Utilizing the potential of rainwater harvesting for the purpose of lawn-irrigation at NUST-Islamabad

By

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THESIS ACCEPTANCE CERTIFICATE

It is certified that the contents and forms of the thesis entitled **"Utilizing the Potential of Rainwater Harvesting for the Purpose of Lawn Irrigation at NUST-Islamabad"** submitted by **Mr. Inayat Ullah**, Registration No. **00000274738** has been found satisfactory for the requirements of the degree of Master of Science in Environmental Engineering.

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Inayat Ullah Sakhi

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LIST OF ABBREVIATIONS

CDA	**Capital Development Authority**
HEIS	**High Efficiency Irrigation System**
IESE	**Institute of Environmental Sciences and Engg.**
NBS	**NUST Business School**
NUST	**National University of Sciences and Technology**
PCRWR	**Pakistan Council of Research in Water Resources**
PMD	**Pakistan Meteorological Department**
PMO	**Project Management Office**
RCC	**Reinforced Cement Concrete**
RW	**Rainwater**
RWH	**Rainwater Harvesting**
RWHI	**Rainwater Harvesting Irrigation**
RWHIM	**Rainwater Harvesting Irrigation Management**
RWHPI	**Rainwater Harvesting Pressurized Irrigation**
RWT	**Rainwater Harvesting Technologies**

ABSTRACT

Pakistan is one of the water-stressed countries, which is in dire need of effective water management. Underground water resources of the country are depleting due to very high rate of abstraction (65000 MCM annually) in which 69%, 23%, and 8% is used for irrigation, industrial, and domestic purposes. Viewing future scenario (PCRWR) by 2025, there will be very little clean water available in the country. National University of Science & Technology (NUST) located in Islamabad faces 1.7 meter/year depletion of groundwater table (Rashid et al., 2018). Current methods of utilizing water are resulting in both, water scarcity and high-energy consumption. Rainwater is one of the least used sustainable water resources that can reduce pressure on water demand, mitigating the utilization of fresh water for irrigation and domestic purposes. The aim of this study was to determine the suitability and estimate the quantity of rainwater at NUST Business School (NBS) that can be used for landscape irrigation through efficient technology (Drip & Sprinkler Irrigation). To achieve these goals, a model of Rainwater Harvesting Pressurized Irrigation (RWHPI) system was installed at NBS Lawn. Two reinforced cement concrete (RCC) Tanks each of 20,000 gallons were constructed to store rainwater coming from NBS rooftop (4343.22 m^2). Meteorological data and land use map of NBS was collected from Pakistan Meteorological Department (PMD) and Project Management Office (PMO-NUST). Rainwater quality and soil tests were conducted at Institute of Environmental Sciences and Engineering (IESE), NUST. Total required irrigation water for 231 planted orchard trees at NBS Lawn equals to 97,020 L/year. We can collect 6.01×10^6 liters of rainwater per year from NBS rooftop. Cost-Benefit Analysis (CBA) of the RWHPI depict that beyond environmental and social benefits, economically we can save 0.22M PKR/Year. Water requirement for horticulture can be met easily if the same system replicates school wise in overall NUST.

INTRODUCTION

1.1 Water Crisis

Water is the basic need of all living beings. It is essential for growth, biodiversity, environment, agriculture and all types of organisms. Water is at the core of sustainable development and is critical for socio-economic development, energy and food production, healthy ecosystems and for the human survival itself (UN-Global Issues, 2017).

Major part of the groundwater extracted is used for agriculture irrigation (USGS, 2018). Intensive groundwater pumping for irrigation depletes aquifers and can lead to negative environmental externalities, causing significant economic impact on the sector and beyond (OECD, 2019). In many countries, the amount of water consumed has exceeded the annual amount of renewal creating a non-sustainable situation (Choudhury & Vasudevan, 2003).

Pakistan ranked third among the countries facing severe water shortage (IMF, 2015) and agriculture is the major contributor to it as 69% of water is used in agriculture, 23% in industrial usage and 8% for domestic purposes (Khoso and Ansari, 2015). In May 2018, the Pakistan Council of Research in Water Resources (PCRWR) announced that by 2025, there would be very little or no clean water available in the country (Shukla, 2018). It must be noted that while per capita availability in the 1950s was approximately 5000 m^3 per annum, it has now declined to below 1000 m^3, which is an internationally recognized threshold of water scarcity (Aziz et al., 2018). Water resources are limited and/or seasonal which made the experts working in the water sector to search for alternate solution to the water shortage (Thamer et al., 2007).

1.2 Weather Conditions in Twin Cities (Islamabad-Rawalpindi)

Islamabad is 545m above sea level, the climate is warm and temperate. The average annual temperature is 20.3 °C in Islamabad.

Rainwater Harvesting (RWH) experts recommend that at least 70 mm rainfall is sufficient for positive potential rainwater harvesting. The rainfall data acquired from Pakistan Meteorological Department

(PMD) whose observatory is relevantly nearer to the campus, i.e., Zero point, Islamabad. Average Annual Precipitation of the last 12 years is about 1270.2 mm.

The climate of Islamabad is a humid subtropical climate with five seasons: Spring (March–April), summer (May–June), Monsoon (July–September), autumn (October–November), and winter (December–February). The hottest month is June, where average highs routinely exceed 38 °C (100.4 °F). The wettest month is July, with heavy rainfall. The coldest month is January, with temperatures variable by location (PMD).

In Islamabad, temperatures vary from cold to mild, routinely dropping below zero. In the hills there is sparse snowfall. The weather ranges from a minimum of −3.9 °C in January to a maximum of 46.1 °C in June. The average low is 2 °C in January, while the average high is 38.1 °C in June. On 23 July 2001, Islamabad received a record-breaking 620 millimeters of rainfall in just 10 hours. It was the heaviest rainfall in 24 hours in Islamabad and at any locality in Pakistan during the past 100 years (PMD).

1.3 Rainwater Harvesting Technologies

Rainwater harvesting (RWH) is the gathering and storage of rainwater for human consumption from catchment surfaces (rooftops, roads, and open spaces) on which rain has directly fallen, by using ordinary and simple scientific methods (Lancaster and Marshall, 2008).

Harvesting rainwater is not a modern technique. Human beings have been storing rainwater for drinking and non-drinking purposes from the past 4000 years (Boers, 1994; Liaw and Chiang, 2014). Ancient civilizations have developed various runoff control methods and constructed dams and reservoir in urbanized areas (Mays and Antoniou, 2013). Rainwater has become a significant alternative source of water in urban and suburban regions of the developed world (Campisano et al., 2013; Hajani and Rahman, 2014).

1.4 Potential Uses of Rainwater Harvesting

1. The rainwater can be harvested for the betterment of human beings as one of best mitigation to flooded roads, to recharge aquifer, to raise water table and to fulfill the water needs of expanding population.

2. Rainwater can be a good replacement of heavily treated drinking water and other uses of water in daily life (Greenman et al., 1967; Bhatti and Nasu, 2010).

3. Rainwater is used for housing schemes as well. Rooftop RWH is being practiced, to meet potable and non-potable water demand in many areas of China (Li and Gong, 2002; Yuan et al., 2003), India (Goel and Kumar, 2005; Pandey et al., 2006), Namibia (Sturm et al., 2009), Spain (Domènech and Saurí, 2011), Ireland (Li et al., 2010), Singapore (Appan, 1997,1999), South Africa (Kahinda et al., 2007), Taiwan (Chiu et al., 2009; Liaw and Chiang, 2014) and USA (Jones and Hunt, 2010).

4. Rainwater was also harvested by the farmers of Afghanistan, Iran and Pakistan for agriculture irrigation in the third century BC (Fooladman and Sepaskhah; 2004, Marcelo and Enedir, 2011; Rahman et al., 2012).

5. RW can be used for irrigation purpose. Rainwater has the potential to supplement the water requirements, through harvesting and using it during off-season. The system is more useful and beneficial in hilly areas, Urban areas, and the places where mostly Rainfalls (Thamer et al., 2007).

6. If native and desert-adapted plants are used for landscaping, RWH becomes effective tool for water conservation (Thamer et al., 2007). By using RWH system, the provided irrigation water is not taken from storage allocated for municipal water supply. This situation can reduce groundwater exploitation, flooding, to control erosion and to improve water quality by holding storm runoff on the site (on site detention), and cost reduction (Thamer et al., 2007).

7. Rainwater is a clean source of water for plants (free from salt). Limitations of rainwater harvesting are few and easily met by good planning and design. Seeing this all suitability and necessities makes it suitable to Harvest Rainwater (Yitayew, 2016).

1.5 Irrigation Types

Contrary to popular belief, there is no such thing as a "best" irrigation system. The selection of an irrigation system is based on soil, crop, economics, water quality, and management considerations. The Natural Resources Conservation Service (NRCS) National Engineering Handbook (NEH) describes the four major irrigation methods: surface, sprinkler, micro, and sub-irrigation.

1.5.1 Surface Irrigation

Water is applied by gravity across the soil surface by flooding or small channels (i.e., basins, borders, paddies, furrows, rills, corrugations).

1.5.2 Sprinkler Irrigation

Water is applied at the point of use by a system of nozzles (impact and gear driven sprinkler or spray heads) with water delivered to the sprinkler heads by surface and buried pipelines, or by both. Sprinkler

1.5.3 Drip Irrigation/Micro Irrigation

Water is applied to the point of use through low pressure, low volume discharge devices (i.e., drip emitters, line source emitters, micro spray and sprinkler heads, gravity, and low-pressure bubblers) supplied by small diameter surface or buried pipelines.

1.5.4 Sub-irrigation

Water is made available to the crop root system by upward capillary flow through the soil profile from a controlled water table. Each irrigation method and irrigation system have specific site applicability, capability, and limitations.

1.6 Rainwater Harvesting System at NUST Islamabad

Rainwater harvesting pressurized irrigation (RWHPI) model was installed at NUST Business School (NBS), National University of Sciences and Technology (NUST), Islamabad (Fig- 1.1).

Figure 1-1 Rainwater harvesting pressurized irrigation (RWHPI) model installed at NUST Business School (NBS)

The research work relates to determination of the RWH potential and its use for highly efficient pressurized irrigation at the National University of Sciences and Technology (NUST) Islamabad Campus. The system was installed considering the ever-growing requirement of water at the campus.

1.7 NUST Business School (NBS)

A model rooftop rainwater harvesting system was installed at a selected part of NBS to determine the potential of RWH (Fig-1.2).

Figure 1-2 NUST Business School

NUST Business School lies at the center of the university having coordinates latitude: 33° 38' 38" N and longitude: 72° 59' 28" W. The total Area of NBS equals to 32,630.94 m² (PMO), which can be divided into three categories as: Rooftops, Open/Green spaces, and Car parking/Paved surfaces.

A. Rooftops ……......................…………………………………….……4343.22 m^2

B. Car Parking/Paved Surfaces …......................……………………….….8239 m^2

C. Open and Green Spaces………… ……......................……….……21521.42 m^2

We collect rainwater for harvesting only from the rooftop of NBS. The total area of NBS rooftop is 4343.22 m^2.

1.8 NBS Horticulture

The total area of NBS-Lawn equals to 34,103 m^2, from which we have selected only 4120 m^2 for drip and sprinkler irrigation system model study (Fig- 1.3).

Figure 1-3 NUST Business School Lawn

Lawn site was selected based on best suitability for the model study. NBS-Lawn consist of Pine Trees, Fruit trees and landscape (Grass). The total number of trees are 231, in which Fruit trees and Pine trees are 34 and 197, respectively. Average spacing between plants (Plant × Plant) is 4m.

1.9 Objectives of the Study

The main objectives of the study were to:

1. Design a model for RWH storage and distribution system for sprinkler and drip-irrigation.
2. Cost-Benefit Analysis of RWH and its distribution system.

This was a pilot scale project. Based on research findings, NUST may incorporate rainwater harvesting pressurized irrigation (RWHPI) system using clean energy with its all-future developmental activities. Furthermore, the results of the research will be shared with Capital Development Authority (CDA), housing Authorities, and Societies, which may want to replicate it at own.

LITERATURE REVIEW

In today's world, water is becoming scarce in some regions. The problem is increasing with each passing day and threatening the sustainable development, human and health of ecosystem. The pollution of freshwater sources and its depletion globally is alarming. Demand of freshwater has surpassed the resource itself. According to a rough estimate, after every 21 years demand of water doubles (Furumai, 2008).

Who is going to have access to the water, and what are they going to pay for it? Irrigation and drainage engineers will be at the center of some of these controversies. At the very least, engineers will provide the data and models that policy makers will use to answer these questions. As such, engineers should have some familiarity with the value of water and the ways that it can be distributed (Yitayew, 2016).

One of the most important concepts in water resources development is sustainability. The basic premise of sustainability is that natural resources should not deplete over time but should continue to provide the same benefit in perpetuity. Sustainability has defined by law in many states as a 100-year supply of water (Yitayew, 2016).

Annual water availability per capita in developing countries like Pakistan has already declined from 5600 m^3 in 1950s to less than 1000 m^3 in 2014. This situation has placed Pakistan in the list of water deficit countries, adversely affecting its economic growth and wellbeing of the citizens mainly due to water shortage for industry and agriculture Bakhsh and Kanwar .

2.1 Rainwater Harvesting Technique

The inhabitants of those areas which have limited freshwater sources are using a traditional method of collection and storage of rainwater for use during dry seasons. The water is collected from terraces of house, roofs or paved areas specially designed for the purpose (Gikas and Angelakins, 2009). Due to population growth, intensive urbanization, land use transformation, climate change and pollution, this conventional practice of collecting the rainwater presents an attractive solution (Vialle *et al*. 2011). Urban runoff and flooding can be avoided by rainwater harvesting.

Rainwater harvesting is one of the oldest systems and potential of rainwater harvesting at NUST Islamabad has been determined which concludes that quality of rainwater is within the limits of NEQs and can be utilized for potable and non-potable purposes (Gardezi, 2015). Generally harvested rainwater is a clean source of water with less minerals content than well or municipal water (Leib et al., 2020).

Rainwater harvesting is generally defined as concentration, collection, storage and use of rainwater run off for different uses including domestic and agricultural purposes (Gould, 1999). Besides its use for agricultural purposes, it can also be used for human consumption, environmental purposes, other domestic activities, and many other small scale productive activities (Oweis *et al*., 2001).

Rainwater harvesting irrigation (RWHI) system has three main components, i.e. rainwater/ runoff collection catchment, rainwater/runoff storage facility, and a low-cost irrigation system that applies water to the crop area during dry periods (de Trincheria Gomez et al., 2018). Storage system is primary component of rainwater harvesting system (Geraldi & Ghisi, 2017; Leib et al., 2020). Assessment of simulation of rainwater for short-term rainfall time series based on two parameters, i.e. Optimal rainwater tank capacity and potential for potable water savings (Geraldi & Ghisi, 2017).

2.2 Rainwater Harvesting Irrigation

RWHI management is a subset of rainwater harvesting technologies and practices that allow concentrating and storing rainwater to be used for off-season small-scale irrigation of high-value crops in arid and semi-arid areas. Thus, off-season RWHI management is specifically meant to conduct off-season small-scale agricultural activities, especially kitchen gardens, trees and high-value horticultural crops along riverbanks (de Trincheria Gomez et al., 2018).

Compliance to irrigation requirements from RWH affects through high evapotranspiration rate (ET_r) and long-enough dry periods, then an alternate water source needed to supplement irrigation from the RWH system. Existing home wells or municipal taps, while reducing the continued competition with home water uses can supplement RWH (Leib et al., 2020).

RWHI with gravity system has the lowest initial cost with the lowest maintenance since there are no high-tech components to fix or replace. The solar powered and battery pumped RWHI system had the highest initial cost and the highest maintenance cost. Several electrical problems encounters in this approach.

RWHI by solar transfer pumping had less initial and ongoing cost, and it is easier to understand how the electrical components worked together. Solar transfer pumping seemed to provide a better balance of cost, complexity, and operational characteristics (Leib et al., 2020).

High Efficiency Irrigation System (HEIS) is required in compliance with needs i.e., drip irrigation and sprinkler irrigation. Both the systems are considered to have higher irrigation efficiency of 70 to 80% for sprinkler and 80 to 95% for drip irrigation system (Bakhsh & Kanwar).

The ability of the RWH system to supply enough water at a sufficiently low cost to be comparable with alternative water supply options is dependent on the local distribution of household types. It hangs on precipitation patterns, and landscape irrigation needs, as well as the use of equipment at the individual household level that is inexpensive to purchase, install, operate, and maintain. If the purpose of the water supplied by the RWH system is limited to outdoor landscape irrigation and above ground cisterns are used for water storage, the costs of equipment and its installation, operation, and maintenance can be kept low (Wurthmann, 2019)

In some semi-arid areas, where rainfall is scarce and insufficient to sustain dryland crop production, rainwater harvesting can form the basis for irrigation in order to improve food security. Some rainwater harvesting and irrigation technologies that are currently in use include roof catchment systems, rock catchment systems, ground catchment systems, small dams and sand dams (Wuta et al., 2018).

Investing in rural water development through RWHI may potentially reduce poverty and improve livelihoods through providing water for agriculture and livestock in arid and semi-arid regions. Several factors that include inadequate funding, lack of technical knowledge, and lack of appropriate technologies have affected upscaling of these technologies. It is important to conduct capacity building in RWHI in schools, technical colleges and universities to boost institutional capacities (Wuta et al., 2018). Best practices for RWHI management at household level are upgraded on-farm ponds and/or low-cost roof catchments connected to manual pumping systems and low-cost drip irrigation kits (de Trincheria Gomez et al., 2018).

The government should coordinate development and institutional reforms to bring all irrigation functions under a single and stronger government department. One of the greatest impediments to uptake of RWHI technologies is the huge costs associated with it; therefore, there is need to enhance access to institutional support services such as credit facilities and external funding to assist smallholder farmers in establishment. Community-based RWHI systems present higher cost-efficiency values than the household-based RWHI systems (de Trincheria Gomez et al., 2018). In addition, science and technology actors should play a major role in availing proven RWHI technologies to farmers at affordable prices (Wuta et al., 2018).

RWHI is one adaptive measure that can be taken in order to give sustainable water source use efficiently, regardless of its numerous advantages and high potential to alleviate impacts of climate change, its applications are still limited (Kahinda *et al*. 2010).

2.3 Irrigation Efficiency

Irrigation efficiency (IE) is the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation (surface, sprinkler, or drip irrigation) (DFID, 2004). All the four types of agriculture irrigation system have various efficiency given as in Table 2.1.

Table 2-1 Potential Efficiencies of agricultural irrigation systems (Solomon 1988)

S.No	**Irrigation Type**	**Irrigation System**	**Potential on Farm Efficiency**
01	**Gravity (Surface)**	Level Basin	80-90 %
		Furrow	65-75 %
		Border	70-85 %
02	**Sprinkler Irrigation**	Hand move or Portable	65-75 %
		Side roll wheel line	65-75 %
		Travelling big gun	60-70 %
		Center Pivot	75-90 %
		Linear Move	75-90 %
		Solid Set or Permanent	70-80 %
		LEPA (Low Energy Precise Application)	80-95 %
03	**Micro Irrigation**	Drip Irrigation	80-90 %

Pressurized irrigation systems (sprinkler and micro) are assumed to have higher application efficiencies than surface irrigation systems. Surface irrigation system application efficiency is decreased by variation in soil permeability and by variation in ponding time across the field. Runoff also decreases efficiency for surface irrigation systems (Yitayew, 2016).

2.4 Sprinkler Irrigation

In this method water is sprayed in the air and allowed to resemble rainfall (Fig- 2.1). The spray is developed by the flow of water under pressure through nozzles (James, 1988).

Figure 2-1 Sprinkler's Installed at NBS Lawn NUST.

2.4.1 Advantages of Sprinkler Irrigation

- Elimination of the channels for conveyance, therefore no conveyance loss.
- Suitable to all types of soil except heavy clay.
- Suitable for irrigating crops where the plant population per unit area is very high.
- It is most suitable for oil seeds and other cereal and vegetable crops.
- Water saving.
- Closer control of water application convenient for giving light and frequent irrigation and higher water application efficiency.

- Increase in yield.
- Mobility of system, component is easy.
- May also be used for undulating area.
- Saves land as no bunds etc. are required.
- Influences greater conducive micro-climate.
- Areas located at a higher elevation than the source can be irrigated.
- Possibility of using soluble fertilizers and chemicals.

2.4.2 Disadvantages of Sprinkler Irrigation

- Incurs high operation expenses due to the energy needed for pumping, labor and relatively large investment in equipment: sprinklers and pipes.
- Sensitivity to wind, causing evaporation losses.
- The unavoidable wetting of foliage in field crops results in increased sensitivity to diseases.
- Debris and sediments can cause clogging.
- Capital cost is high with greater operational costs due to higher energy requirements.

2.5 Drip Irrigation

Drip or trickle irrigation is a type of irrigation that slowly applies small amount of water to part of the plant root zone (Connell, 2003)(Fig- 2.2).

Figure 2-2 Drip Irrigation system Installed at NBS Lawn NUST

2.5.1 History of Drip Irrigation

It has been used since ancient times when buried clay pots were filled with water, which will gradually seep into the grass. Modern drip irrigation began its development in Afghanistan, 1866 when researchers began experimenting with irrigation using clay pipes to create combination of irrigation and drainage systems (Afnan Babiker, 2013). In 1913, E.B. House at Colorado State University succeeded in applying water to the root zone of plants without raising the water table. Major improvement has been achieved by introduction of drip irrigation through the usage of plastic pipes. This led to introduce various types of system components began in Europe and America. The first drip type, which called (Dew hose), was developed by Richard Chapin (Wikipedia 2005).

2.5.2 Development of Drip Irrigation

Originally, drip irrigation was developed as sub-surface irrigation applying water beneath the soil surface. The first such experiment began in Germany in 1869, where clay pipes were used in combination of irrigation and drainage systems (Jensen, 1993).

The first reported work in the U.S.A. was made by house in Colorado in 1913. Subsequent to 1920; perforated pipes were used in Germany which made this concept feasible. Since then, various experiments have centered on the development of drip systems using perforated pipes made of various material (Jensen, 1993). In 1925 – 1932, some experts in France and Russia used sub-surface drip irrigation. In England it was used between1945 – 1948 to irrigate tomato plants in green house. Technological development of plastic pipes after the Second World War, made the use of drip irrigation system practical. Micro – irrigation research began in Germany about 1860, and in the 1940s it was introduced to England especially for plastic pipes and the development of emitters in the 1950s, it has since become an important method of irrigation in Australia, Europe, Japan, Mexico, South Africa and United States (Schwab *et al.*, 1981).

2.5.3 Advantages of Drip Irrigation

Drip irrigation system offers special agronomical, agro-technical and economic advantages for efficient use of water and labor, these include:

- A major advantage of drip irrigation systems is the close balance between applied water and crop evapotranspiration that reduces surface runoff and deep percolation to a minimum (Ceunca, 1989).
- For perfect drip irrigation system design, about 40% of the irrigation water is saved with an application efficiency of 85% 95% as compared with other irrigation systems.
- Trickle systems produce higher ratio of yield per unit area and yield per unit volume of water than typical surface or sprinkler irrigation systems (Ceunca, 1989).
- Lower pressures mean reduced energy for pumping.
- High levels of water management are achieved because plants can be supplied with precise amounts of water, (Marr and Rogers, 1993).
- Providing better salinity control and better disease management since only the soil is wetted whereas the leaf surface stays dry (Hanson and May 2007).

- Utilization of saline water resources. With drip irrigation, low soil moisture tensions in the root zone can be maintained continuously with frequent applications. The dissolved salts accumulate at the periphery of the wetted soil mass, and the plants can easily obtain the moisture needed. This enables the use of saline water containing more than 3000mg/liter total dissolvent substances which would be unsuitable for use with other methods (Phocaides, 2001).
- Labor and operating costs are generally less, and extensive automation is possible.
- Water applications are precisely targeted. No applications are made between rows or other non-productive areas.
- Field operations can continue during irrigation because the areas between rows remain dry, resulting in better weed control and lower Production costs.
- Fertilizers can be applied efficiently to roots through the drip system.
- Watering can be done on varied terrains and in varied soil conditions.
- Soil erosion and nutrient leaching can be reduced (Marr and Rogers, 1993).
- Frequent or daily application of water keeps the salts in the soil water more dilute and leached to the out limits of the wet zone to make the use of saline water more practical (Jensen ,1993).
- Use of trickle irrigation is practical even in fields that have 5%-6% slope without erosion (Elobeid, 2006).
- Trickle irrigation needs no leveling, no drainage and no other field operations like ridging.

2.5.4 Disadvantages of Drip Irrigation

Drip irrigation on the other hand, has a number of disadvantages which are as follows:

- Expense, initial cost can be more than overhead system, (Phocaides, 2001).
- Clogging of emitters which occurs when water is not properly filtered and the equipment not properly maintained, (Buks *et al,* 1977).
- The sun can affect the tubes which damage them and shortening their usable life.
- Drip irrigation might be unsatisfactory if herbicides or top-dressed fertilizers, which need sprinkler irrigation for activation.
- Germination problems: In lighter soils sub-surface drip may be unable to wet the soil surface for germination, which requires careful consideration of the installation depth.

- Waste of water, time, and harvest, if not installed properly, this system requires careful study of all the relevant factors like land topography, soil, water, crop and agro-climatic conditions and suitability of drip irrigation systems and its components.
- Salinity: salts applied with irrigation water may build up in the root zone usually at the edge of the wetting pattern.

2.6 Irrigation Equipment and Joining Techniques

According to (Phocaides, 2001) irrigation system installation consists of various types, fittings, valves, and other equipment depending on the kind of the system and the type of installation. Most installations have the same structure, and relatively small range of equipment can meet the requirement of a whole region. Irrigation equipment includes:

- Pipes
- Pipe connector (fittings)
- Flow control devices
- Filters
- Fertigation equipment
- Water emitters sprinkler
- Automation equipment
- Water lifting devices.
- Control head

2.6.1 Pipes

The pipes are the basic components of irrigation network. There are various kinds and types available in many pressure ratings and in different sizes (diameter). They are mainly made of rigid Polyvinylchloride (PVC) and Polyethylene (PE). Quick coupling light steel pipes and lay flat hoses are used in smaller scale. As mentioned by (Ali, 2003) the pipes mainly in use for farm land irrigation system are:

- Rigid polyvinylchloride (PVC) pipes.
- Polyethylene pipes.
- Steel threaded pipes.
- Quick coupling aluminum pipes.

2.6.2 Flow Control Devices

A control appliance device installed in a fluid supply system, in order to ensure that the fluid reaches the desired destination, at the proper time, in the required amount (flow rate), and under the right pressure. Fluid devices as mentioned by (Ali, 2003) can be divided into three main classes:

- Directional devices (Meter).
- Measuring devices or valves.
- Auxiliary devices which include:
- Shut-off valves or stop valves.
- Check valves.
- Regulating valves.
- Meters.
- Pressure gauge.
- Safety valves.

2.7 The Basic Parts of Drip System

2.7.1 Isolation Valves

Isolation valves are manually operated used for infrequent shut-off of water. They are located at the water source (Stryker, 2001) so water can be shut off during non-irrigation season or may be installed for shutting down the whole system for repair.

2.7.2 Pumping Station

It consists of the power unit (internal combustion engine or electric motor) and a centrifugal deep-well, or submersible pumps.

2.7.3 Pressure Gauge

It is required for properly monitoring the operation of pressurized irrigation systems. It allows quick check to ensure that the system work at the correct pressure.

2.7.4 Main Line

It is the largest diameter pipeline of the network that goes from the water source to the control valves, which enable conveyance of the flow velocity and friction losses so as to deliver water to the sub-main line. It is usually made of galvanized steel, copper, PVC, which is not damaged by the sun light. So, the main line should be buried or protected or apply several coats of paint if it is above ground. The sizes of these pipes range from 63 – 160 mm (2 – 6 inches), which depends on the area of the farm and the design of the system (Phocaides, 2001).

2.7.5 Fittings

These are an array of coupling and closure devices which are used to construct a drip system including connectors, tees, elbows, plugs and end caps. They are of many types (Wilson and Bauer 1998).

2.7.6 Control Valves

Control valves are those devices that turn on and off the water to individual (circuits) or areas of the yard that are irrigated to separate from one to another. They can be automatic (electric power using a solenoid) or manually operated. Most drip irrigation systems will need at least two different types: an emergency shut-off valve and a control valve.

2.7.7 Sub Main Line

Are smaller diameter pipelines which range from 16 to 50 mm (0.5 -1.5 Inches). It is extended from the main line, to which the flow system is diverted for distribution to the various plots (Phocaides, 2001).

2.7.8 Filters

A filter unit which cleans the suspended impurities in the irrigation water so as to prevent blockage of holes on passage of drip nozzles is a 12-essential part of the drip irrigation system. The filtration of the irrigation water is essential to avoid blockage damage to the drip irrigation emitter. The types of filter used depended on the kind of impurities contained in the water and the degree of filtration required on the emitter. Their size should be the most economical with the lowest friction losses ranging from 0.3 – 0.5 bar. The following types of filters are available:

2.7.9 Gravel Filters

These filters also called media filter, are closed cylindrically tanks, which contain gravel grain of 1.5-3.5 mm or a basalt sand filter bed. Where the irrigation water source is an open reservoir, they are installed at the beginning of the head control of the system. Water entering the tank from top passes through the gravel bed, which traps the large particles of unbroken organic matter, mostly algae and exits through the outlet at the bottom of the tank. They are equipped with the necessary inlet, outlet and drain valves, and a back-flushing arrangement.

The filter body is epoxy coated metal minimum 8.0 bars PN and is 50 – 180 cm high and 40 – 100 cm in diameter, they are available in threaded connection sizes of 2.54 – 20.32 cm (Phocaides, 2000).

2.7.10 Hydro Cyclone (Sand Separator) Filters

These are closed conical metal tanks placed at the beginning of the head control unit where needed. They separate sand or silt from well or river water through the creation of centrifugal force by a vortex flow inside the filter. This force drives the solids downward to a collecting chamber attached below and lets the clean water out. They are epoxy coated, PN 8.0 bars, and are available in threaded connection sizes of 2.54 – 20.32 cm (Phocaides, 2000).

2.7.11 Screen type Filter

These are used for final filtration as a safeguard for either moderate quality water or following a primary filtration with gravel or hydro cyclone filters. They are installed at the end of the head control before the main pipeline.

They are made of epoxy coated metal or high engineering plastics in various cylindrical shapes (horizontal on-line, vertical angle, etc.), and are equipped with interchangeable perforated filtering elements, inlet, outlet and drain valves and pressure (PN) of 8.0 bars. The degree of filtration ranges from 60 – 200 meshes.

2.7.12 Lateral Line

It delivers water to the emission devices from the sub-main or direct from main line (Joseph, 1981). Its diameter is 13, 16, or 22 mm.

2.7.13 The Emitters

They are devices that control how fast the water drips out onto the soil.

Most of them are small plastic element that either screw or snap onto a drip tube or pipe. Some models are preassembled as of a tube with build-in emitters (Self-cleaning) Emitters are divided by type of flow in the following:

- Orifice emitter.
- Vortex emitter.
- Long-path emitters.
- Twin-chamber tubing.
- Compensating emitters.

- Flushing emitters.
- Micro or spaghetti tube (Ismail, 2002).

2.7.14 Hydraulics of Emitters

Emitters are devices which allow water to flow from supply to the soil.

The hydraulic characteristic of the emitters determines the rate water flow through the emitter. Many types of emitters have been manufactured to overcome hydraulic limitations. (Karmeli and Keller, 1975) classified emitter characteristics as follows:

- Flow regime.
- Pressure dissipation.
- Lateral connection.
- Water distribution.
- Flow cross – section.
- Cleaning characteristics.
- Pressure compensation.
- Construction material.

The hydraulic characteristics of each emitter are directly related to the mod of the fluid motion (flow regime) inside the emitter as characterized by the Reynolds number (Re) [$Re = VD/\gamma$].

Where V is velocity, D is diameter and γ is kinematic viscosity.

2.8 Hydraulics of Lines

The flow regime throughout a drip irrigation system is hydraulically steady, spatially varied pipe flow with lateral out flows. The total discharge in the distribution networks (laterals sub-mains and main lines). Do not decreases with respect to distance from the pump, (Wu and Gitlin, 1979). The laterals and sub-mains have similar hydraulic characteristics and are designed to maintain a small pressure variation along the lateral line. The main line is designed in terms of input pressures and minimal required pressures at any sub-main line (Howell *et al.* 1980). Drip irrigation distribution lines are normally considered to be smooth pipes and either the Darcy–Weisbach or Hazen William's equation can be used to compute friction losses for the pipelines. The Darcy – Weisbach equation is:

$H_f = 6.38 \, FL \, D^{-5} Q^2$…………………………………………………………………… (2.1)

Where:

H_f = the pipe friction loss (m).

L = the pipe length (m).

D = the inside diameter (mm).

F= A dimension less friction factor.

Q = Pipe flow rate (L/h).

An acceleration of gravity of 9.81m\sec^2 was assumed in this equation which proposed a simplified form of Darcy- Weisbach equation as:

$H_F = 0.465 \, L D^{-4.75} Q^{1.75}$…………………………………………………………...…... (2.2)

This equation incorporates a friction factor estimated from the Blasius Equation for smooth pipes with water temperature of 20 ºC.

The empirically developed relationship.

2.9 Drip Irrigation System Design

Drip irrigation system are usually designed and managed to deliver frequent light application of water to wet only a portion of the soil surface. A reasonable design objective for widely spaced crops is to wet at least one-third and as one- half of the potential horizontal cross-sectional area of the root system. However, in closely spaced crops with rows spaced less than 1.8 m a part, the percentage of the wetted area often reaches 100% (Keller and Bailer, 1990), (Elobeid, 2006) and (Michael, 1978) stated that the general information required for designing a drip irrigation system is as follows:

2.9.1 Water Source

The source of water is usually a well or a tank storing rainfall runoff. This should be viewed in terms of amount, quality, and availability.

2.9.2 Types of Crops

Different crops require different plant spacing and irrigation requirement.

The general layout of the system and specially the emitters will depend on the type of the crop.

2.9.3 Topographic Condition

It is necessary to know the general land slope to determine the size and the location of main and sub main lines and in the calculation of the total dynamic head necessary for selection of the size of the pumping unit.

2.9.4 Soil

The soil infiltration rate, water holding capacity, texture and structure, and bulk density must be known when selecting emitter type and determining spacing and setting up irrigation schedules (Frequency of irrigation and amount).

2.9.5 Climatic Records

The climatic records are needed to calculate the crop water requirement in various seasons of the year.

The main line design is based on the input pressure, the required pressure, and the slope of the energy gradient line that elicits a total energy higher than that required at any sub-main for irrigation (Mohtar 1995). A drip irrigation system is made by combination of different sizes of plastic pipes. Any one of the following empirical equations could be used to estimate the loss of head due to friction in a drip irrigation line:

Blasius equation:

$$F = \frac{0.316}{RE1/4} \quad \ldots\ldots (2.3)$$

Where:

F= Friction coefficient Re = Reynolds number.

Hazen-William's equation:

$$H_F = \left(\frac{Q1.852}{D4.871}\right) L \quad \ldots\ldots (2.4)$$

Where:

H_f = Friction loss in m

Q = Total discharge in the main pipe, lit./sec.

L = Length of the pipe section, m.

D = inside diameter of the lateral, cm, or m

Equation (2.4) is frequently used to compute the energy of a main line section. Hydraulically, the pressure variation along a lateral line will cause an emitter flow variation along the lateral and pressure variations along a sub-main will cause a lateral line flow variation (into each lateral line) a long a sub main. For the most used emitters and assuming turbulent flow in the laterals, the emitter flow (or line flow for sub-main) and the pressure head can be expressed by the following function:

$$Q_i = C\sqrt{h_i} \qquad (2.5)$$

In which:

Qi = Emitter flow (or into lateral for sub- main) at the section.

C = Coefficient.

hi = pressure head at the (i^{th}) section.

The way of computing the emitter flow variation is by comparing the maximum emitter flow with the minimum emitter flow. The one which is commonly used defines:

$$Q_{var} = (q_{max} - q_{min}/q_{max}) \qquad (2.6)$$

In which:

Q_{max} = is the maximum emitter flow.

Q_{min} = is the minimum emitter flow.

$$H_{var} = (h_{max} - h_{min}/h_{max}) \qquad (2.7)$$

In which:

H_{max} and H_{min} the maximum and minimum pressure head, respectively, along the lateral (or sub main).

In drip irrigation design, the design criteria are generally based on an emitter flow variation of less than 20% percent for lateral line, and flow variation of less than five percent (about ten percent pressure variation) for sub – main (Michael, 1978).

2.10 Evaluation of Drip Irrigation System

Drip irrigation can be applied for the following research topics and objectives:

- Optimal soil moisture for crop growth.
- Water use by different crops under drip irrigation.
- Improved crop yield and quality.

- Unsaturated soil water movement.
- Irrigation water quality, movement, and distribution of salt in root zone.
- Interaction of irrigation and application of fertilizer on crop growth.
- Irrigation system design and management (Michael, 1978).

2.11 Drip irrigation system uniformity:

The efficiency of trickle irrigation system depends on the uniformity with which water is discharged from the emission devices. The major factors affecting uniformity are the design characteristics of the emitter, pressure difference in the system due to friction losses, elevation, and clogging, (Solomon, 1979).

2.11.1 Distribution (Emission) uniformity

To determine whether a system is operating at acceptable and economic efficiency, the uniformity of distribution in the central portion of the field should be evaluated. Using the system and low one-quarter average catch rates from the sample test flowing equation is suggested by (Merriam and Keller, 1978).

$$D_u = q_{25}/q_{av}*100 \qquad (2.8)$$

Where:

Du = Distribution (Emission) uniformity (%).

q_{25} = Average rate of discharge of lowest one- fourth of the field data of emitters discharge readings (L/h).

q_{av} = Average discharge rate of all the emitters checked in the field (L/h).

2.11.2 Coefficient of Uniformity

One of the widely used is Christiansen uniformity coefficient (Mosh, 2006):

$$C_u = (1-\Sigma x)/Mn*100 \qquad (2.9)$$

Where:

Cu = Coefficient of uniformity.

Σ_x = variation from mean of the emitter discharge reading.

M= Mean of the emitter discharge readings (L\h).

N= Number of emitters.

2.11.3 Scheduling Uniformity

In drip irrigation, the soil volume in the root zone is only partly wetted and the availability of moisture is restricted. The soil moisture depletion should not exceed 40% of the available soil moisture in the late growing stages of vegetables and fruit trees, and 20 – 30 % in the early stages of vegetable. However, in order to obtain higher yields, the common practice is to irrigate every day at the later stages. Proper irrigation scheduling can be arranged by using tension meters to indicate the soil moisture tension in the root zone (Phocaides, 2001). Irrigation scheduling involves two decisions when to irrigate (timing) and how much to apply quantity. These decisions are critical to the management of any irrigation system. The concept of drip irrigation implies a rather high irrigation frequency compared to conventional methods (Howell *et al.*1980).

Scheduling uniformity shows the efficiency of the system. Scheduling uniformity can be determined by the following equation:

$$S_u = (1/D_U) \quad \text{……………………………………………………………………………} \quad (2.10)$$

Where:

Su= Scheduling uniformity.

Du= Emission uniformity.

2.11.4 Coefficient of Variation (C_V %)

In drip irrigation, the design criteria are generally based on an emitter flow variation of less than 20% for lateral line, and flow variation of less than 5% (about 10% pressure variation) for submain (Michael, 1978).

$$Cv = (S_d /X)\ 100 \quad \text{……………………………………………………………...………...} \quad (2.11)$$

Where:

Cv = Coefficient of variation

S_d = Standard deviation depths of water of all catch cans (mm).

X = Mean depths of water of all catch cans (mm)

2.11.5 System Capacity

System capacity depends on the irrigation application rate, time to complete irrigation and interval between irrigations. (Wu, 1975) suggested an equation to calculate the system capacity as follows:

$Q = I_g \times A \div T$... (2.12)

Where:

Q: Drip irrigation system capacity (m^3/h).

I_g: gross irrigation water requirement (m).

A: Global area to be irrigated (m^2). T: Irrigation time (h).

2.11.6 Irrigation Application Depth

For most irrigation areas, the depth of water application per irrigation turn is assumed to equal the readily available soil water that can be stored in the root zone. The capacity of the soil profile to store water for crop use depends on the soil type and the effective rooting depth. A high storage capacity within the root zone indicates a relatively high effectiveness (Ghassemi *et al*. 1995).

2.12 Soil moisture contents

The soil moisture measurement and capacity of soil to store water is important to verify that the proper amount of water is being applied (Abdalla, 2003). It is expressed by a given amount of water contained in a unit mass or volume of soil or by stress or tension under which the water is held by the soil, (Michael, 1978).

2.12.1 Methods Used for Soil Moisture Measurement

- Soil feel test.
- Gravimetric method.
- Tension meters.
- Electrical resistance blocks.
- Neutron probe method.

Using the gravimetric method of sampling, the soil moisture content can be calculated according to the following equation:

Soil moisture content% = $(W_w - W_d / W_d)$ 100... (2.13)

Where:

W_w: Mass of wet sample.

W_d: Mass of oven dry sample.

2.12.2 Soil Moisture Related to Drip Irrigation System

The distribution pattern of soil water resulting from trickle sources can be very different from those resulting from more conventional modes of irrigation (Abdalla, 2003). One of the most important considerations in the design of trickle system is the volume of soil wetted by a single emitter. This must be known in order to determine the total number of emitters required to wet a large enough volume of soil to ensure that the plant's water needs are met (Risse and Chesness, 1989).

2.12.3 Soil Wetting Pattern

A basic need for better drip irrigation systems is information about the moisture distribution pattern, shape and volume of soil wetted by emitter (Levin *et al*, 1979). The volume of wetted soil represents the amount of water stored in the root zone. Its depth should coincide with rooting depth while its width should be related to the spacing between emitters. One possibility for controlling the wetted volume of a soil is to regulate the emitter discharge rate according to the soil hydraulic properties, (Bresler, 1978) (Lubana and Narda, 2001). The wetting front is an important factor in drip infiltration, indicating the boundaries of the wetted soil volume (Bresler, 1978). A simple technique known as the pit method was developed by (Battam *etal.*2003) for design and management of drip systems. Soil texture is an unreliable predictor of wetting and for adopting different spacing of emitters. For different soil texture, site-specific information on soil wetting is required (Thorburn *et al*, 2003). Under given climatic conditions, the effect of soil type on the depth-width-discharge combination is influenced by water holding capacity and hydraulic conductivity of the soil, (Zur, 1996).

The wetting pattern with Surface drip irrigation cannot be affected only by irrigation management, but also Surface drip irrigation design aspects such as emitter spacing and drip line depth. Dripper function can also be modified after installation. In one study, heterogeneity of the soil in the neighborhood of a subsurface emitter that had been disturbed by farm equipment resulted in low emitter flow, leading the authors to suggest using soil conditioners to Improve and stabilize the soil structure around the dripper the soil moisture should be managed, (Shaviv and Sinai, 2004). The wetting pattern has also been enhanced by the addition of plastic barriers beneath the drip line (Brown *et al.,* 1996) (Charlesworth and Muirehead, 2003).

2.13 Crop Water Requirement (CWR)

Crop water requirement under trickle irrigation systems is different from crop water requirement under surface and sprinkler irrigation systems because the field wetted area is reduced, resulting in less evaporation from the soil surface.

Most methods of estimating crop water requirement provide estimates of Evapotranspiration which probably contain a significant soil evaporation Component (Doorenbos and Pruitt, 1977) (Gangopadhayaya, *et al.*, 1966) and (Jensen, 1974). Crop water requirements are usually expressed in units of water volume per unit land area (m3 /ha), depth per unit time (mm/day), (Jensen, 1983). Crop water requirement, which is equal to crop evapotranspiration can be calculated according to the following equation:

$$ET_c = ET_o \times K_c \quad \text{(2.14)}$$

Where:

ET_c = Crop Evapotranspiration (mm/day).

ET_o = Reference Crop Evapotranspiration (mm/day).

K_c = Crop Coefficient

2.14 Orchard Trees Water Requirements

In year one with a canopy diameter of 0.5 m, apply 3 liters per tree in winter. This increases to 12 liters, 30 liters and 60 liters in years two (canopy diameter of 1.0 m), three (canopy diameter of 1.5 m) and four (canopy diameter of 2.0 m). Rates in spring (x 2), summer (x 2.5) and autumn (x 1.5) are higher than those in winter. Maximum water use in year four in summer would be 160 liters per tree. Irrigate two to three times a week in sands and one to two times a week in heavy clays. Mulching can assist water conservation, particularly in the absence of irrigation (FAO-UN).

Table 2-2: Water Requirements for Orchard Trees.

Season	Winter	Spring	Summer	Autumn
Water Requirements	60 L	120 L	150 L	90 L
Water requirements per week/season	5 L	10 L	12.5 L	7.5 L
Water Required/Year/Plant	420 L/Year/Plant			

MATERIALS AND METHODS

3.1 Site Selection for Rainwater Harvesting

NUST Business School (NBS), National University of Sciences and Technology (NUST) Islamabad site was selected, for RWH Model Study. The site was selected due to passage of rainwater drainage channel through its lawn. Hence, making it an appropriate site for the collection of rainwater and its usage for irrigating the same lawn. (Fig-3.1) and (Fig-3.2).

Figure 3-1 NUST Business School Lawn (Inside Fence)

Figure 3-2 NUST Business School Lawn (Outside Fence)

3.2 Installation of Solar System for Drip Irrigation

Drip irrigation system requires low pressure to run. Therefore, solar panels were installed to run the drip irrigation system. For this process, a setup (Fig- 3.3) was developed which included a solar water pump with specifications as:

- Submersible Stainless-steel pump with controller (BLDC Technology)
- Voltages 24 V DC
- Head 50 m
- Outlet 1 inch

This solar water pump runs on a single solar panel having specification as:

- Solar PV Panels Poly grade A (Poly out peak power)
- (PM) > 250 watt

- Max: System Voltage = VMP 36 V
- Max: Power Current = IMP 8.1 A
- 25 years efficacy warranty

Therefore, we installed the model, which fulfilled the requirements of Drip irrigation, and enough pressure was generated. Moreover, this made the model more environmentally friendly.

Figure 3-3 Drip Irrigation Setup at NBS Lawn

3.3 Project Bidding and System Installation

Installation of model completed successfully. The overall system was installed in two phases. In the first underground RCC (Reinforced cement concrete) storage tanks in NBS-lawn were constructed by Project Management Office (PMO). In the second phase Drip and Sprinkler irrigation system was installed.

Contract was awarded based on competitive bidding, in which different directorate/Offices of NUST were involved. At the end contract was awarded to M/s Flow Engineering Technologies. Installation of the complete system took around one month.

3.4 Construction of Storage Tanks

Two RCC tanks were constructed in the middle of NBS lawn in the way of water flow channel. Each tank has the water storage capacity of 20,000 gallons. Therefore, the maximum of 40,000 gallons of rainwater can be stored in the tanks at a time. Dimensions of the storage tanks are as follows:

- Length = 18 ft.
- Width = 18 ft.
- Height = 8.5 ft.

The total cost of RCC Tanks equaled to 2.7 Million PKR. Each tank has a separation wall designed in the middle, which reduced construction cost (Fig- 3.4).

Figure 3-4 Construction process of RCC Storage Tank

3.5 Material Purchased for Drip and Sprinkler Irrigation at NBS-NUST

Purchased accessories for the project are listed in Table: 3.1 is given in Part (A), Part (B), Part (C), and Part (D) as;

Table 3-1: Purchased Accessories for the Project

Part A: Solar Panel, Pump and Assembly etc. for Pumping			
Sr. No.	Item Description	A/U	Quantity
01	Submersible Stainless-steel pump with controller (BLDC Technology) Voltages 24 V DC, Head 50 m head 1 Inch Outlet. AC, Head 80 m, 01 Inch Outlet.	N/A	(1+1)02
02	Solar PV Panels Poly grade A (Poly out peak power (PM) > 250-watt, Max: System Voltage = VMP 36 V, Max: Power Current = IMP 8.1 A with 25 years efficacy warranty.	N/A	(2+2)04
03	Base Structure (GI) for Solar Panels	N/A	(2+2)04
04	DC Cable 6 mm	100 ft	01
05	3 Core, 4 mm cable for Pump	100 ft	01
06	DC/AC breakers and DP box for set up	N/A	(2+2)04
07	Base frame for coupling of motor and pump	N/A	(1+1)02
08	Installation and Operation of Setup	N/A	
09	Earthling with Copper rods	N/A	02

Part B: Setup for Sprinkler System					
Sr. No.	Item Description	Make Standard	Specifications	Quantity	A/U
		1. PVC/PE Pipe			
01	PE Pipe	PN10	40 mm	280	Meters
		2. Filtration and Fertigation			
01	Disc Filter	Imported/ISO 9912 or Equivalent	10 m3 / hr.	01	Number
02	Venturi Assembly	Imported/ ISO 15873 OR Equivalent	1 Inch	01	Number
		3. Emitting System/ Laterals			
01	Drip Line (Plain Dripper)	Local	16 mm	800	Meter
02	Drippers	Imported/ ISO 9260 or Equivalent	8 LPH	450	Numbers
		4. Sprinklers			
01	Mini Sprinklers	S16	1400 lph	04	Numbers
		5. Drip Fitting			
01	GTO	Imported ISO/Equivalent	16 mm	40	Number
02	Joiner	Imported ISO/Equivalent	1 inch	01	Number
03	End Plug	Imported ISO/ Equivalent	16 mm	40	Number

6. ***Valve system Monitoring Equipment's***					
01	PVC Ball Valve	Imported ISO/ Equivalent	1.5 SHD-80	3	Number
02	Air release Valve	Imported ISO/ Equivalent	1 Inch	01	Number
03	Pressure Gauge	Any ISO or Equivalent	2.5-inch dia (1-10 bar)	02	Number
04	Flush Valve	Imported ISO/ Equivalent	40 mm	02	Number
05	Hand Valve	Local	2 inches for By pass	01	Number
06	NRV (PN-16)	PN-16	Kitz, Local, Brass	02	Number
07	Flow Meter	Imported	02	01	Number

Part C: Setup for Drip Irrigation System				
Sr. No.	Items Description	Make Standard	Specifications	Quantity
01	PE Pipe	PN10	40 mm	169
01	Disc Filter	Imported/ ISO 9912 or Equivalent	10 m3 / hr.	01
02	Venturi Assembly	Imported/ ISO 15873 or Equivalent	1 inch	01
01	Drip Line Plain	Local	16 mm	1200
02	Dripper	Imported/ ISO	16 mm	8 LPH
01	GTO	Imported/ ISO	16 mm	40
02	Joiner	Imported/ ISO	16 mm	40
01	PVC Ball Valve	Imported/ ISO	1.5-inch SHD	01

02	Air Release Valve	Imported/ ISO	1 inch	01
03	Pressure Gauge	Imported/ ISO	2.5-inch dia	02
04	Flush Valve	Imported/ ISO	40 mm	03
05	Handle Valve	Local	2 inches bypass	01
06	NRV (PN-16)	Kitz, local.	2 inches	01
07	Flow Meter	Imported	2 inches	01
01	PVC Fitting	Mau Atlas	PVC	13
02	Head Unit	BSEN- 10255	(LG 3 GI) 02 inch	01
01	Transportation	NBS Building		
02	Installation and operations	As per Attached		

Part D: Underground RCC Tanks				
Sr. No.	Items Description	Make Standard	Specifications	Quantity
01	RCC Tank	ACI	20000 gallons	02

3.6 Operating Mechanism

The operation of the process consists of two setups.

1) Drip Irrigation Assembly (Direct Current, DC)
2) Sprinkler Irrigation Assembly (Alternating Current, AC)

Drip irrigation assembly ran through solar energy and was further divided into two portions as:

a) Drip Irrigation Side-A
b) Drip Irrigation Side-B

DC water pump had the 50 m head and 01-inch outlet. Therefore, the area had to be divided into two portions to deliver water equally with high pressure. While AC water pump had 80 m head and 01-inch outlet, and Sprinkler System required extra pressure to run.

Diameter of main and sub-main high-density polyethylene (HDPE) pipe for each process was 40mm and that of lateral was 16mm. Length of main and sub-main pipes for drip irrigation (DC) was 169 m and that of Sprinkler Irrigation (AC) was 280 m. Length of laterals for Drip Irrigation (DC) equaled to 1200 m.

3.7 Drip Irrigation System

As mentioned above drip irrigation system, running on solar panels, was divided into two sections "A" and "B". On a good sunny day pump was able to transmit water to all the plants of Side-A and Side-B separately. The total number of plants on Side-A equaled to 109 with 218 Drippers, and Side-B with 88 Plants and 176 Drippers. Side-A was comprised of 14 laterals and side-B was comprised of 12 laterals. Due to a smaller number of drippers and laterals length on side-B, Solar water pump was able to supply water with relatively high pressure at Side-B as compared to Side-A.

3.8 Sprinkler Irrigation System

Six sprinklers, in addition to drippers, were installed in NBS-lawn to water the landscape (Fig-3.5).

3.8.1 Types of Sprinkler

Three types of sprinkler systems were installed which are described below.

3.8.2 Rotary Sprinklers

Two rotary sprinklers were installed in the lawn which rotated mechanically while spraying streams of water equally in all directions with a flowrate of 400 lph. Their spreading radius equaled to 10-11 m.

3.8.3 Pop-Up (Spray) Sprinklers

Three Pop-up sprinklers were installed which sprayed water in all directions with a flow rate of 200 lph. Their spreading radius equaled to 3 m.

3.8.4 Pop-Up (Angular) Sprinklers

One Angular sprinkler was installed which sprayed water in a fixed direction that could be changed manually. The sprinkler could spread water at the radius of 3 m with the flowrate of 150 lph.

Figure 3-5 Six type of Sprinklers installed at NBS Lawn.

3.9 Drip irrigation's Parameters Measurement

The lawn was irrigated every day; however, readings of different parameters were taken at different.

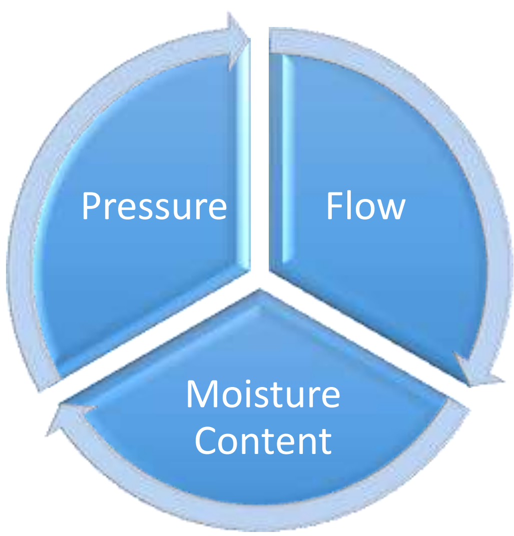

Figure 3-6 Drip-Irrigation System Experimental Flow Chart

intervals. Drip-irrigation application time was 1-hr. Experimental flow sheet chart is given as Fig-3.6.

3.9.1 Measurement of flow rate of drippers

Flow rate was measured using a graduated cylinder and a stopwatch. In order to obtain accurate data, multiple readings were taken at each reading point and their mean was considered. The reading points were located at the head, mid-point, and tail of each lateral.

3.9.2 Measurement of dripper's pressure

The pressures at the head, middle-point, and tail of the lateral lines were measured using pressure gauge. The pressure gauge was not fixed at the lateral lines (Fig- 3.7).

Figure 3-7 Measurement of Drippers Pressure at NBS

3.9.3 Measurement of Moisture Content

Moisture content (MC) was measured after one hour of irrigation at the head, middle-point, and tail of the lateral lines.

Moisture Content was measured by two methods:

a) Tensiometer

b) Oven dry Method

Through moisture meter, MC was measured directly on site. While in oven dry method, sample of soil was carried to IESE lab and experiments were performed (Fig-3.8 & Fig-3.9).

Figure 3-8 Measurement of Moisture Content Through Tensiometer

Figure 3-9 Measurement of Moisture Content Through Oven Dry Method

3.10 Sprinkler Irrigation's Parameters Measurement

To determine Distribution Uniformity (D_U) and Precipitation Rate (P_R) catch cans were laid out. Cans were laid at least 1-yard from the sprinkler's head to avoid spray deflection by the catch cans (Fig- 3.10). Same type of cans were set on level. Between 16 to 20 catch cans were laid down around each sprinkler.

System was turned on for 3 to 10 minutes for sprays and 10 to 30 minutes for rotors. Simple disposable-cups were used, and then the depth of water was measured using a ruler. Runtime in minutes were noted from the collected data.

3.10.1 Distribution Uniformity (D_U)

Distribution uniformity (D_U) emphasizes under-watered areas and is the calculation that irrigation auditors typically use in landscape audits. Its formula is:

Percent D_U = Average catch in the low quartile x 100 / Average catch overall.

Catch-can readings were ranked from low to high. Took the average of the lowest 25 percent of the catch-can readings. Divided the average lower quartile by the average of all the catch-can readings. Then, multiplied the resulting decimal by 100 and express as a percentage.

As a basic guideline, you should have a D_U of 70% or higher for rotor systems and a D_U of 50 percent or higher for spray-head systems. The higher the D_U, the better. If your D_U falls below these values, you may need to upgrade your system to achieve greater uniformity.

3.10.2 Precipitation Rate

To calculate the precipitation rate. The following equation will help in determining system's precipitation rate:

Precipitation rate (mm/hour) = (average can reading (ml) x 3.66 / Test time (minutes) x entrance area to catch can (square inches)) * 25.4

3.11 Investigation of Soil at the Selected Site

Soil Investigation consisted of four processes which are discussed below:

First of all, soil samples were taken from the NBS-lawn. Two grab samples were taken, and one composite sample was taken. Then, in Geo-Tech Laboratory NUST Institute of Civil Engineering (NICE), sieve analysis and hydrometer analysis tests were carried out on three samples to ascertain the soil classification. Then soil texture triangle method was used to determine the soil type.

Figure 3-10 Measurement of Distribution Uniformity and Precipitation rate of Sprinklers

3.11.1 Sample Taking

Two methods of sampling were used (Fig- 3.11).

1. Grab Sampling
2. Composite Sampling.

Figure 3-11 Soil Sample Taken from NBS Lawn

3.11.2 Sieve Analysis (AASHTO T 88, ASTM D 422)

Sieve analysis is performed to determine the distribution of the coarser and larger-sized particles (Fig-3.12).

In Sieve Analysis Test the main apparatus required are as, Set of ASTM sieves containing sieve # 4, 10, 20, 40, 60, 100, 200 and Balance sensitive to 0.1gm.

Calculations:

% Retained = (Mass of soil retained / Total Mass of sample) x100

% Passing = 100 – Cumulative percent retained

Figure 3-12 Sieve Analysis Test Conducted on Samples taken from NBS Lawn

3.11.3 Hydrometer Analysis (AASHTO T 87-70 & T88-70 ASTM D 421-58 & D422-63)

Hydrometer method is used to determine the distribution of the finer particles. After Sieve Analysis, Hydrometer Analysis can be done. In Hydrometer Analysis Silt and Clay percentage is determined (Fig-3.13).

P = Soil in suspension= Ra/Wxl00 → **01**

D= dia of soil = Kx √L/T → **02**

Where,

T = Time in minute

R = Hydrometer readings with composite correction (Actual hydrometer Reading)

L = Effective depth of hydrometer in cm

D = Diameter of Soil Particle

P = Soil in Suspension (%)

A = Correction factor using specific gravity from table

W = Weight of Air-dried sample

Figure 3-13 Hydrometer Analysis Test Conducted on Sample Taken from NBS Lawn

3.11.4 Soil Texture Triangle

The soil texture triangle is one of the tools that soil scientists use to visualize and understand the meaning of soil texture names. The textural triangle is a diagram which shows how each of these 12 textures is classified based on the percent of sand, silt, and clay in each given in Fig-3.14.

Note: these percentages are based on the USDA definition of sand and silt only.

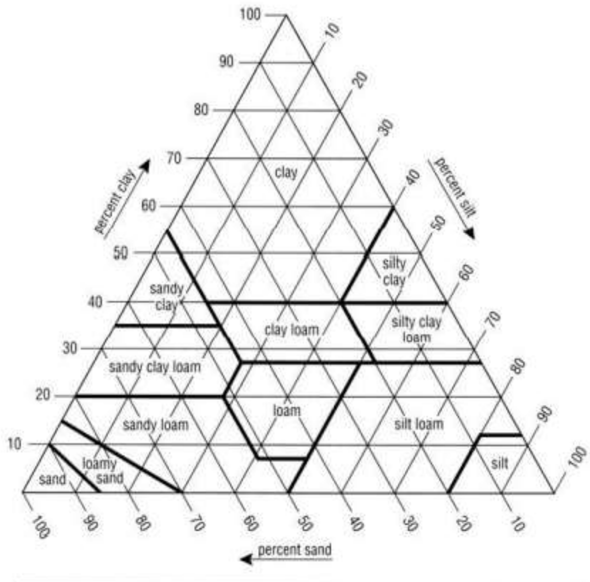

Chart showing the percentages of clay, silt, and sand in the basic textural classes.

Figure 3-14 USDA soil textural triangle (Credit NRCS, National Agronomy Manual. Part 504)

Table 3-2: Properties of Soil Texture (Credit NRCS, National Agronomy Manual. Part 504)

Using the table below, determine the properties of each of the soil samples analyzed above.

Soil texture	Nutrient-holding capacity	Water-infiltration capacity	Water-holding capacity	Aeration	Workability
Clay	Good	Poor	Good	Poor	Poor
Silt	Medium	Medium	Medium	Medium	Medium
Sand	Poor	Good	Poor	Good	Good
Loam	Medium	Medium	Medium	Medium	Medium

3.11.5 `Soil Classification

The results of three samples with Percentage of Sand, Silt, and Clay is given in Table 3.3.

Table 3-3: Soil Classification of NBS Lawn

Sand (%)	Silt (%)	Clay (%)	Soil Type
11	29.23	59.77	Clay
13.1	28.71	58.19	Clay
19.93	16.91	63.16	Clay

Hence, the general soil type of NBS-NUST area can be assumed as "Clayey" for further analysis of run-off etc. However, while calculating the run-off, vegetation cover has been taken into account as well.

3.12 Estimation of Run-off from Roof-top

The rainwater harvesting potential from the roof top and other surface area of NBS-NUST was calculated using following relations (Khan, 2003);

$$V = A \times R \times C \quad (03)$$

Rainwater harvested (ltr) = Ave. daily rainfall in mm (M/1000mm) x catchment area

(Sqm) x run-off coefficient x 1000 (ltr / cum)

Where, V= Volume of water, A= Effective area of rain fall

R= Average annual rainfall, C= Coefficient of run-off

The coefficient of run-off depends upon the roofing material.

Where, the runoff coefficients were identified using international references as well as based on the surface infiltration capacity of the conditions at NUST as given in Table 3.4.

Table 3-4: Coefficient of Runoff for different surfaces (Persyn, Glanville, Richard, Laflen, & Dixon, 2004)

Runoff Coefficients		
Character of Surface	High	Low
Roof Metal, Gravel, Asphalt	0.95	0.75
Paving Concrete, Asphalt, Brick	0.95 0.85	0.7 0.7
Soil Flat (2% Slope or Less), Bare Fllat (2% Slope or Less), With Vegetation	0.75 0.60	0.2 0.1

Table 3.4 above reflects the coefficient of runoff for concrete ranges from 0.95 to 0.7. Thus, a figure of 0.9 was used for the calculation of runoff from the rooftop of NBS-NUST, using equation 3.

3.13 Runoff Estimation from Land Surface

Runoff estimation can be done through Analytical, Metric or Empirical methods. Whereas many empirical formulae are in use all over the world to develop rainfall - runoff relationship in a catchment. The most used is Soil Conservation Service (SCS) Curve Number (CN) method. The SCS Runoff Curve Number method is developed by the United States Department of Agriculture (USDA). SCS and is a method of estimating runoff (Hjelmfelt, 1991).

The method is based on initial abstraction and loss rate (Yu, 1998). In this method, the rainfall occurring prior to direct run-off is presumed to be the initial abstraction such that the volume of the direct run-off is equal to the volume of rainfall (Pilgrim, 1987; Muterja, 1990). It is suitable technique for analysis of infiltration behaviors of small catchments particularly where there is no run-off gauging systems are installed. The initial abstraction is an important estimate for storms occurring on dry antecedent conditions, as it tends to offset underestimation of initial infiltration capacity resulting from the use of an average rate (Chow, 1964). This procedure gives the runoff value from the total precipitation minus infiltration using the following relationship.

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)} \quad (04)$$

Where, Q = runoff (inches)

Ia = Initial abstraction (Inches)

S = Potential maximum retention (Inches)

P = Total rainfall (Inches)

The initial abstraction "Ia" is taken as; Ia = 0.2 S

Thus,

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (05)$$

Here the potential retention "S" is commonly expressed in terms of runoff Curve

Number (CN) through the following relationship;

$$S = \left(\frac{1000}{CN}\right) - 10 \quad (06)$$

The recharging capacity of a soil is determined by Antecedent Moisture Conditions (AMC), as well as by the physical characteristics of the catchment (Fogel, 1980). The CN which is also known as Watershed Index "W" depends upon (i) soil type, (ii) general hydrological conditions, nature, and extent of the vegetative cover and (iii) at the Antecedent Moisture Conditions (AMC) at the start of the storm period which produces the runoff.

Soil type classifications used in adoption of SCS Curve Number and determination of Antecedent Moisture Conditions is as in Tables 3.5 & 3.6, (Khan, 2003);

Table 3-5: Soil type classification

Soil Group	**Characteristics**
A	Soil having very low runoff potential, for example deep sands with very little silt and clay
B	Light soils and / or well-structured soils having an average infiltration when thoroughly wetted, e.g. light sandy loam, silt loam
C	Medium and Shallow Soils having below average infiltration when thoroughly wetted, e.g. Clay loam
D	Soil having Runoff potential, e.g. heavy soils, particularly clay of heavy swelling capacity, and very shallow soils underlain by dense clay horizon

Table 3-6: Antecedent Moisture Conditions (AMC)

AMC	**Rain in previous five days**
I	less than 13 mm

II	13 -38 mm
III	more than 38 mm

Based soil classification done as in Table 3-3. As mentioned earlier, the rainfall data of last 12-years analyzed, (2009-2020) obtained from the rain gauge installed at Zero-point Islamabad by the Pakistan Meteorological Department. The analysis of the daily rainfall data of last six years (Appendix-II) shows that 98 events of 38mm or greater rainfall occurred during this period, out of which only 25 events took place within consecutive 5-days. Whereas 187 events of rainfall ranging from 13 to 37 mm occurred out of which 63 events took place within consecutive 5-days span. Hence, Antecedent Moisture Condition - II is assumed to prevail in the NUST open land catchment area.

Based on above mentioned analysis, i.e., clayey soil, AMC-II and having soil group conditions at NUST, the Watershed Index " W" or Curve Number comes out as 80 (Khan, 2003) for further calculations of surface run-off from the open land catchment. Whereas taking vegetation of the land surface into account and conditions of the soil at NUST the coefficient of run-off has been taken as 0.65.

3.14 Rainwater Quality

To determine the water quality of the harvested rainwater, scientific laboratory-based techniques were used to analyze the data. Periodic samples were taken (soon after the rain fall as well as during non-rainfall period) to observe the trend of different water quality parameters. Water quality study was carried out for a period of 8-months (Sep-2020 to Jan-2021). Impacts of wet versus dry spells on water quality was specifically observed. Furthermore, the storage water tanks were placed in series in a way that the overflow of preceding tank(s) was connected to fill the following water tank(s), mainly to observe any variation in the pH, and Turbidity. Interesting results have been discussed.

Results and Discussion

4.1 NUST Business School land use plan

The land use plan of the NUST Business School (NBS) was obtained from PMO-NUST office Islamabad. As per the NBS land use plan, the whole area is divided into Three-main categories:

1. Roof tops
2. Open/green areas (pervious),
3. Paved areas under roads, footpaths, parking etc. (impervious).

About 63.1 % area is Pervious (Green belts / Grounds / Lawns etc.), 24.2 % is under Car Parking, footpaths, and other impervious pavements, and 12.7 % forms the roof -top surface of the planned buildings (Table 4.1 & Fig-4.1).

Table 4-1: Land Use Analysis of NBS

S.No.	Category	Covered area (m^2)	Percent area (%)
1	Rooftops	4343.22	12.7%
2	Paved Surfaces /parking	8239	24.2%
3	Green / Open Areas	21521.42	63.1%
	Total Sum	34103.64	100%

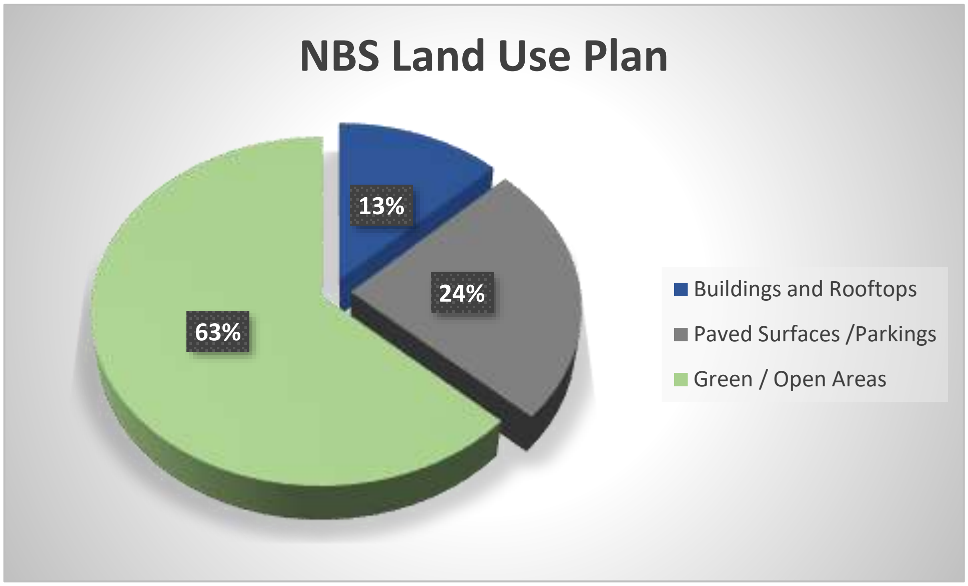

Figure 4-1 Land Use Analysis NBS (Percent wise Distribution)

4.2 Precipitation Data of Islamabad region

The rainfall data of the weather station installed at Zero Point Islamabad by the Pakistan Meteorological Department (PMD) was obtained. Because of its central location, this station is considered as the most suitable for gauging the Islamabad rainfall patterns, hence the best representative of the rainfall pattern and related calculations for this research as well. Table 4-2 and its graphical presentation in Fig-4.2 reflect the trend of rainfall during the research period, i.e., 2020. The analysis shows that average annual rainfall of Islamabad is around 1572.1 mm in 2020. The maximum rainfall (about 45%) occurs during the Monsoon period (July-Sep).

Table 4-2: Monthly Rainfall Data for Research Period (2020)

Month	Rainfall (mm)
Jan	111.6
Feb	65.5
Mar	231.8
April	115
May	132
June	89
July	219.5
Aug	398.7
Sep	95
Oct	0.0
Nov	92.8
Dec	21.2

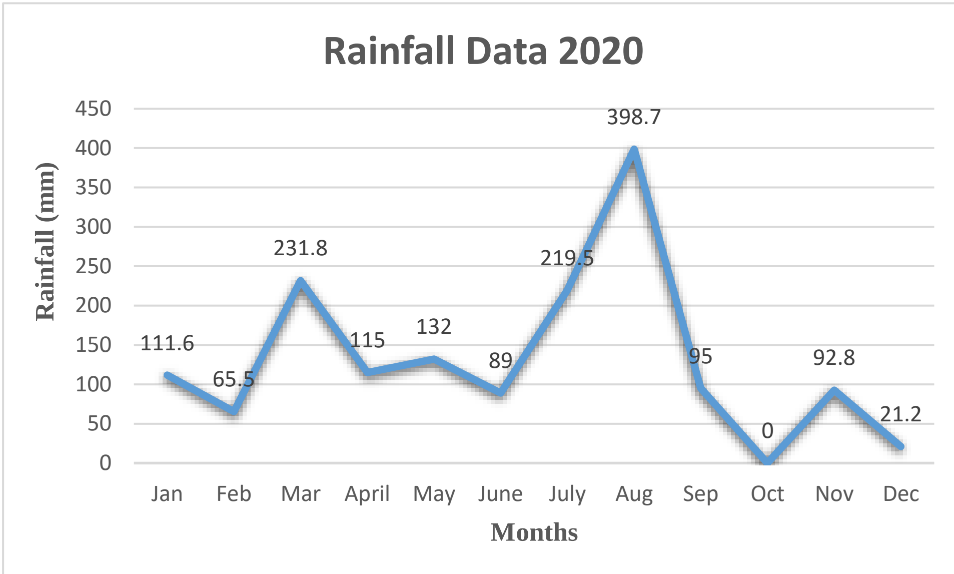

Figure 4-2 Monthly rainfall during the research period (2020)

The trend of rainfall during last 12-years (2009 - 2020) is also shown through Fig-4.3.

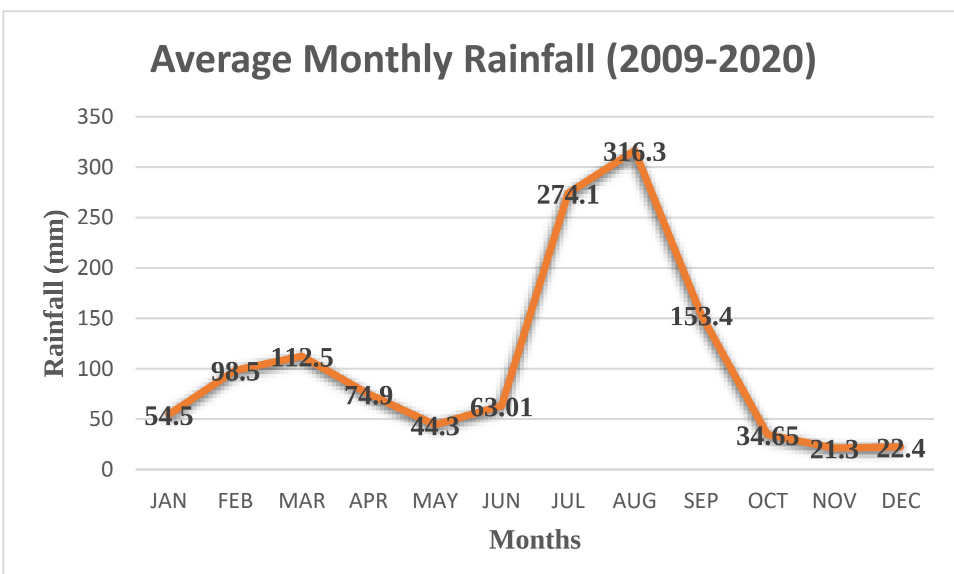

Figure 4-3 Average Monthly Rainfall from (2009-2020) (Source: PMD, Station: Zero Point Islamabad)

Fig-4.3 shows that average annual rainfall of Islamabad is around 1270.2 mm. The maximum rainfall occurs during the Monsoon period (July-Sep). Generally, there are two dry (April - June & Oct - Dec) and two wet spells (Jan. - Mar. & Jul. - Sep.).

Maximum Monthly rainfall during the last 12-years occurs in month of Jul-Sep approximately 58.5%, which shows that this rainwater must be stored.

4.3 Rainwater harvesting potential at NUST Business School

The results of installing rooftop rainwater harvesting system at a part of NBS buildings was very encouraging. The catchment area of the model building was 4343.2 m^2. Based on average annual rainfall 1572.1 mm/year in 2020 and using the runoff coefficients for respective catchment surfaces as mentioned in Table-6 above. It was calculated that an amount of 1.6 Million Gallon/year or 4383.6 MGD can be harnessed from the roof tops of NBS buildings. Similarly, the RWH potential from paved areas and open land areas was calculated as 2.7 MG/year and 8.5 MG/year respectively (Table-4.3).

Table 4-3: Total Annual RWH Potential of NBS

Unit	Buildings and Roof-Top	Parkings and Paved Areas	Green/Open Land	G-Total
Mln Ltr / Year	6.01	11.28	20.9	38.19
MG / Year	1.6	3.01	5.53	10.14
MG / Month	0.13	0.25	0.46	0.84
Gallon/ Day	8246.57	4383.6	15150.68	27780.8
%	15.7	29.7	54.6	100

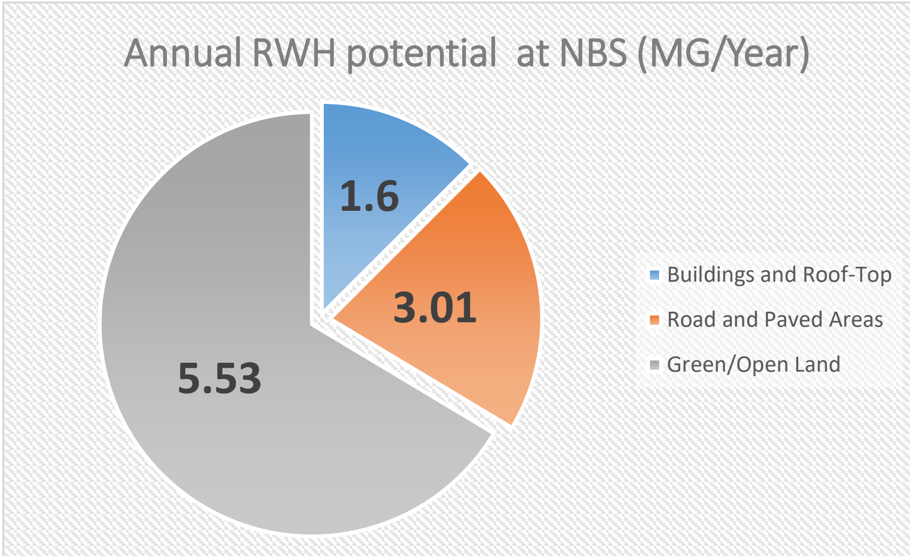

Figure 4-4 Annual RWH Potential of NBS (MG/Year)

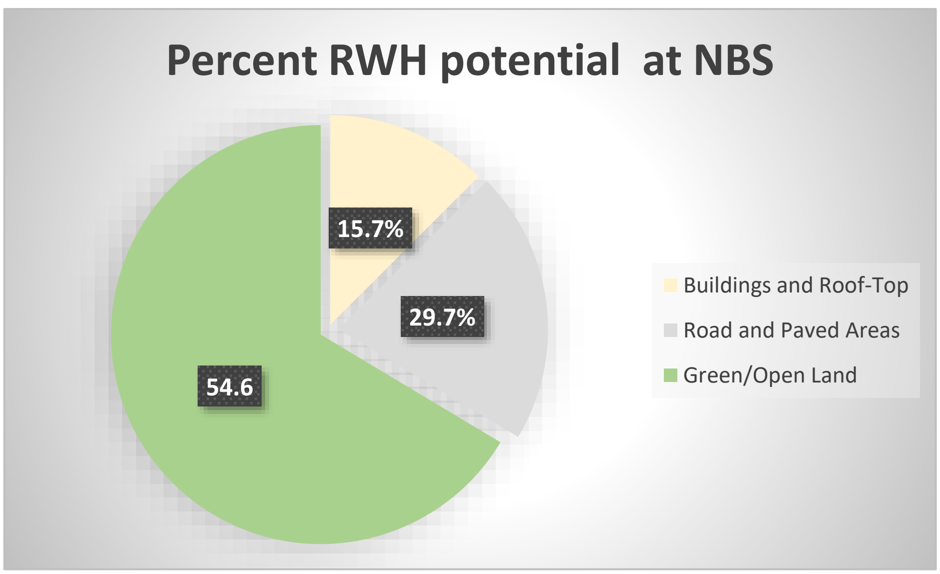

Figure 4-5 Percent wise RWH potential from different surfaces at NBS

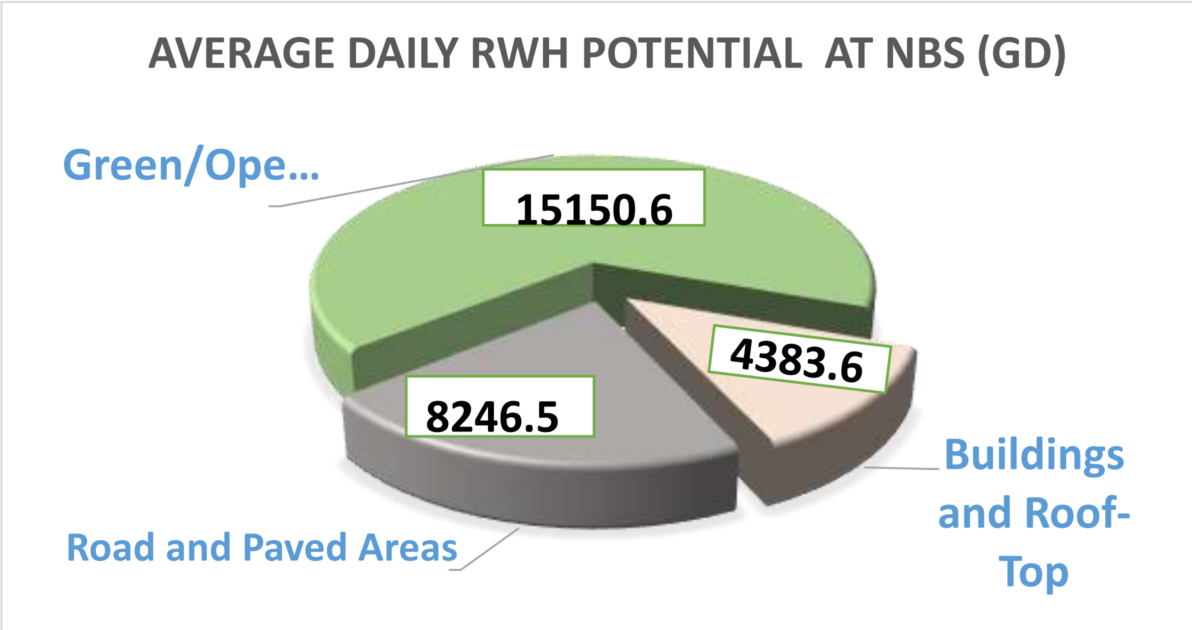

Figure 4-6 Average daily RWH potential at NBS-NUST Islamabad (GD)

Hence, the overall potential of RWH at NBS has been found as 12.8 MG /year or 0.035 MGD, which seems to be a huge resource to be capitalized. The results are very encouraging, as the current daily demand of NUST is only 0.52 MGD (PMO).

In the current RWH system installed at NBS, we only store rainwater coming from Buildings Rooftop of NBS which equals to 6.01 MG/year or 4383.6 Gallons per day.

4.4 Hydraulic Performance of drip irrigation system

The hydraulic performance of the system is presented in Table 4.4 and 4.5. The distribution uniformity (D_U), uniformity coefficient (U_C), Flow Variation (Q_{var}) and Coefficient of Variation (C_V) of drip

Irrigation was found to be 65.7%, 98.7%, 17.91% and 24% for side-A and 93%, 95.7%, 11.02%, and 5.28% for Side-B, respectively.

Considering the classification of (Merriam and Keller 1978) the Distribution Uniformity (D_U) is good, Uniformity Coefficient (U_C) as (ASABE standards, 1999) is Excellent, Flow Variation (Q_{var}) of drip irrigation according to reference of (FAO, 1984) should be equal to or less than 20% and both sides have flow variation less than the required standard. Coefficient of Variation (C_V) is very good as represented by (Keller and Bliesner, 1990).

Table 4-4: Hydraulic Performance of the drip irrigation system Side-A

Emission Uniformity (E_U) %	Uniformity Coefficient (U_C) %	Flow Variation (Q_{var})%	Coefficient of Variation (C_V)
65.7%	73.2%	17.91%	24%

Table 4-5: Hydraulic Performance of the drip irrigation system Side-B

Emission Uniformity (E_U) %	Uniformity Coefficient (U_C) %	Flow Variation (Q_{var}) %	Coefficient of Variation (C_V)
93%	98.7%	11.02%	5.28%

4.5 Effect of Pressure on Drippers

Table 4.6 & 4.7 shows the pressure variations in the lateral lines of the drip irrigation Side-A and Side-B. The pressure in some lateral lines was less than the pressure recommended for the drip irrigation system (7.3-14.5 psi). This could be due to topography of the land or due to potential fouling and leakages in the pipes. The pressure variation in the lateral lines of the Side-A drip irrigation system was found to be 19.5%, and Side-B 14.4%, hence less than 20%. This agrees with the standard design of drip irrigation system, as the allowed pressure variation in standard design of drip irrigation system is 20% as stated by (Vermeiren and Gobling, 1980).

Table 4-6: Pressure variation along the laterals (Side-A)

Laterals No. (Side-A)	Pressure (psi)	Mean (Pressure-psi)	Mean Flow rate (lph)
01	0.6	0.4	1.5
	0.3		
	0.4		
02	1	0.9	2.2
	0.9		
	0.8		
03	1.5	1.4	2.7
	0.45		
	1.3		
04	1.9	1.8	3.1
	1.87		
	1.7		
05	2.5	2.3	3.6
	2.4		
	2.2		
06	3.01	2.8	4.8
	2.88		
	2.7		
07	3.5	3.3	4.6
	3.4		
	3.2		
08	3.78	3.6	5.1
	3.6		
	3.55		

09	4.6	4.2	5.8
	4.1		
	3.9		
10	5.0	4.9	6.5
	4.92		
	4.8		
11	5.66	5.4	6.8
	5.5		
	5.1		
12	5.9	5.8	7.2
	5.8		
	5.71		
13	6.6	6.4	7.8
	6.4		
	6.3		
14	7.3	7.1	8.1
	7.2		
	6.9		

Table 4-7: Pressure variation along the laterals Side-B

Number of Laterals (SIDE-A)	Pressure (psi)	Mean Pressure (psi)	Flow rate (lph)
01	8.6	8.3	8.5
	8.5		
	7.9		
02	9	8.9	8.3
	8.9		
	8.8		

03	9.5	9.3	8.5
	9.33		
	9.3		
04	10.4	9.9	8.1
	9.89		
	9.7		
05	10.93	10.7	8.4
	10.8		
	10.6		
06	11.9	11.5	8.4
	11.67		
	11.2		
07	12.65	12.5	8.3
	12.56		
	12.4		
08	13.87	13.3	8.3
	13.7		
	13.6		
09	14.48	14.2	8.5
	14.4		
	13.9		
10	14.93	14.8	8.4
	14.9		
	14.8		
11	15.1	15.1	8.2
	15		
	14.95		
12	15.05	15.1	8.4
	15.1		
	15.2		

4.6 Pressure-Flow relation

As shown in Fig-4.7, pressure and flow rate are directly proportional to each other until pressure reaches 6.6 PSI. At 6.6 PSI pressure, the turbo emitters installed approach the design flow rate of 7.98 L/h. Increasing pressure after 6.6 PSI on emitters, shows a stable variation between 7.98-8.7 L/h of discharge from emitters which could be due to variation in manufacturing of Turbo emitters, soil particles, and inlet of Drippers.

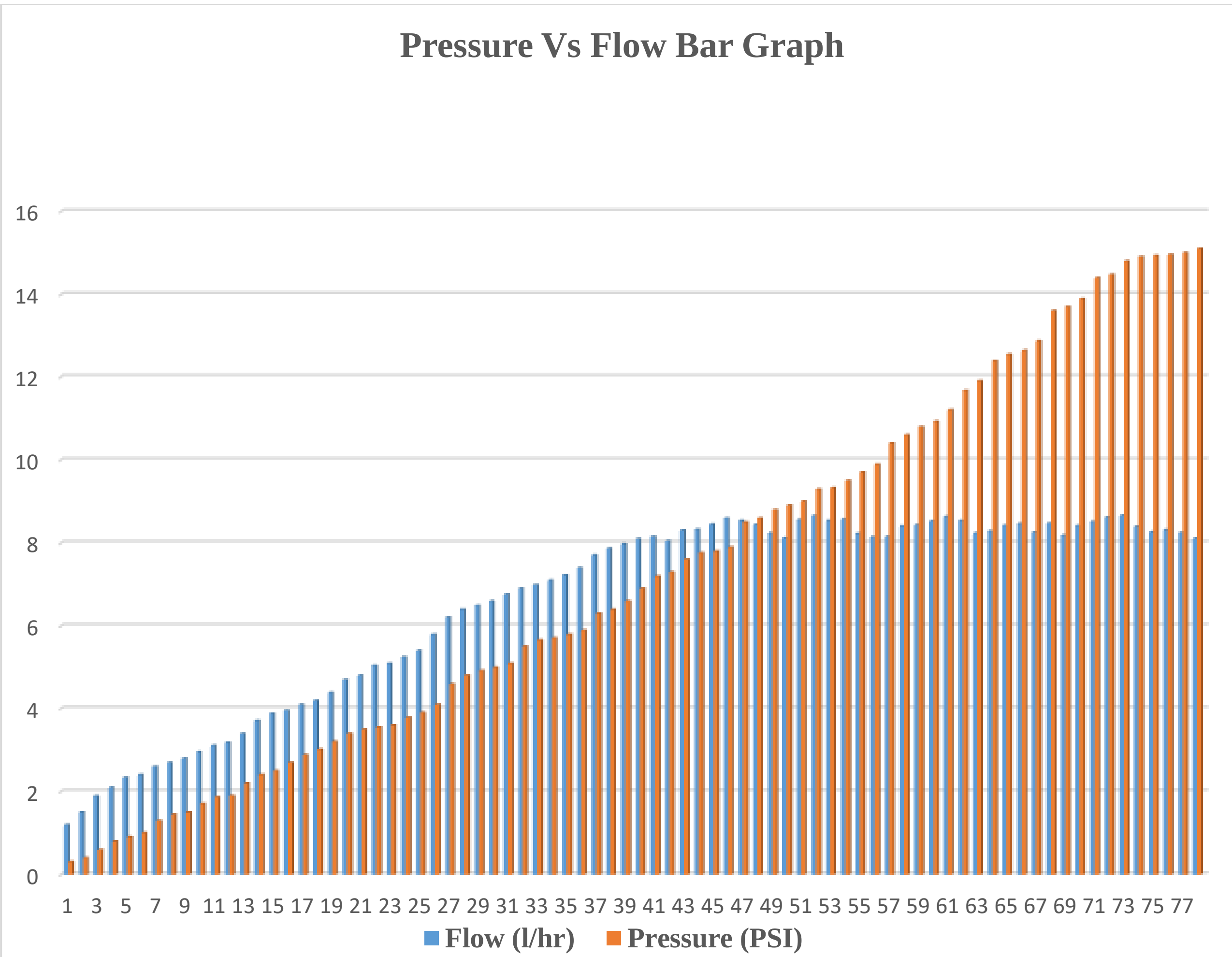

Figure 4-7 Pressure-Flow relation of Drip-Irrigation System at NBS

4.7 Soil Moisture content

Soil Moisture Content after 1-hr of every irrigation was measured. Table 4.8 and Figure 4.8 shows the results of soil moisture content. The analysis of data showed that there was no significant difference in soil moisture content during the initial treatments (after first irrigation) but in the later stage (last irrigation), a significant difference in soil moisture content was observed. The highest moisture content observed in the initial stages of irrigation i.e., after Four days, three days and two days was 5.0 %, 4.6 %, 4.4 % respectively. However, the highest moisture content observed in the later stage i.e. after 20 days of irrigation was 25.2 %. These results indicate that the soil moisture content will gradually increase from the initial stages to the later stages. These findings are in accordance with (Meshkat et al. 2000) who reported that an irrigation regime with high frequency irrigation could cause the soil to remain wet, due to the great changes in soil moisture distribution along the growth period.

Table 4-8: Soil moisture content (%) in initial stage (after first irrigation)

Treatments	Soil moisture content (%)
T1	5.0
T2	4.6
T3	4.4
T4	25.2

Where, T1 = 4-days of treatment, T2 = 2-days of treatment, T3 = 3-days of treatment, T4 = 20 days of treatment.

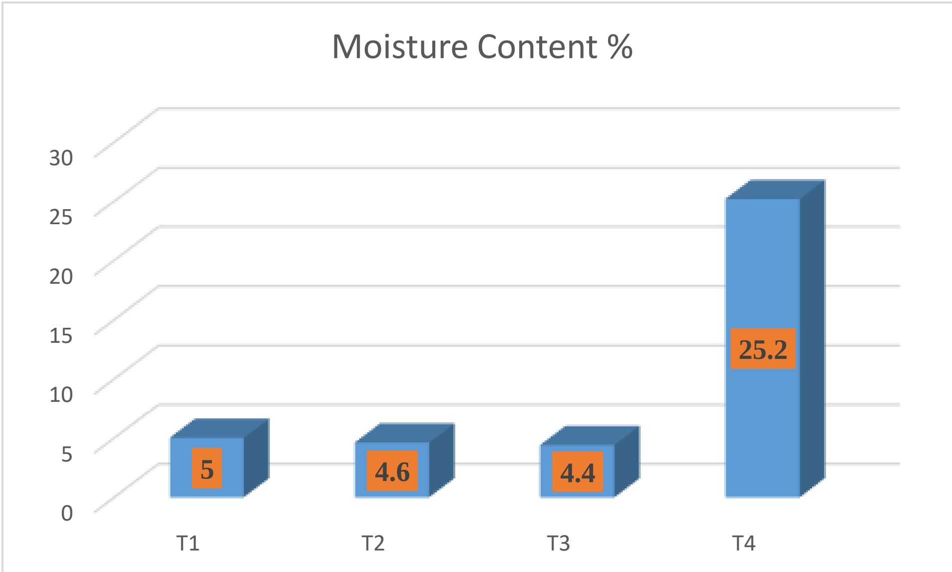

Figure 4-8 Soil moisture content (%) in initial stage (after first irrigation) and after every day Irrigation.

4.8 Results from Sprinklers (Distribution Uniformity and Precipitation rate)

Spread radius, Pressure, flow rate, precipitation rate and Distribution Uniformity (D_U) of all the installed sprinklers were determined. The comparison of the results obtained from these sprinklers is depicted in the Table 4.9.

Table 4-9: Radius, Pressure, Distribution Uniformity (DU), Flowrate, and Precipitation rate of Sprinklers Installed

Sprinkler Type	Radius (m)	Pressure (Bar)	Flowrate (L/hr)	D_U (%)	Precipitation Rate (mm/hr)
Spray Sprinklers	3	2	200	51.2	26.9
Angular Sprinklers	3	1.5	150	55.2	29.21
Rotary (Impact) Sprinklers	10	2.5	400	75.7	40.4

The obtained results indicated Rotors to be the best among all. As D_U, precipitation rate, and spread radius of Rotors were observed as 75.7%, 40.4 mm/hr, and 10 m respectively.

4.9 Rainwater Quality

The water quality of the harvested rainwater from the model RWH System was regularly monitored for a period of 6-months from the day of its installation i.e., Sep 2020 to Feb-2021. The water quality parameters such as pH, Temperature, and Turbidity were measured. The general quality of the collected samples were found very much within the acceptable range.

4.9.1 Turbidity

Constructing the storage tanks in series was found to be advantageous. As the turbidity reduced in tanks downside in the series (Figure. 4.9 & 4.10). Samples collected directly from storage tank contained negligible turbidity.

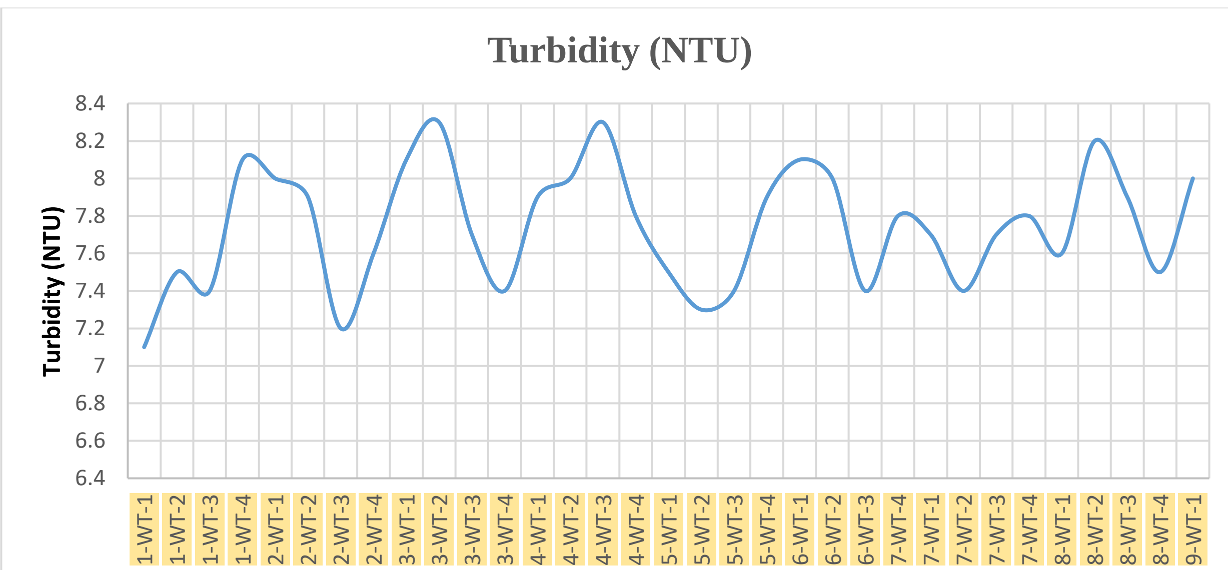

Figure 4-9 Turbidity (NTU) trend of rainwater quality RWH System installed at NUST

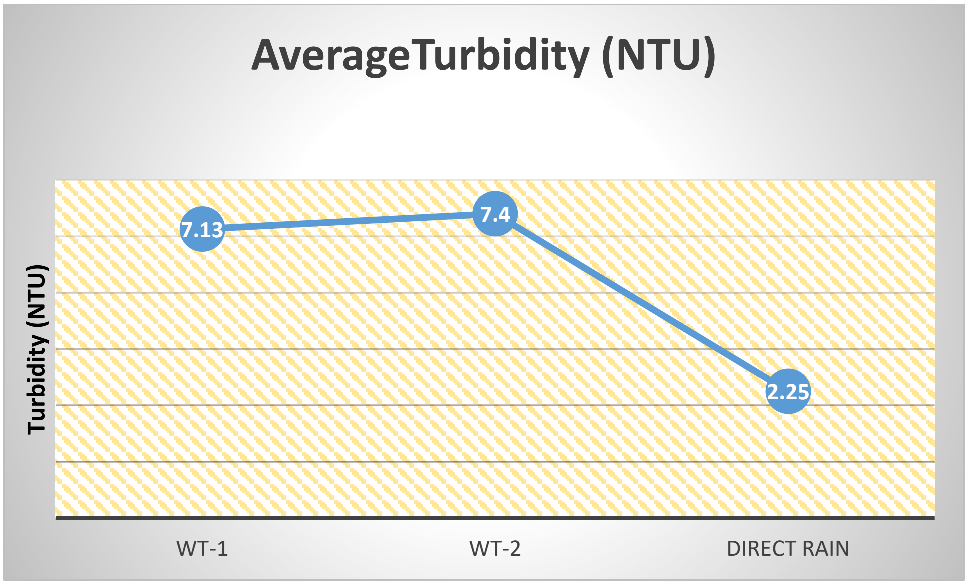

Figure 4-10 Average turbidity trend of rainwater quality samples, collected from the RWH.

4.9.2 pH Values

Figure 4.11 & 4.12 show a slight increase in the pH values of some samples taken from rainwater Tanks. This increase in pH could be due to slight contamination with alkaline impurities on its way to the storage tank.

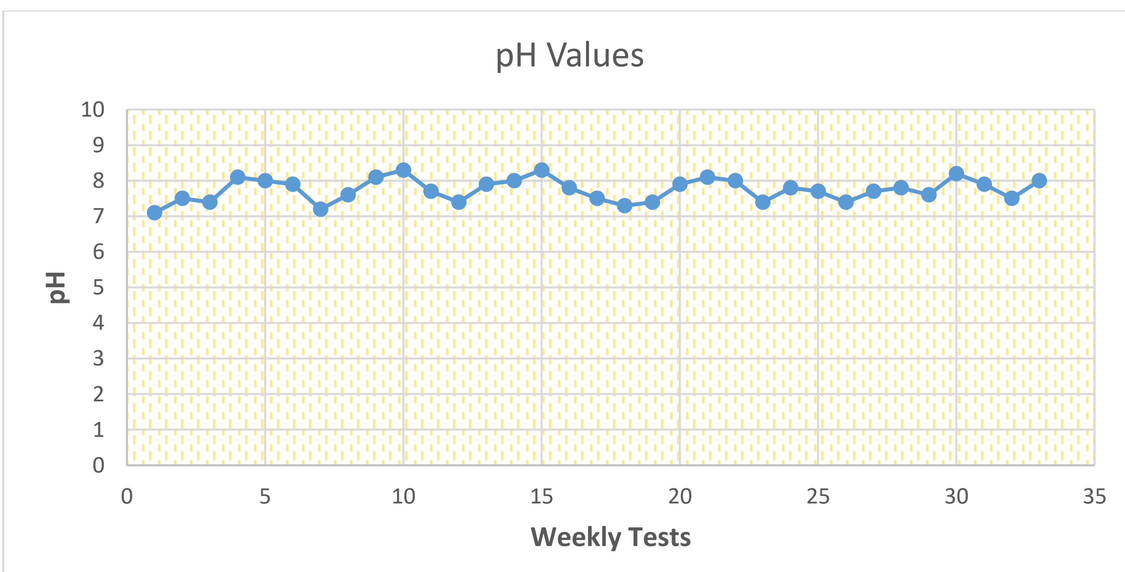

Figure 4-11 pH trend of rainwater quality samples, collected from the RWH System installed at NBS - NUST.

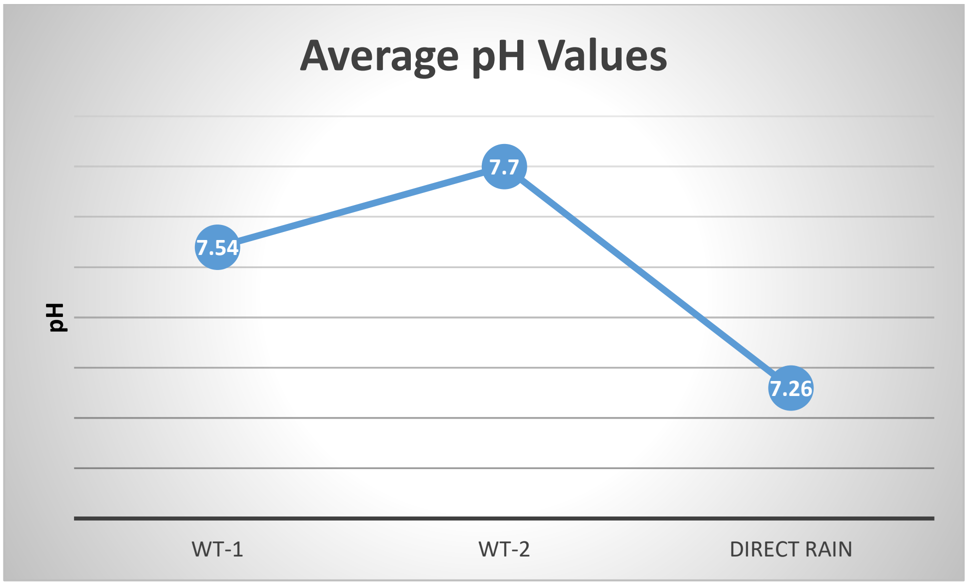

Figure 4-12 Average pH trend of rainwater quality samples, collected from the RWH System installed at NUST.

4.10 Cost Benefit Analysis

Methods of analyzing the profitability of projects comprised of different techniques. One of the most well-defned methods is Cost-benefit analysis (CBA). CBA, sometimes also known as benefit–cost analysis, is a systematic approach to estimating the strengths and weaknesses of alternatives used to determine options which provide the best approach to achieving benefits while preserving savings (David R, 2013).

Possible benefits earned by running rainwater harvesting in the NBS-NUST can be divided into following three categories.

1. Environmental benefits
2. Social benefits
3. Economic benefits

As the measurement of all the above-mentioned benefits does not fall in the scope of the study, only certain economic benefits of the study were estimated.

4.10.1 Environmental Benefits

- Mitigation of Water Shortage problem.
- Landscape development.
- Creating new habitat for local faunas.
- Enhancing Biodiversity by landscape development.
- Reduce dependency on ground water.
- Reduce soil erosion.
- Mitigation of Air Pollution.
- Use of Clean Energy.
- Sustainable approach by not using Groundwater.

4.10.2 Social Benefits

- Raising social awareness about water shortage.
- Teaching students about the use of uncommon water resources.

4.10.3 Economic Benefits

- Supplying irrigation water through efficient technology.
- Significantly decreases in cost of water transportation.
- Decreases in flood control costs.
- Reducing infrastructure damages.
- Improvement in crop yield.
- Efficiency of water application increases.

Total costs of supplementing water for irrigation of the lawn in the study area consist of capital cost and operating cost. The capital cost of the project includes storage tank charges and other costs such as piping, connections, and storage tank cost. Operating cost comprises annual storage tank cleaning and annual pipes cleaning and maintenance. Table 4.10 presents annual capital and operating costs of Drip and sprinkler irrigation based on official price list from PMO NUST and M/s Flow Engineering Technologies.

4.10.3.1 Water Cost

Cost of one Bowser with water capacity of 8,000 liters equals to 8,000/- PKR (PMO-NUST). There are 231 total Number of Plants; we are giving water through drip irrigation system.

8000 Litres = 8000 PKR

1 Litre = 1 PKR

4.10.3.2 Water Requirement for Drip Irrigation System

Total water Requiremnt can be calculated as,

Number of Plants * Yearly water requirement……………………. (4.1)

231*420 = 97,020 L/year

Value from equation (1) gives water efficiently applied through drip irrigation to plant roots. According to Shamshery et al. 2017, Drip irrigation system can reduce water consumption by 70% compared to conventional flood irrigation system.

4.10.3.3 Water Requirement for Conventional Irrigation system

$$= \frac{(\text{Water Requirement for Drip Irrigation System})(100)}{(30)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4.2)$$

$$= \frac{(97020)(100)}{(30)}$$

= 3,23,400 Liters/Year

4.10.3.4 Water Cost through Conventional Irrigation System

1 L = 1 PKR

3, 23,400 Liters/Year = 3, 23,400 PKR/ Year.

4.10.3.5 Cost of RCC Storage Tanks

Two RCC tanks construction cost given by PMO NUST is 27,00,000/- PKR. The estimated life of Underground water tank is 50 years (PMO-NUST).

4.10.3.6 Trickle Irrigation System Installation Cost

The capital cost of Drip and Sprinkler Irrigation System Installation for 1.02 Acre NBS lawn equals to 576,180/- PKR. The Project have lifetime of 15 years, which will run free of cost on solar energy system.

Gardener is required to operate the system, which already we have in NBS. The salary of who comes 3,00,000/- PKR/Year (Administration DD-Horticulture). Maintenance Cost of Drip and Sprinkler Irrigation System is 3% of the Capital cost per year (NRCS NEH, part 652, irrigation guide, Chap 5) which equals to 17,285/- PKR/Year.

Table 4-10: Annual Costs of Surface and Drip Irrigation System

S. No.	Type	Cost of Conventional irrigation system (PKR/ Year)	Cost of Trickle Irrigation (PKR/Year)
1.	Cost of Water/Transportation	3,23,400	0
2.	Cost of Storage Tank	0	50,000
3.	Cost of Labor (Gardener)	3,00,000	3,00,000
4.	Capital Cost of Installation	0	38,412
5.	Maintenance Cost	0	17,280
Total Cost (PKR/ Year)		3,23,400/-	1,05,692/-

4.10.3.7 Annual Benefits of the Trickle irrigation system

Annual Benefits = 3,23,400 - 1,05,692 = 2,17,708/- (PKR/Year)

This huge amount annualy, we can save by RWH and then using through Trickle Irrigation system at NBS. The said amount we are saving from NBS per year. The project will be more significant, if we deploy this in overall NUST.

Table 4-11: Cost Benefit Analysis (CBA) of Conventional Irrigation System and Drip Irrigation System at NBS

Conventional Irrigation System	Trickle Irrigation System	Profit
0.32M PKR / Year	0.11M PKR / Year	0.22M PKR / Year

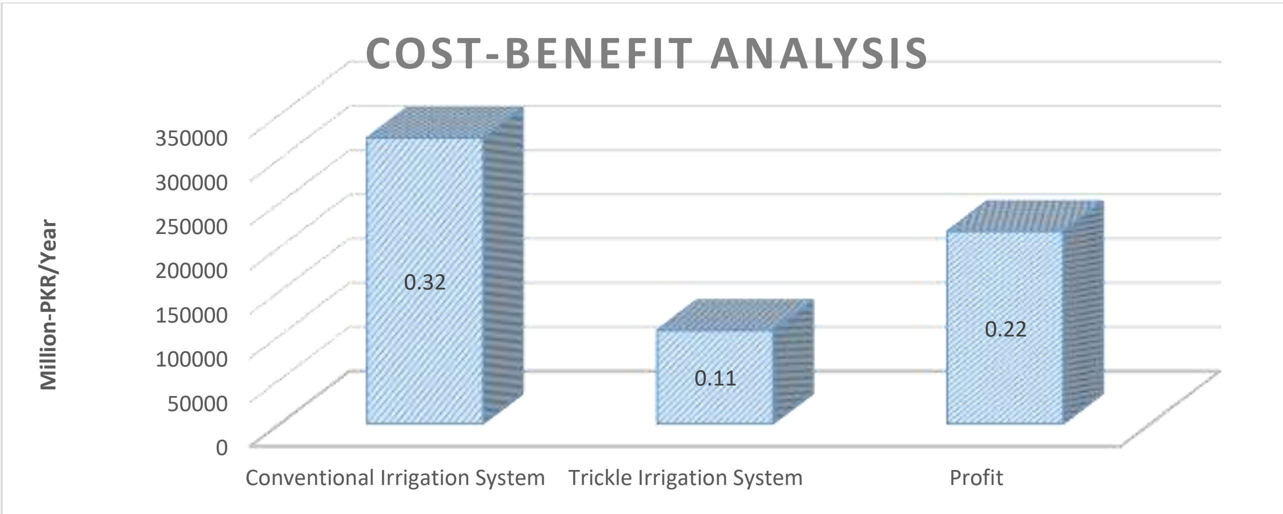

Figure 4-13 Cost Benefit Analysis (CBA) of Conventional Irrigation System and Drip Irrigation System at NBS

RECOMMENDATIONS

1) Based on the research findings, NUST may incorporate rainwater harvesting with all its future developmental activities. Furthermore, rainwater harvesting should not be limited to the rooftops only, but harvesting should also be done from paved areas and landscapes.
2) Since only a fraction of rainwater can be stocked in the present storage facilities, more storage tanks are needed to be constructed to avail maximum benefits and meet the water requirements of NUST.
3) Design changes were made to reduce the construction cost of RCC storage tanks. More research, however, should be carried out to further reduce the construction cost of tanks to enhance the economic viability of rainwater harvesting.
4) Research findings have shown pressurized irrigation system to be highly efficient in terms of water conservation. Therefore, the system should be extended further to irrigate the other landscapes and gardens of the university.
5) Research findings should be shared with the Capital Development Authorities (CDA) to replicate the system in other parts of Islamabad including residential and industrial areas.
6) Rainwater has the potential to be utilized for potable usage. Further research needs to be carried out to ascertain the water quality standards and economic feasibility of treatment methods.

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