consists of alluvium and Murree/Kamrial Formation. A test well should be drilled to a depth of 200 feet to optimize water extraction and storage.

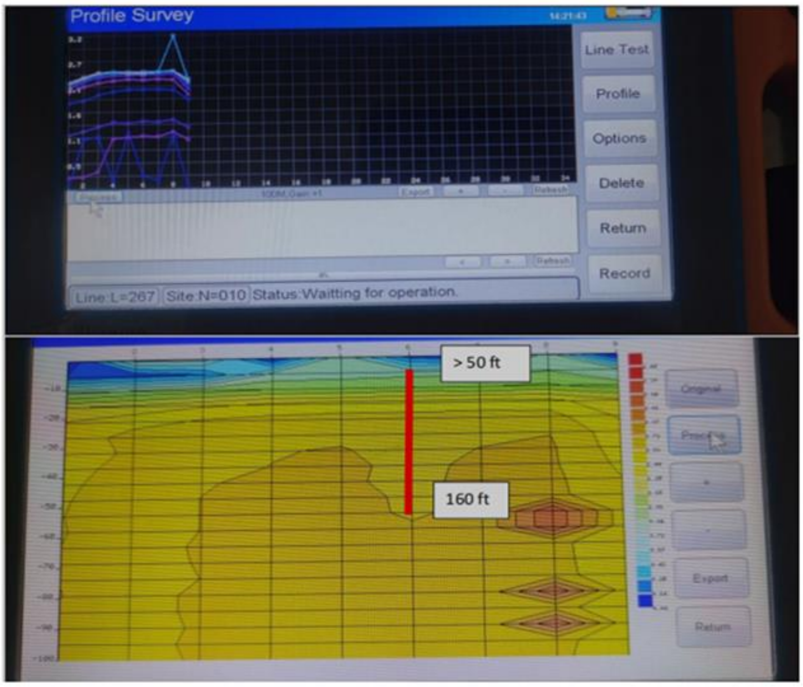

Figure 12: Terameter Display at Site 4

4.5 Development of IDF Curves

To aid in the design of roof water harvesting models, we utilized Intensity-Duration-Frequency (IDF) curves developed by Engr. Syed Adnan Shah in his thesis, "Development of Intensity-Duration-Frequency (IDF) Curves for Islamabad and Abbottabad under Varying Climatic Conditions." These curves provide essential information on rainfall patterns and intensities, critical for calculating design discharges and selecting appropriate pipe diameters for efficient water conveyance.

Engr. Shah's research analysed historical rainfall data from the Pakistan Meteorological Department (PMD), capturing the variability and intensity of rainfall in Islamabad. This extensive dataset ensured that the IDF curves accurately reflect the region's hydrological behaviour.

The IDF curves illustrate the relationship between rainfall intensity, duration, and frequency for each month. Using these curves, we calculated the design discharge for the roof water harvesting systems at NUST, representing the maximum flow rate the system needs to handle during peak rainfall events.

Based on the design discharge, we determined the required pipe diameter to be approximately 10.19 inches. To ensure practicality, we opted to use two 6-inch pipes in parallel, providing the necessary capacity and flexibility for maintenance and future upgrades.

The use of IDF curves from Engr. Shah's thesis allowed us to accurately calculate design discharges and select appropriate pipe diameters, ensuring the reliability and efficiency of our roof water harvesting systems. This approach enhances the sustainability of water resources at NUST and serves as a model for other institutions implementing similar rainwater harvesting initiatives.

4.6 Simulation of Rainfall Runoff

The simulation of rainfall runoff provided the basis for the suitability analysis of sites and the design of water harvesting systems. The simulations demonstrated that flash flooding could be reduced by retaining water in the proposed harvesting sites, addressing the issue of water scarcity in H-12 during peak summer months.

4.6.1 Methodology

The simulation involved using advanced geospatial analysis tools such as Fireworks and ArcGIS to model the topography and hydrology of the NUST campus. The data from the resistivity surveys and IDF curves were integrated into the simulation to create a detailed representation of rainfall runoff patterns.

Figure 13: Infraworks Model of NUST H-12

The simulation results showed that the proposed harvesting sites could effectively capture and retain significant volumes of rainwater, reducing the risk of flash flooding and increasing water availability during dry periods.

4.6.2 Results

The total water harvested from roof water harvesting was calculated to be 37,637,011.48 liters, equivalent to 37,637.01148 cubic meters. This substantial volume of water highlights the potential of rainwater harvesting to address water scarcity issues on campus.

4.7 Self Backwashing Filter Design

Rainwater harvesting filtration systems are designed with multiple important features in mind: low cost, energy-saving, easy integration to existing building hydraulic systems, adaptable effectiveness of treatment to meet different water quality standards, and self-cleaning capacity.

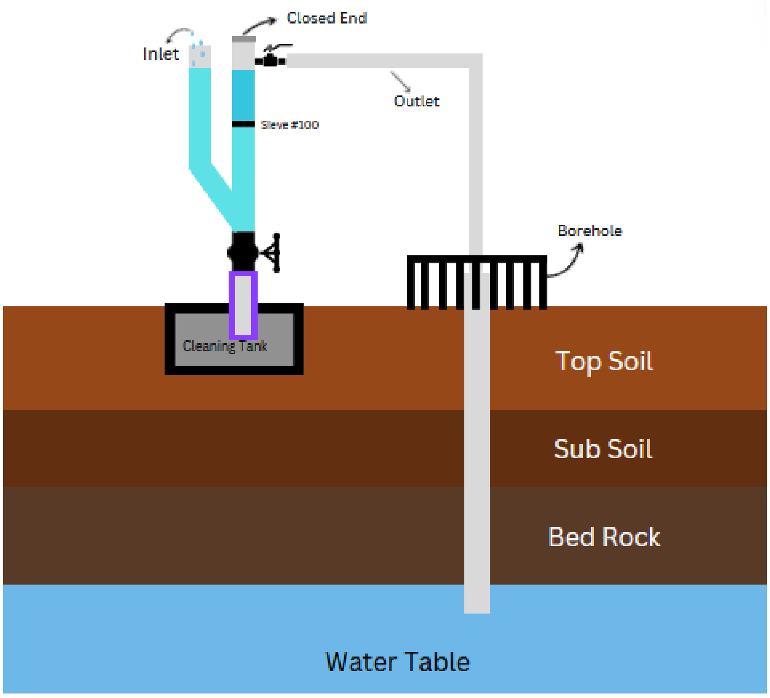

Figure 14: Self- Backwashing Roof Water Harvesting Mechanism

Up-flow filtration linked to a down-flow back washing design powers the system. At first, when there isn't any rain, the device uses no electricity and stays in standby mode. Rainwater enters the system and moves upward through the filter media as it becomes accessible. In this step, the purified water is sent to a recharge well while impurities and debris are trapped in the filter media. Once the filter gets clogged, backwashing process will be performed. During this process, the flow is reversed, and treated water is used to clean the filter medium. This backwashing ensures that the filter remains effective without requiring manual maintenance. After backwashing, the system resets itself to start filtering again. If rainwater continues to enter, the system can perform multiple backwashing cycles, ensuring continuous filtration and maintenance of water quality.

The rainwater collecting solution offered by this self-backwashing device is dependable and effective. The technology is highly adaptable to the current building infrastructure while minimizing the use of energy and maintenance needs. It offers a cost-effective approach to maintaining water quality and ensuring a consistent supply for the recharge well.

CHAPTER 5

SUMMARY

5.1 Discussion

Critical issue of water scarcity and rainwater mismanagement by developing sustainable water harvesting techniques tailored for the NUST H-12 campus is addressed. Through a systematic approach, we evaluated existing rainwater harvesting models, conducted comprehensive water quality testing, performed resistivity surveys, and utilized advanced data analytics to inform our strategies.

Our study revealed key findings. The evaluation of the NICE Ground Bore, NICE Backyard Bore, and Volleyball Ground systems showed varying efficiencies, with suggestions for improvements to enhance their performance and capacity. Water quality testing confirmed that harvested rainwater met WHO standards for non-potable uses, supporting its safe utilization for recharging purposes. Detailed resistivity surveys identified optimal sites for new rainwater harvesting infrastructure, guiding the placement of bio retention areas, percolation pits, and roof water harvesting systems. Using IDF curves, we calculated design discharges and selected appropriate pipe diameters, ensuring systems could handle peak rainfall events effectively. Simulations of rainfall runoff demonstrated that the proposed sites could significantly reduce flash flooding and improve water availability. Additionally, we designed an innovative, energy-efficient self-backwashing filtration system to maintain water quality with minimal maintenance.

5.2 Conclusion

The project has laid a strong foundation for sustainable water management at NUST. By optimizing existing systems and implementing new, strategically placed infrastructure, we can significantly mitigate water scarcity issues on campus. Our findings and methodologies provide a replicable model for other urban areas facing similar challenges.

The successful integration of advanced technologies and stakeholder collaboration underscores the project's potential to enhance water resource sustainability. This initiative not only addresses immediate needs but also positions

NUST as a leader in innovative water management practices, contributing to long-term environmental sustainability and resilience.

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