CONSTRAINING RAINWATER HARVESTING POTENTIAL AT NUST USING COMPUTATIONAL APPROACH

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APPROVAL SHEET

Certified that the contents and form of this thesis titled "Constraining rainwater harvesting potential at NUST using computational approach" submitted by Ms. Aaima Rashid, Arman Iqbal and Muhammad Jawad Rana, have been found satisfactory for the requirement of the degree.

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Dedication

We dedicate this thesis to our parents who have always showered their love and affection on us. We are forever indebted to them for their prayers and constant support.

Abstract

Pakistan is one of the 36 most water stressed countries, which may be attributed to factors such as rapid population growth, unplanned urbanization, unregulated industrialization, increased agricultural activities, mismanagement and unjust distribution and contamination of water resources. This calls for exploration of sustainable water resources. Our project falls under the goal 6: Clean water and sanitation for all, of Sustainable Development Goals by United Nations. This project aims to explore potential of roof rainwater harvesting system at NUST due to its relatively good quality and simple maintenance. A time-series analysis was conducted to account for the variation and distribution of rainfall in Islamabad. The Tangki National Hydraulic Research Institute of Malaysia (NAHRIM) model was used to carry out 105 simulations on three usage scenarios based on the expected quality of harvested water. Turbidity, alkalinity, pH, hardness, microbiological contamination, heavy metal, and phenolic compounds were considered in assessment of roof rainwater quality at NUST. Islamabad experiences most rainfall in July and August and highest variation was also observed during these months. Irrigation usage scenario required the minimum treatment. The potable water scenario gave maximum water-saving efficiency for all buildings in the range of 1 to 30 cubic meters of tank capacity. Total Demand and Non-potable demand resulted in higher storage efficiency for all buildings considered. Around 90 percent tank capacities were in range 25-30 m^3 at maximum water saving efficiency. The Press Building of NUST achieved the maximum water saving efficiency of 95 percent in case of potable demand scenario. A detailed excel database was also created for optimization of tank size for 35 buildings in NUST. A total of 36,290 cubic meters of water can be saved per year if tanks are built on maximum water-saving efficiency criteria, which accounts for 2.73 % of total demand at NUST.

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Chapter 1

1 Introduction

This section states the motivation to carry out this project. It revisits the theoretical aspects of rainwater harvesting system, highlights the existing rainwater harvesting technology in Pakistan and NUST, problem statement and objectives of the project.

1.1 Background

The availability of fresh water in Pakistan is an alarming problem that requires immediate attention and action. Asian Development Bank has placed Pakistan in the Red Zone and declared it a water stressed country. In Pakistan, freshwater availability has declined to around 1100 m3/capita/year which is a concerning figure (Young et al., 2019). 122 billion cubic meters of water is withdrawn from canals (Amir and Habib, 2015). A significant percentage of freshwater resources are contaminated due to untreated discharge of effluent from industries. Consumption of water from the resources that are chemically and microbiologically contaminated causes various diseases. Being a developing country with limited financial and technological resources, Pakistan needs to employ sustainable solutions for fresh water that are also economically friendly.

1.2 Theory

Rainwater harvesting is a sustainable way to consume fresh water. It also helps manage storm water runoff and reduces burden on stormwater management infrastructure. Since 4500 BCE in Asia, rainwater harvesting has been used for agricultural and irrigational purposes (Ghimire et al., 2017). Rainwater harvesting can be a method of great utility especially in water stressed countries that receive ample rainfall.

Rainwater harvesting can be categorized into two main categories.

1. Surface Runoff Rainwater Harvesting
2. Roof-top Rainwater Harvesting

The aim of our project was to assess the potential of rooftop rainwater harvesting.

1.3 State of the Science

Currently, NUST makes use of Rainwater on 59% of its land area by directing it to NUST lakes and allowing it to recharge groundwater. 22% area remains unutilized for rain harvesting. Figure 1 is the map provided by Project Management Office (PMO), NUST showing the percentage of area being used to harvest rainwater and the area still unutilized.

1.4 Problem Statement

The problem of water scarcity is also a prime issue at NUST, Islamabad. According to Project Management Office, NUST, out of the total peak demand of 8 lac gallons/day, NUST is only able to supply 5-6 lac gallons/day, and that leaves us at a shortage of 2 lac gallons/day.

NUST supplies all its water by means of tube wells. There are currently 11 tube wells installed outside the premises of NUST, which operate at maximum capacity. i.e., 22 hours/day, to meet as much water demand of NUST as possible. No water is supplied to NUST by Capital Development Authority. According to PMO, NUST, installing more tube wells to meet the deficiency is not a viable option. Apart from the amount of water, quality has also been a pressing concern for Water management authorities. In this, Microbiological contamination is the most common issue. This compels us to consider alternative fresh water sources that will help us meet the demand. Among viable options, rainwater harvesting is one of the most promising solutions, especially in the context of non-potable use.

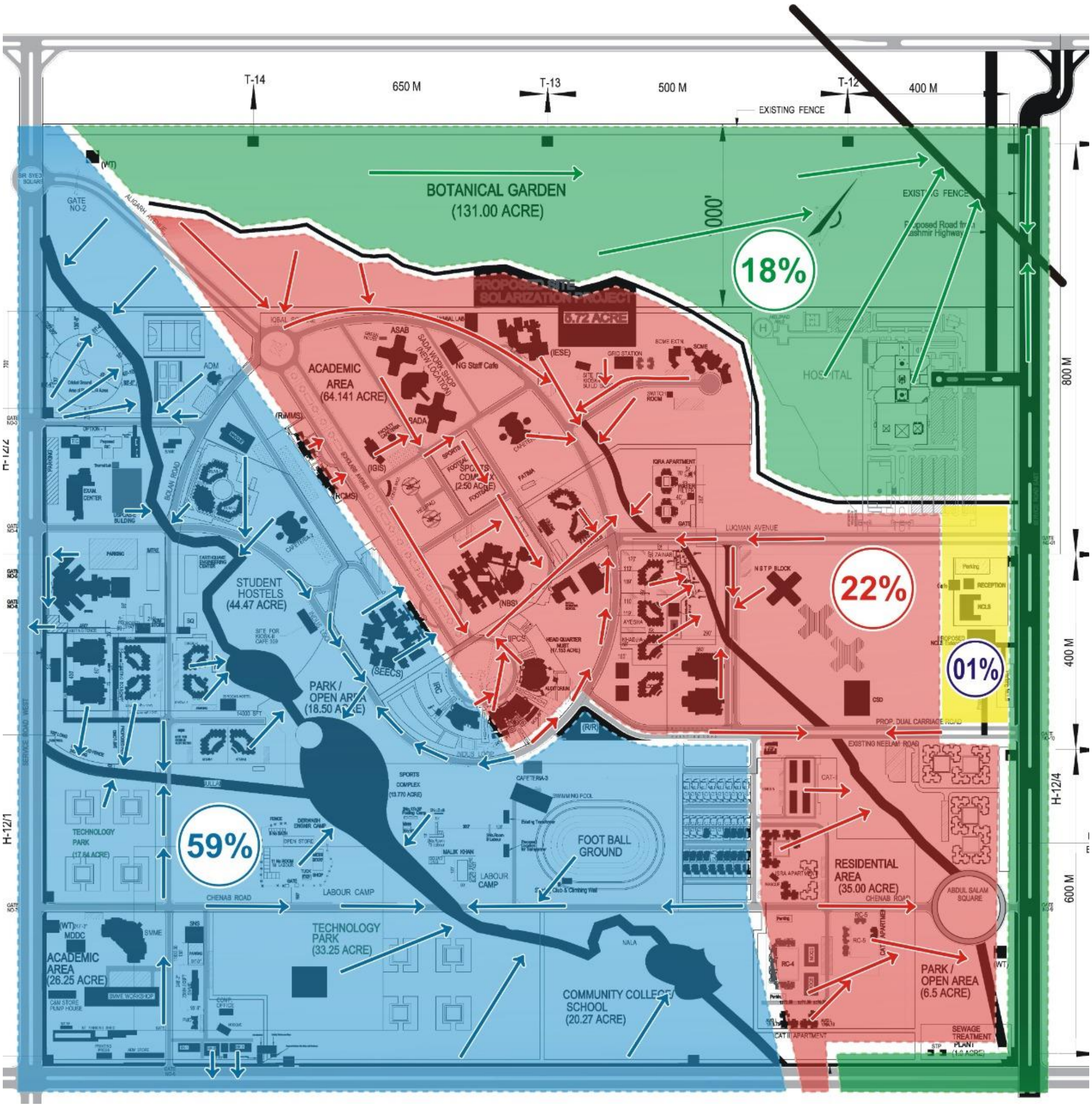

Figure 1: Area of NUST, H-12 in percentage being utilized for surface runoff rainwater harvesting [Source: Project Management Office, NUST (2017)]

1.5 Objectives

The objectives of our project are as follows:

1. Performing temporal and dimensional analysis of precipitation in NUST in context of Rainwater Harvesting
2. Evaluating and calibrating the performance of existing models using experimental data for NUST.
3. Scaling up and conducting reliability analysis of rainwater harvesting system for NUST
4. Evaluating harvested water quality to rank usage scenarios

Chapter 2

2 Literature Review

The literature review conducted for the project was divided into five categories.

2.1 Rainwater Harvesting prospect in Pakistan

Water scarcity issue is on the rise in Pakistan due to excessive population growth, urbanization, and development in industrial and agricultural section. The groundwater water resources are also depleting at an alarming rate. Rainwater Harvesting is identified as a vial source of fresh water to reduce dependency on groundwater and effective storm water management in Islamabad and Rawalpindi. (Ahmed *et al.*, 2019)

According to SamSam rainwater harvesting tool, 45 percent of non-potable demand can be met if the roof size is 220 m^2 for four people and 400 m^2 for eight people in areas with significant rainwater like Islamabad and Lahore. (Hassan, 2016)

In Islamabad, 22 percent of water demand of a 5 *marla* house (116 m^2) with average of 4 people can be using roof rainwater harvesting system (Rashid *et al.*, 2018). The roof rainwater harvesting system is an economical solution to Lahore present and future water crisis (Siddiqui and Siddiqui, 2018).

2.2 Rainwater Harvesting and Quality

2.2.1 Centralized and Decentralized rainwater harvesting system

Decentralized rainwater harvesting systems are found slightly more efficient in terms of reliability and cost than centralized rainwater harvesting system. (Słyś and Stec, 2020)

2.2.2 Pond and Roof rainwater harvesting system

Roof rainwater harvested system has better quality and is better suited for existing buildings while pond rainwater harvested system is recommended for new colonies. (Zabidi *et al.*, 2020)

2.2.3 Rainwater harvesting in NUST

NUST has total roof harvesting potential of 57 MG/year given that all of roof runoff is stored and utilized. After 3 stage sedimentation and first flush device, quality of roof rainwater was within National Standards for Drinking Water Quality (NSDWQ) except biological contamination (Zaheer and Shah, 2011). The rainwater harvested in NUST lakes can be treated using Swiss Pak filter for non-potable purposes (Nawaz and Baig, 2018).

2.2.4 Quality of Roof Rainwater

Roof material has slight effect on quality of water, aluminum coated rooftops result in worse quality, however, still falls under the water quality standard of World Health Organization

(Adeyeye, Akintan and Adedokun, 2020). Longer duration of rainfall results in better quality of water. (Asrah Bin Muhamad and Abidin, 2016)

Heavy metals like copper and iron can be found in rainwater exceeding acceptable limits (Igbinosa and Aighewi, 2017). Air pollution of the region contributed towards poor quality of rainwater. (Hasan, Driejana and Sulaeman, 2017) found sulfate, ammonium, and nitrate in decreasing percentage in rainwater. Lead concentration were also found beyond permissible limits.

On site treatment of roof harvested rainwater can be as high as US$ 180/m3 and operation and maintenance cost is 0.8 cents/Liter for simplified system (Tran *et al.*, 2021).

2.3 Time Series Analysis

The rainfall distribution, variation and amount have effect on roof rainwater harvesting system efficiency. The length of wet and dry spells must in incorporated in the design (Waweru, 1999). Depending on the rainfall pattern, shorter than 30 years' time series to simulate rainwater harvesting system could give reliable results (Soares Geraldi and Ghisi, 2018)

2.4 Modeling and Simulation

Ineffective and careless design of rainwater harvesting system reduces its reliability (Taffere *et al.*, 2016). In order to determine and achieve maximum reliability with effective design, modeling and simulation is used in various studies including (Waseem Ghani *et al.*, 2013), (Fulton, 2018), (Jay Gohel, Hina Bhatu, 2020), (Molaei, Kouchakzadeh and Haghighi Fashi, 2019), (Khan *et al.*, 2017a), (Ward, Memon and Butler, 2010).

Different modeling approaches include water mass balance, yield after spillage, yield before spillage. The yield after spillage is the most used due to its conservative approach. Performance indicator for rainwater harvesting system include Water Saving Efficiency, Storage Efficiency, Overflow Ratio, Detention Time, Demand Area Ratio and Deficit Rate (Semaan *et al.*, 2020).

2.5 Optimization of Tank Size

Optimization of tank capacity is the most important design criteria in effective rainwater harvesting system. (Campisano and Modica, 2012) uses minimum cost and regressive model approach to determine tank size for drinking water. Other studies (Hashim *et al.*, 2013), (Khan *et al.*, 2017b) (Ruso, Akintuğ and Kentel, 2019) (Lucas, Coombes and Geary, 2004) and (Goh and Ideris, 2021) use rainfall data, catchment size, runoff coefficient, first flush and water demand as input to computational model to determine optimum tank size.

2.5.1 Runoff coefficient

An average value of 0.81 is recommended for all roof types. The runoff coefficient shows significant variation on different rainfall intensities (Liaw and Tsai, 2004).

Chapter 3

3 Methodology

3.1 Data Collection

3.1.1 Roof Area

A typical Roof-Harvested rainwater collection system relies on a roof which drains via a gutter and attached pipe into a storage container. Based on roof characteristics, we calculate the rainwater harvesting potential and also predict how much water demand of building could be meet at given rainfall data. They also help us to optimize a tank for the collection of rainwater because inflow to the tank is directly to the roof area. The ground floor data of all buildings of NUST was collected from Project Management Office (PMO) NUST. We were considering ground floor area as a roof area as the buildings are built straight in NUST. See the data in **Appendix 1**

3.1.2 Total Demand

Demand is one of the censorious and important variables of rainwater harvesting systems. The reason is that by using demand data, we calculate optimal tank size of rainwater harvesting system. That is why, rainwater tank is the most expensive component of system. We collected daily total water demand of each building of NUST from project management office (PMO) which was calculated by multiplying population with authorized scale of each building.

3.1.2.1 Population

Population data of NUST buildings was collected from PMO NUST based on the consensus of 2017. See **Appendix 1**

3.1.2.2 Authorized Scale

Water is supplied to a specific building according to per-head consumption rate and the scale which is used to select per-person water demand is called authorized scale of water demand. Project management office (NUST) provided us the authorized scale of water demand of each building.

3.1.3 Meteorological Data

The Climate data required is dependent on time step used in rainwater tank in modelling and data duration type like daily rainfall data, monthly rainfall data and annually rainfall data. Climate data is sourced from historical daily climate records provided by weather stations in the locality of interest. The historical climate data help in calculating the amount of rainwater collected in tank and at what extent, they meet the water demand of specific building. We used daily and monthly rainfall data and monthly humidity and temperature data for time series analysis.

We collected 5-year monthly rainfall, temperature and humidity data from Pakistan meteorological Department, one-year (2020) daily rainfall data from Dr. Salman (IGIS) NUST and historical rainfall data of 38 years from Dr. Faheem Khokhar (IESE) NUST.

3.2 Time Series Analysis

A statistical technique called time series analysis was conducted to decompose the meteorological data of rainfall (mm), temperature (℃) and relative humidity (%) at 1200 obtained from Pakistan Meteorological Department.

Decomposition means separating the noise from time series data to identify trend, seasonality, and cycle in the raw data. The duration of time series data was 5 years, 2016 to 2020, and the resolution was monthly average. Trend and seasonality strength were also calculated using equation 1 and 2 respectively (J Hyndman, 2018).

$$F_T = \max\left(0,1 - \frac{\mathrm{Var}(R_t)}{\mathrm{Var}(T_t + R_t)}\right) \quad (1)$$

$$F_s = \max\left(0,1 - \frac{\mathrm{Var}(R_t)}{\mathrm{Var}(s_t + R_t)}\right) \quad (2)$$

R language and Studio was used to create time series plots, decomposition plots, seasonal and box plots for the data. The following libraries were used in R code:

1. lubridate (Grolemund & Wickham, 2011)
2. ggplot2 (Wickham, 2016)
3. tidyverse (Wickham et al., 2019)
4. dplyr (Wickham, et al., 2020)
5. astsa (Stoffer, 2020)
6. readxl (Wickham & Bryan, 2019)
7. urca (Pfaff, 2008)
8. ggfortify (Tang, et al., 2016)
9. tsutils (Kourentzes, 2020)

Appendix 3

contains the R script for time series analysis.

3.3 Evaluation of Rainwater Quality

To determine the most appropriate treatment system for the harvested rainwater, it is imperative to know its initial quality. The quality is determined by experimental analysis of rainwater for physical, chemical, and microbiological parameters. According to National Environmental Quality Standards for Drinking Water in Pakistan, the physical, chemical, and microbiological parameters are mentioned in table below.

Rooftop harvested rainwater quality is affected by several factors, including atmospheric pollution, land use, material of catchment, local micro-climate, traffic, and industrial activity. For this reason, experimental data of the area under consideration is of utmost importance if we are to decide suitable treatment options.

Experimental data for roof harvested rainwater at NUST was taken from Zaheer & Shah, 2011. It covered the physical parameters of turbidity, pH, alkalinity, hardness and also presence of indicator bacteria, a parameter for the measure of microbiological contamination. The averaged results for these physical parameters are demonstrated in the Figure 20 to Figure 23.

Experimental data for heavy metals in roof-harvested rainwater was not available during this study. Hence, literature was consulted for the missing parameters to have a better idea of the water quality.

3.4 Model Selection

Two models were selected and tested: Rainwater Harvesting tool by Federal Energy Management Program (FEMP) of United States and Tangki NAHRIM version 2.0 by National Water Research Institute of Malaysia written in R script.

The model by FEMP took monthly rainfall data, efficiency factor and catchment area to calculate monthly rainwater harvesting potential based on equation 3.

$$V_R = A \times d_r \times E \quad (3)$$

V_R = volume of rainfall collected (gallons)

A = catchment area (square feet)

d_r = depth of rainfall (inches)

E = efficiency factor

The Tangki NAHRIM 2.0 was finalized because it was open source, incorporated first flush, and of its tank size optimization ability based on two types of performance indicator: storage and water saving efficiency.

The Tangki NAHRIM 2.0 also generated MS excel file comprising of more detailed analysis of rainfall data, average number of no rain days in a month, average volume of spillage and yield per year, average number of days per year with yield fulfilling demand and with spillage and percentage of time the tank remained empty and partially filled.

3.5 Simulations

The simulations were run in a Web App developed by National Water Research Institute of Malaysia for 35 of NUST buildings shown in Table 1. All the building with tilted roofs and missing data of population, roof area or water demand were excluded from this study as the model required all these parameters as input. Only the building with a straight built i.e., whose ground floor area equaled roof area were chosen.

3.5.1 Input Parameters

3.5.1.1 Rainfall Data

The model required a daily rainfall data as a csv file, first column as date in the format of DD/MM/YYYY and second column as depth in mm. Since the rainfall data acquired was monthly data of 38 years, it would have been lethargic to create the file manually. The Excel VBA code was written to insert specific number of rows between each reading to add daily monthly data. **Appendix 3**

shows the excel VBA code.

The daily rainfall data was available for the year 2020 only. The simulation was run taking only 2020 daily data and results obtained and compared with monthly rainfall data of 2020 manipulated in three ways:

1. Monthly average rainfall divided equally on all month days
2. Monthly average rainfall divided on first 10 days of the month
3. Monthly average rainfall divided on 10 random days of the month.

The second manipulation (dividing monthly average on first 10 days of the month) gave closed result to daily rainfall data result and hence this method was adopted to turn monthly rainfall data into daily rainfall data in the csv file.

3.5.1.2 First flush

The first flush value was set at 1 mm as suggested by (Doyle and Shanahan, 2010) to get suitable quality water for non-potable purposes.

3.5.1.3 Run-off coefficient

Run-off coefficient was taken 0.8 as suggest by (Liaw and Tsai, 2004) after conducting experiments for all roof types.

3.5.1.4 Roof catchment area

The ground floor area data was obtained from Project Management Office of NUST and only the building with same roof area were considered in the study. Therefore, the ground floor area was considered as catchment area of the buildings.

Departments	Residential Buildings	Administration buildings
1. IESE	17. CIPS/Dinning Hall	29. Main Office
2. NBS	18. Fatima Hostels (1 & 2)	30. MI Room
3. SEECS	19. Ayesha Hostel	31. PMO
4. SADA/C3A	20. Zainab Hostel	32. Press Building
5. ASAB	21. Iqra Apartments	33. HBL
6. SCME	22. Ghazali Hostel (1 & 2)	34. Admin Building
7. S3H	23. Attar Hostel (1 & 2)	35. Al Jazari Block
8. IGIS	24. Razi Hostel (1 & 2)	
9. RCMS	25. Rumi Hostel (1,2 & 3)	
10. RIMMS	26. SM Barrack	
11. NIT	27. Isra Apartments	
12. Exam Center	28. Gymnasium	
13. NICE		
14. UPCAS-EN		
15. SNS		
16. NCLS		

Table 1: Name of the buildings selected of NUST selected for simulations.

3.5.1.5 Tank Capacity Range

Model required a range of tank capacity as input to provide efficiencies against. A range of 1 to 30 m^3 was used in simulations as NUST is based on 4 km^2 area and buildings are not congested. Considering huge demands, maximum capacity of 30 m^3 was reasonable.

3.5.2 Calculations

The rainfall runoff from roof is calculated using rational method by (Mitchell 2007; Khastagir & Jayasuriya 2010) in (Goh and Ideris, 2021) shown in equation (4).

$$R_i = C \times (P_i - F) \times A \qquad (4)$$

▲i = time interval

R = rainfall runoff from roof

C = runoff coefficient

P = precipitation

F = first flush depth

A = roof area

Tangki NAHRIM model uses Yield After Spillage (YAS) approach where rainwater is consumed after the spillage had occurred and the equation (5) and (6) shows this approach.

$$Y_i = min\begin{cases} D_i \\ V_{i-1} + R_i \end{cases} \tag{5}$$

$$V_i = min\begin{cases} S - Y_i \\ V_{i-1} + R_i - Y_i \end{cases} \tag{6}$$

Y = yielded rainwater to fulfil demand

D = demand

V = volume of active storage of tank

S = tank storage capacity.

To evaluate the performance of the system at different tank capacities, two criteria efficiency were calculated, water saving efficiency and storage efficiency, show in equation

$$WSE = \frac{\sum_{i=1}^{n} Y_i}{\sum_{i=1}^{n} D_i} \times 100 \tag{7}$$

$$SE = \left[1 - \frac{\sum_{i=1}^{n} Qs_i}{\sum_{i=1}^{n} R_i}\right] \times 100 \tag{8}$$

WSE = Water Saving Efficiency

SE = Storage Efficiency

Water saving efficiency is the percentage of demand fulfilled by the rainwater harvesting system at a specific tank size. Storage efficiency is how much of the roof runoff is stored and utilized in tank after spillage.

3.6 Usage Scenarios

There are several end-uses for water at the domestic and institutional level and roof-harvested rainwater can be used for any of them. According to American Water Works Association (2016), about 60% of water is used for outdoor purposes, mainly for watering green space. About 30% is used for indoor non-potable purposes, including toilet flushing and faucets and about 10% is used for potable purposes, including drinking and cooking.

3.6.1 Non-Potable Use of Rainwater

If the roof-harvested rainwater is to be used for irrigation purpose, then it needs to fulfill some basic quality standards. Irrigation water quality standard provided by Water and Power Development Authority (WAPDA). WAPDA gives guidelines for 4 parameters which include electrical conductivity, TDS, Sodium Adsorption Ration and Residual Sodium Carbonate. These values are mentioned in the Figure 24.

3.6.2 Potable Use of Rainwater

If the rainwater is to be used for potable purposes, then the values for quality parameters provided by National Environmental Quality Standards for Drinking Water must be below the maximum acceptable limits. Information regarding whether rainwater quality parameters are under the safe limits set NEQS is shown in Figure 25.

3.7 Database

The results for all simulations were compiled in an MS Excel database created with the help of VBA code. The model generates separate file for each simulation of each building. Each building had 3 simulations which means a total of 105 excel sheets were combined to create a database. For MS excel VBA code, see **Appendix 3**

Chapter 4

4 Results and Discussion

This section summarizes the collected data, analysis of results of time series analysis, quality evaluation and, modeling and simulation of three usage scenarios.

4.1 Data Collection

Figure *2* shows the ground floor area in square feet of NUST considered as roof area in simulation. IESE has the largest ground floor area, hence, largest roof catchment area. This graph is divided into 3 locations of NUST.

Figure 3 shows the population of each building in NUST as per 2017 census. SEECS and NBS has the highest population.

Figure 4 shows the total demand of each building in NUST obtained by multiplying population with authorized scale (Table 2). Collective demand of boy's hostel, excluding Rumi Hostels, has the highest demand followed by Isra Apartments.

Figure 5Figure 6,Figure 7 shows the meteorological data used in time series analysis.

Appendix 1

shows the data used in simulations.

Figure 2: Ground floor area (square feet) data of NUST buildings considered as a roof area is provided by PMO.

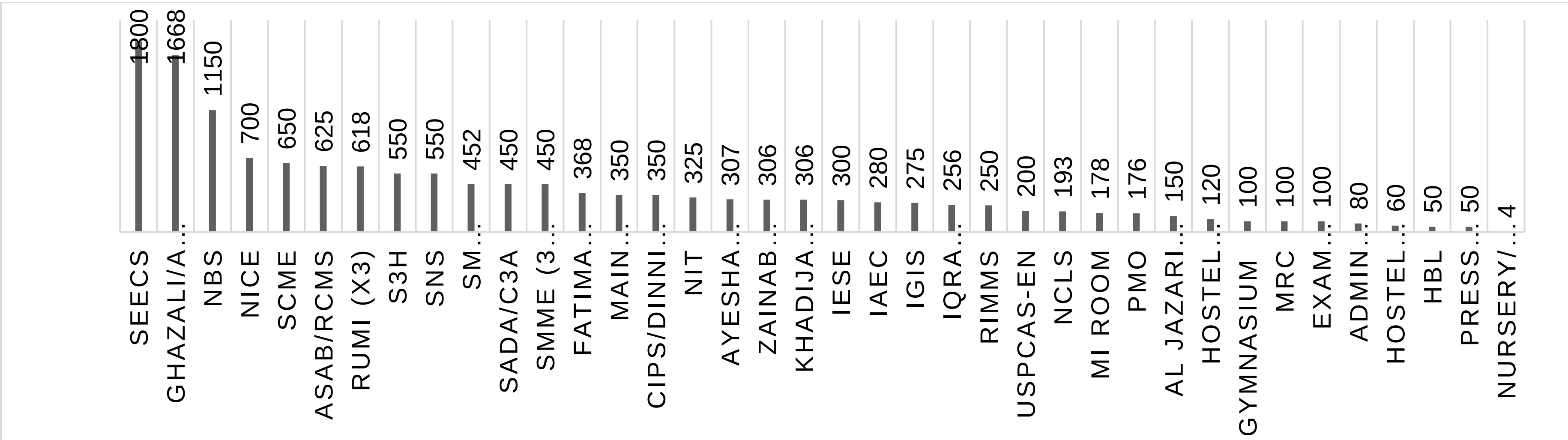

Figure 3: NUST Population data of all buildings,Project management office(PMO). .

Demand

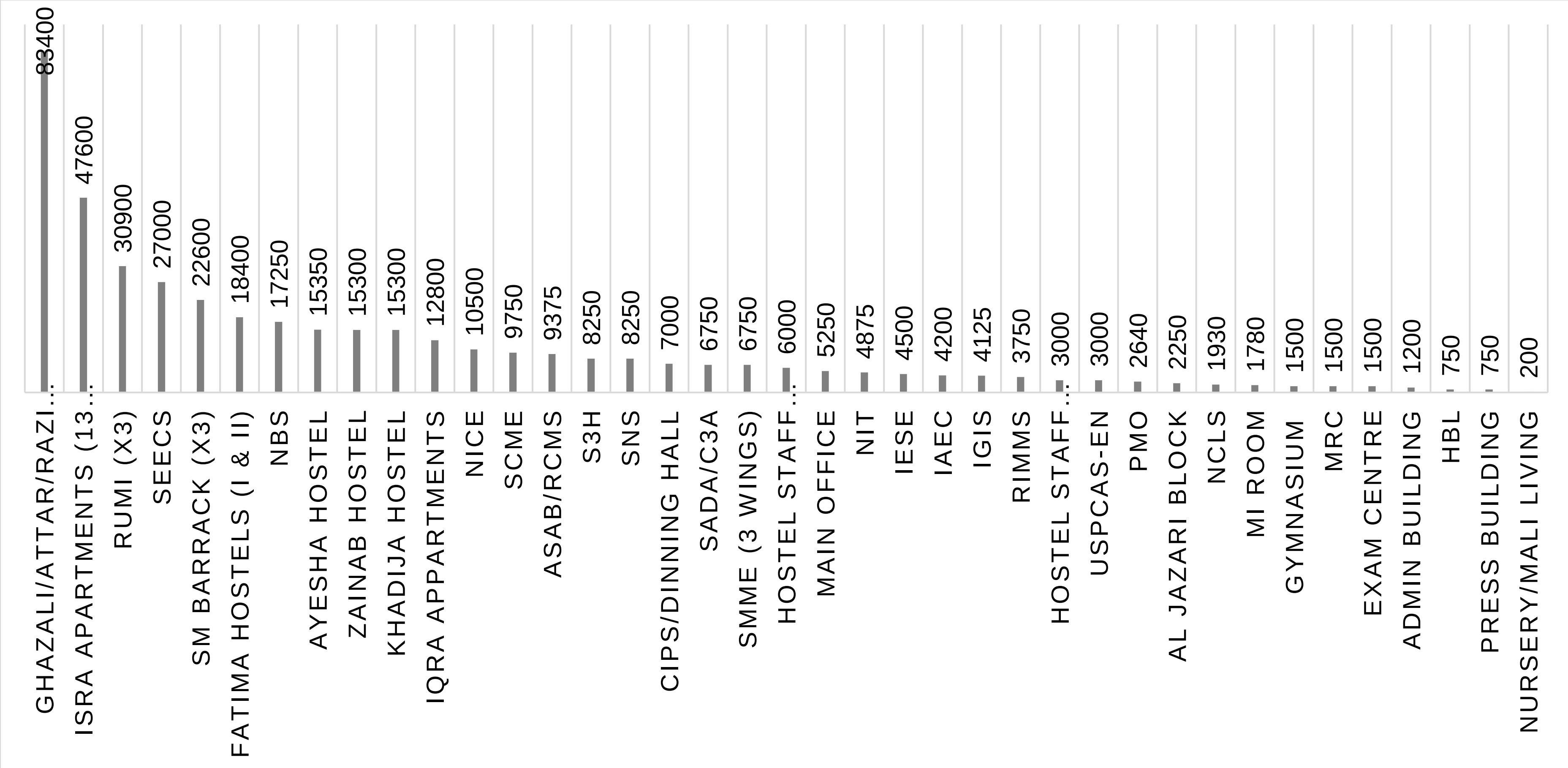

Figure 4: Project management office, NUST is provided total water demand (gallons/day) data of all buildings.

Authorized scale

Types of Buildings	Quantity of water supplied (Gln/head/day)
Accommodation	50
Dinning Facility	20
Educational Institute	15
School	15
MI Room	10
Administration	15

Table 2: per-head water demand of NUST provided by PMO.

Average Monthly rainfall

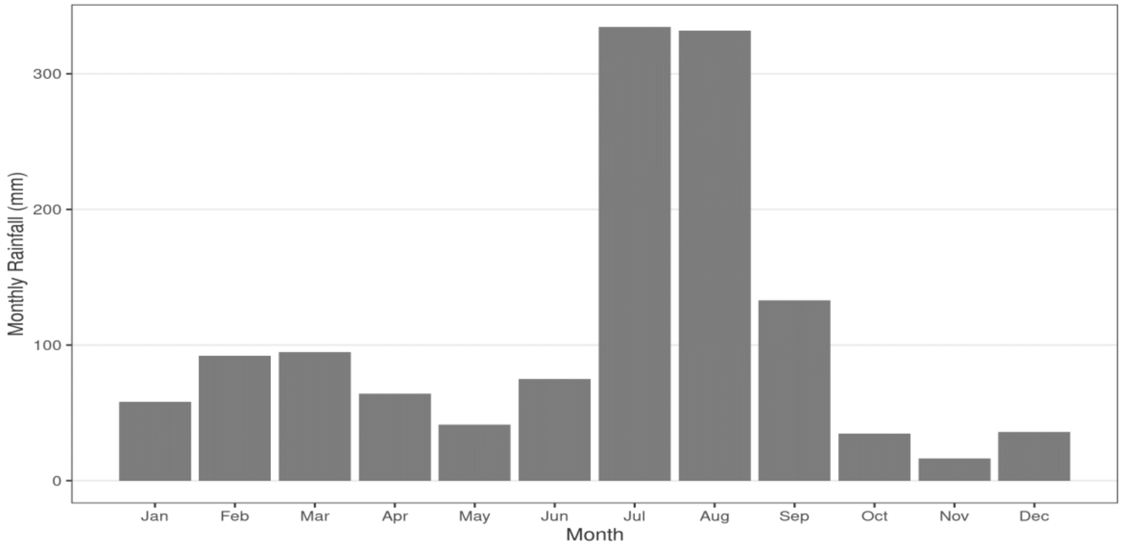

Figure 5 Monthly historical rainfall data of 38 year

Temperature

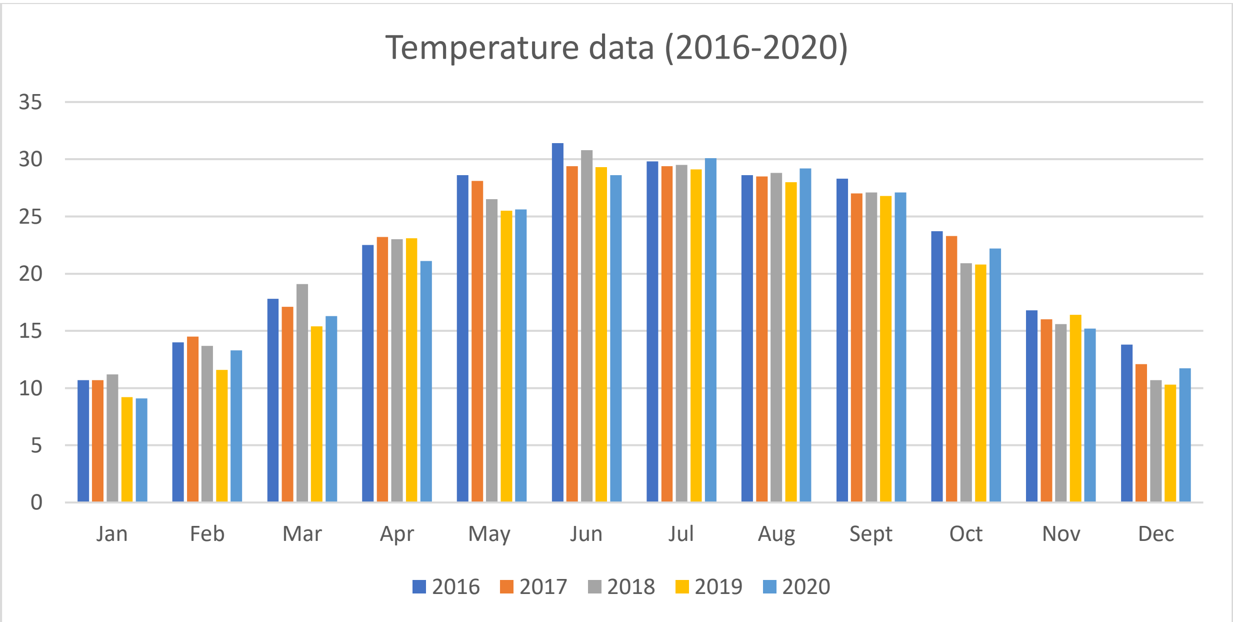

Figure 6: Temperature data of 5 years (2016-2020) collected from PMO

Humidity

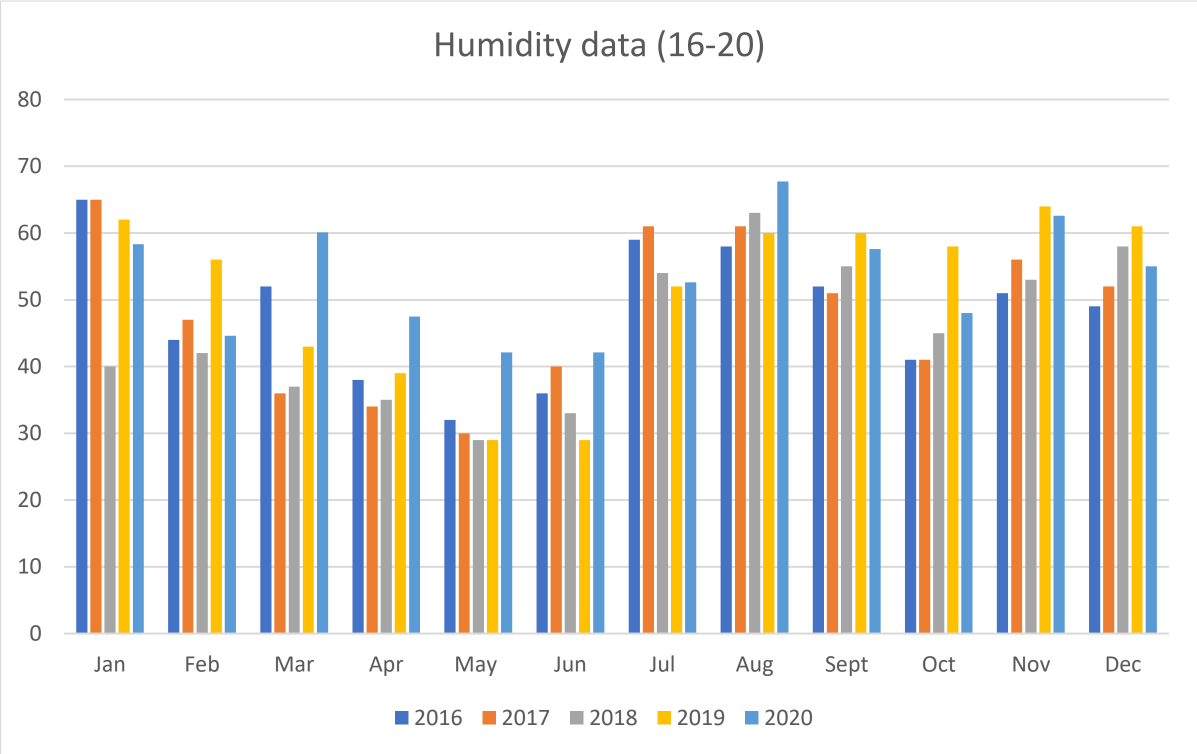

Figure 7: Humidity data of 5 years (2016-2020) collected from PMO

4.2 Time Series analysis

4.2.1 Rainfall

Figure 8 shows the Time series plot for monthly average rainfall. The two highest peaks can be observed in the year 2018 and 2019.

Figure 9 shows the decomposed time series of rainfall into three components: remainder, seasonal trend, and trend. The rainfall trend strength calculated using equation 1 is 0.02 and seasonal strength calculated using equation 2 is 0.8.

Figure 10 shows the seasonal plot of rainfall data. The driest period of the year September to December and the year experience the most rainfall in July and August.

Figure 11 shows the seasonal box plot for rainfall. The most variance in data can see by the thickest box in the month of August, March and July in descending variance. The month of April, September and December rainfall data has least variance. The thick line in the middle of the box indicates the average value for that month over the period of 5 years.

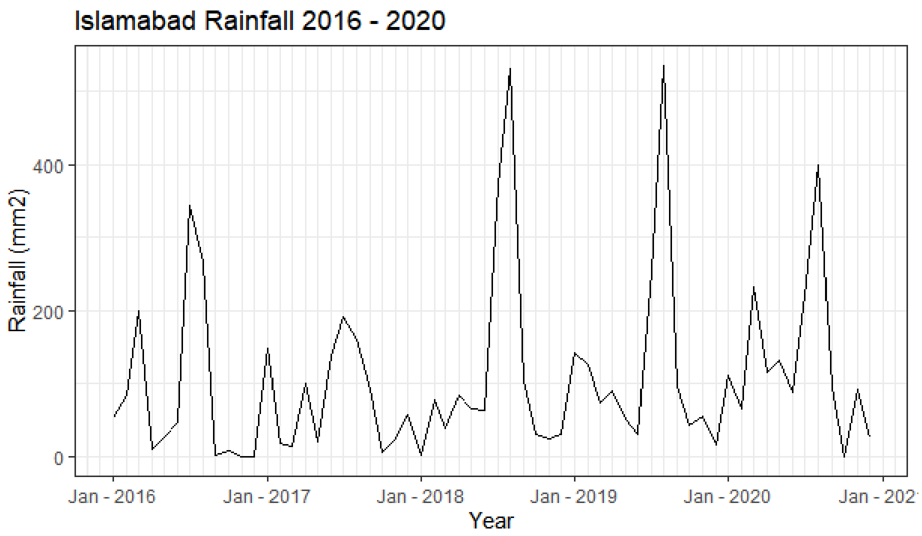

Figure 8: Time Series Plot for monthly average rainfall data of Islamabad

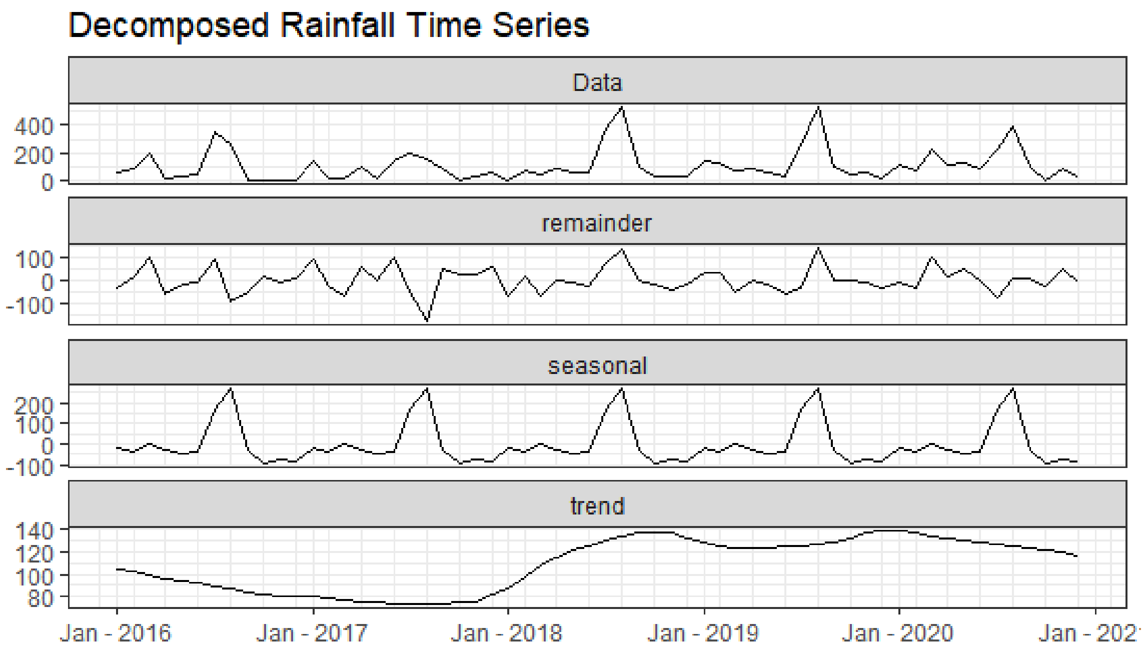

Figure 9: Decomposed Rainfall Time Series

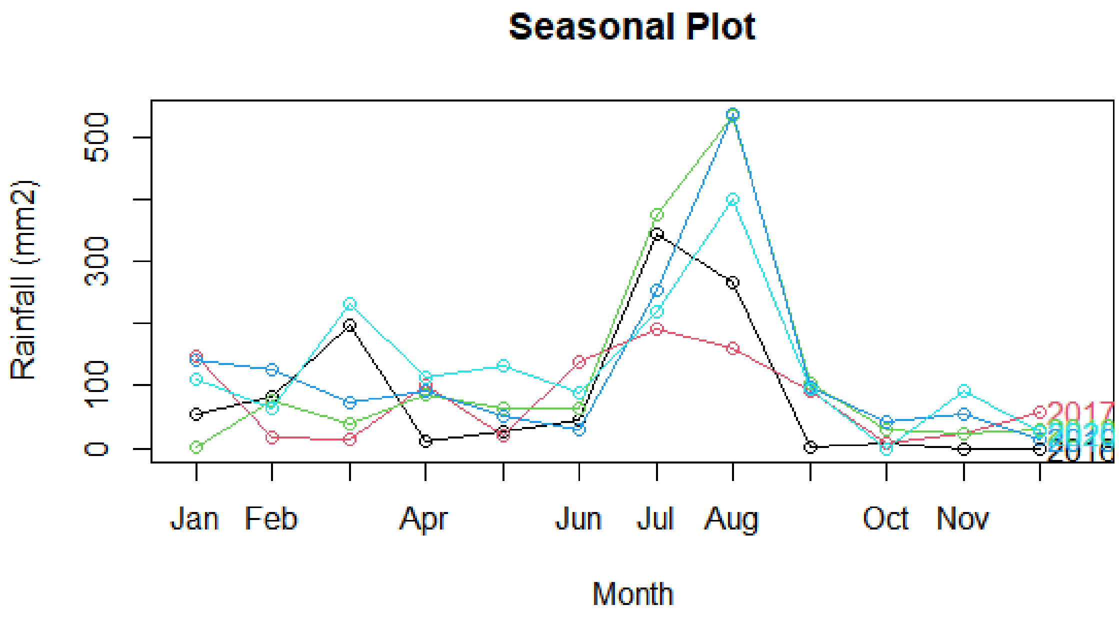

Figure 10: Seasonal Plot of Rainfall

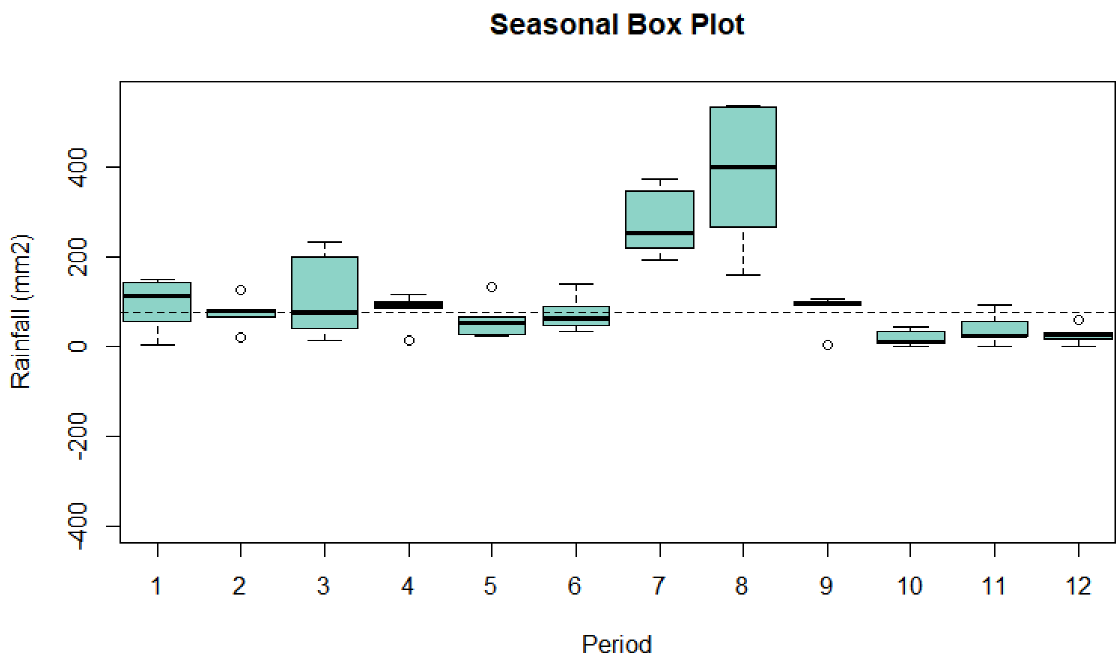

Figure 11: Seasonal Box Plot of Rainfall

4.2.2 Temperature

Figure 12 shows the time series plot for temperature. The cyclic nature of the monthly average temperature data is very prominent.

Figure 13 shows the decomposed temperature time series. The trend strength for temperature data was higher than rainfall data. The trend strength for temperature was 0.2 while the seasonal strength was 0.8.

Figure 14 shows the temperature seasonal plot. The monthly average temperature steadily increases and peaks in July and then steadily decreases.

Figure 15 shows the seasonal box plot of monthly average temperature. There is not much monthly variance in temperature data.

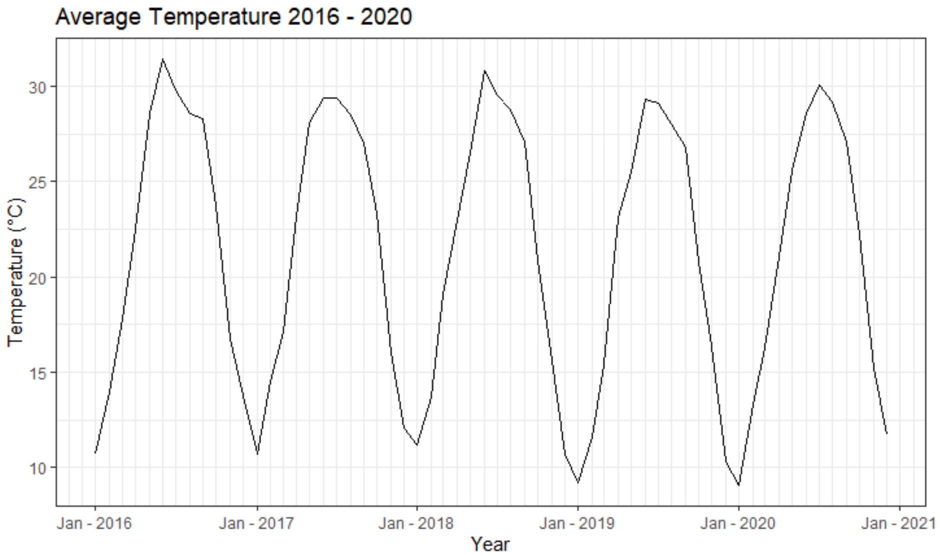

Figure 12: Time Series Plot for average monthly temperate of Islamabad

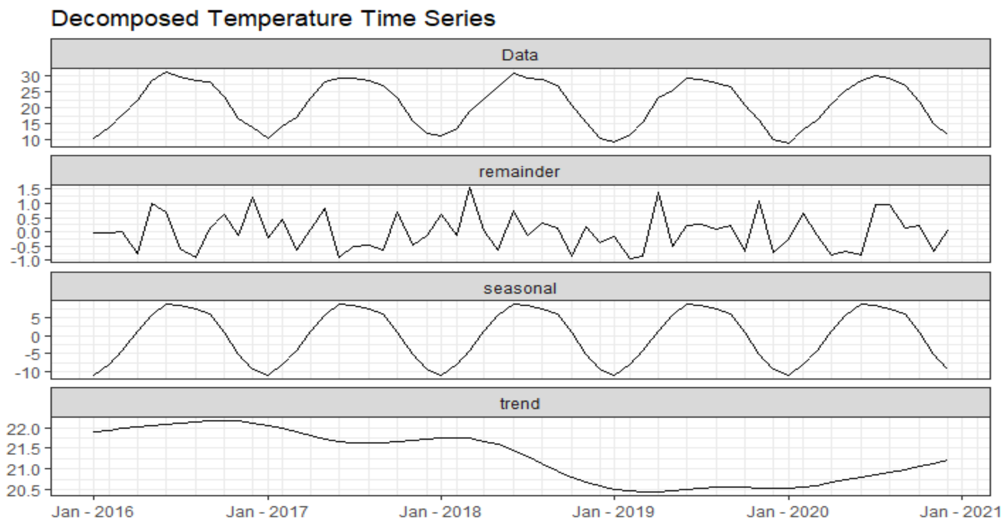

Figure 13: Decomposed temperature time series

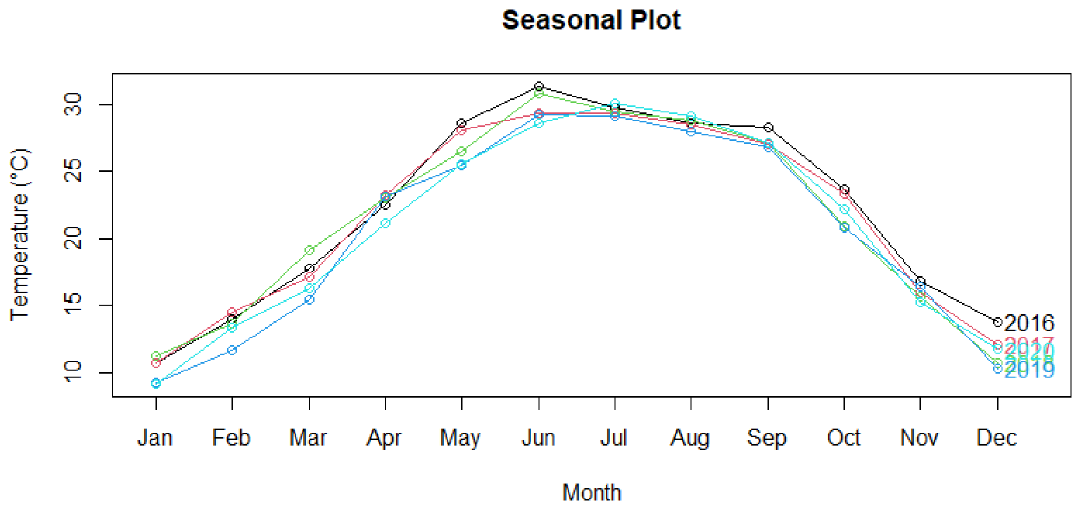

Figure 14: Seasonal Plot of Temperature

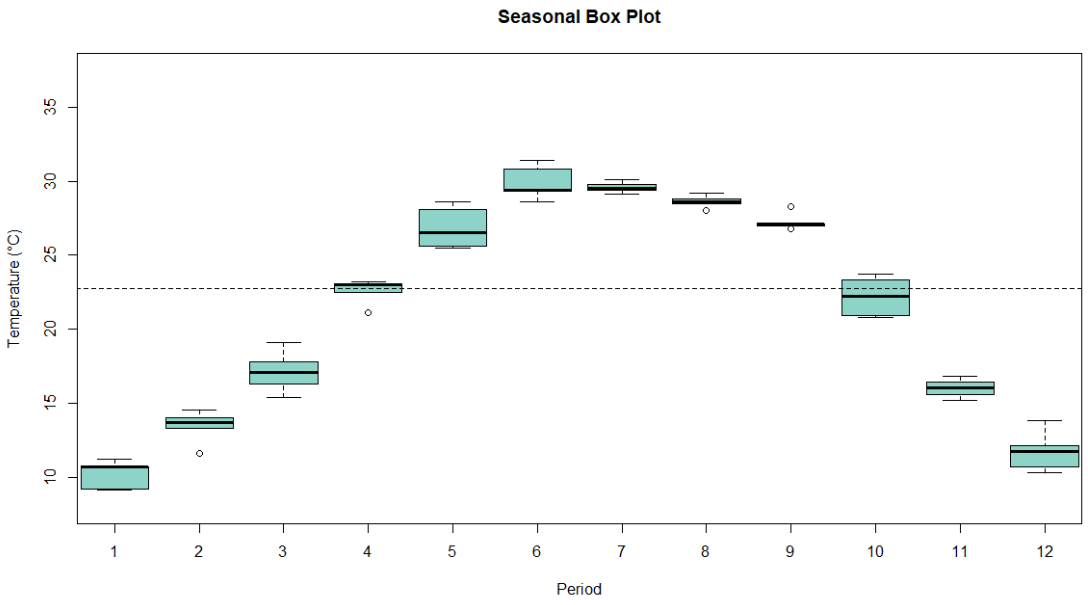

Figure 15: Seasonal Box Plot of Temperature

4.2.3 Relative Humidity

Figure 16 shows the time series plot for monthly average relative humidity at 1200 UTC in Islamabad.

Figure 17 shows the decomposed relative humidity time series. The trend strength in humidity data was highest at 0.4 and the seasonal strength was same as for rainfall and temperature i.e., 0.8.

Figure 18 shows the seasonal plot of relative humidity. The driest air is observed in the month of May and June.

Figure 19 shows the seasonal box plot of relative humidity with highest variance in March. The least variance is observed in February and August, but these months have an outlier data point indicated with a small circle on the graph.

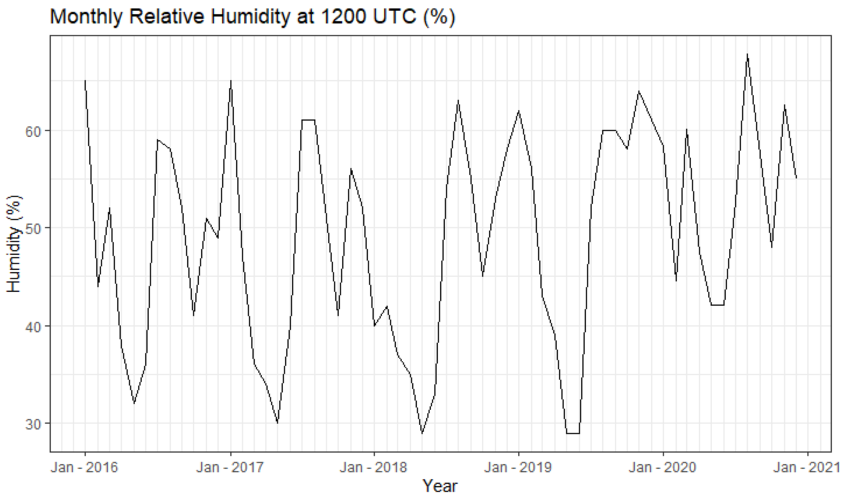

Figure 16: Time Series Plot of Monthly Relative Humidity at 1200 UTC

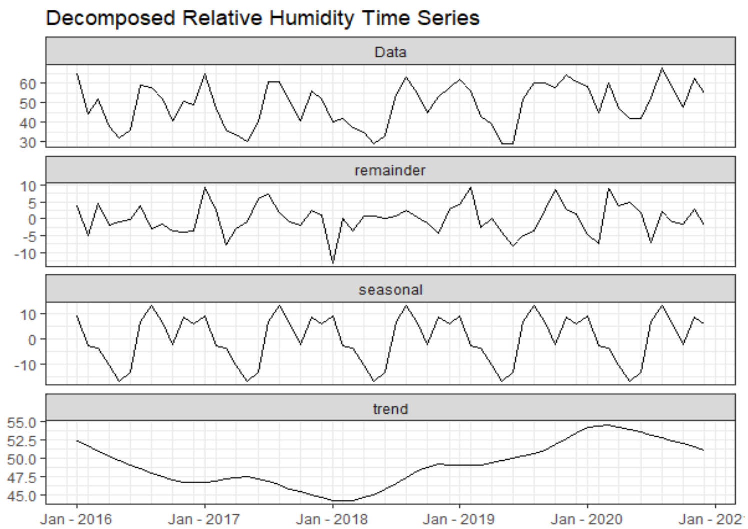

Figure 17: Decomposed relative humidity time series

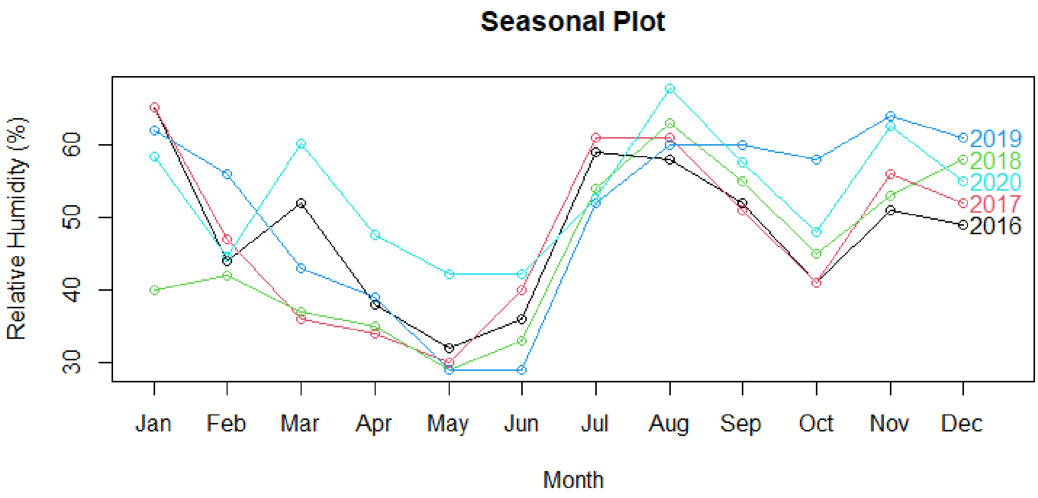

Figure 18: Seasonal Plot of Relative Humidity

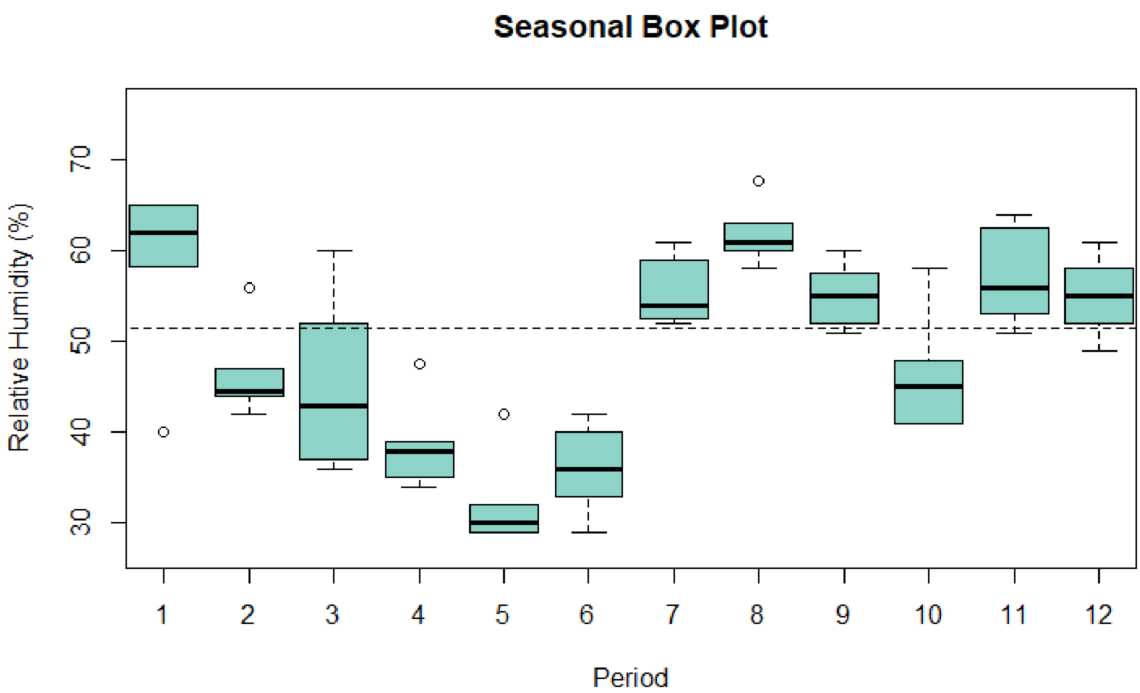

Figure 19: Seasonal Box Plot of Relative Humidity

4.3 Quality Evaluation

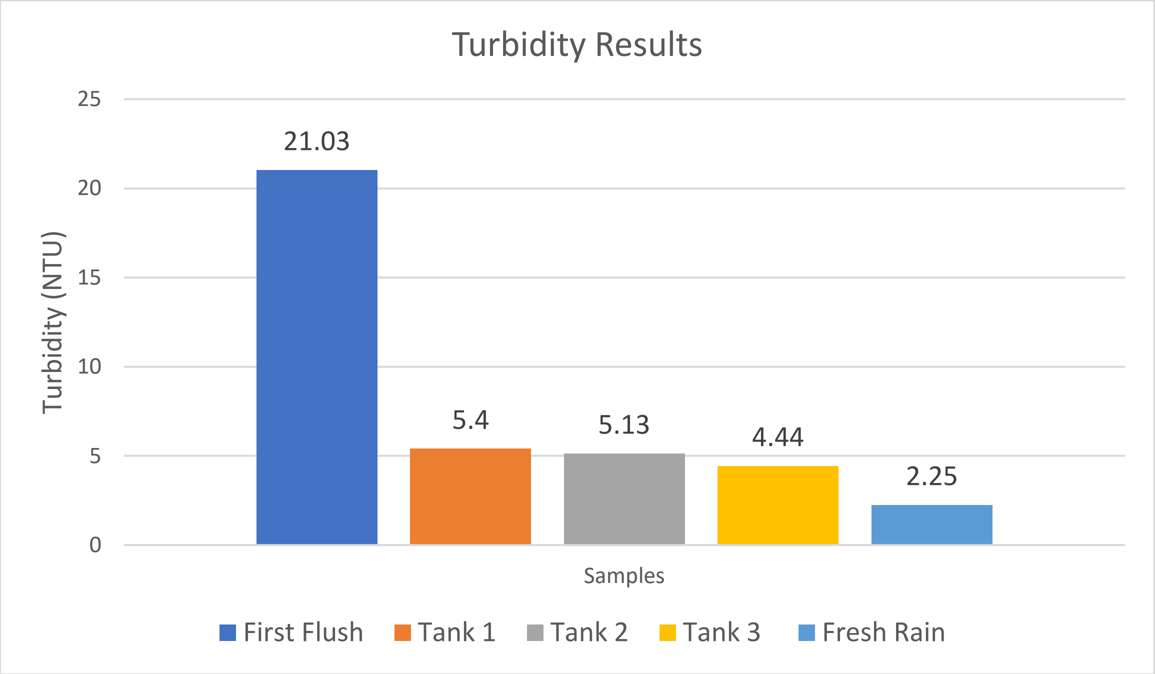

Figure 20: Average Turbidity of Rainwater Samples

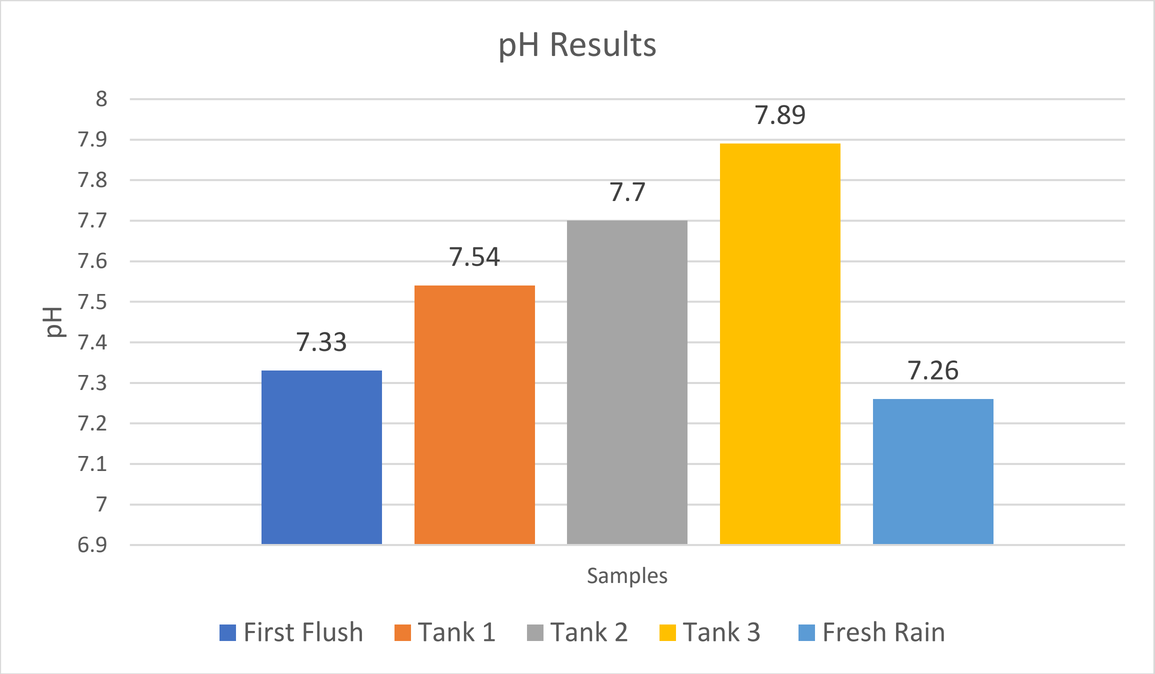

Figure 21: Average pH of Rainwater Samples

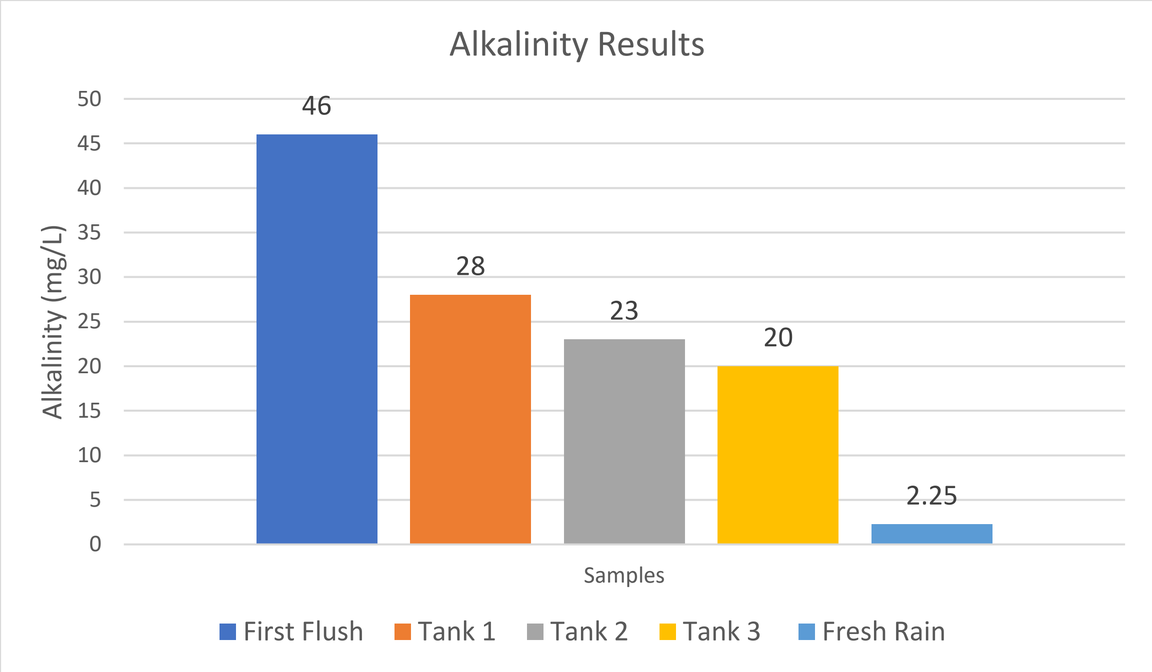

Figure 22: Average Alkalinity of Rainwater Samples

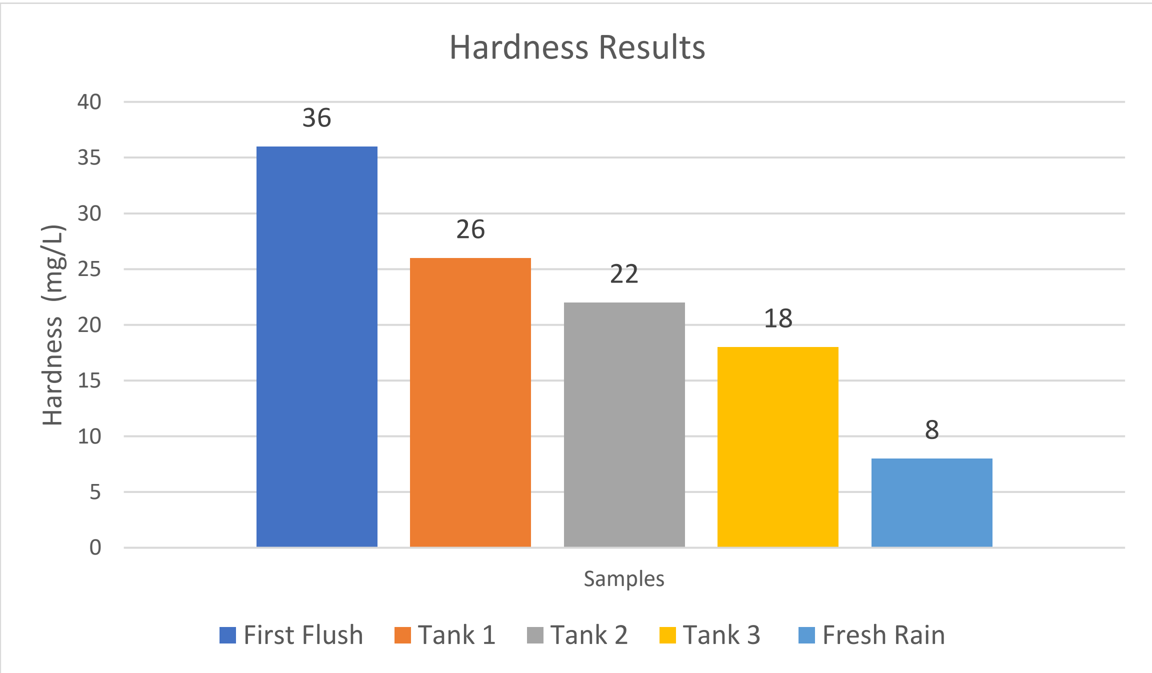

Figure 23: Average Hardness of Rainwater Samples

From Figure 20 to Figure 23, it can be seen that the roof harvested rainwater is generally quite clean. In Figure 20, after the first flush, average turbidity of the water is around 5 NTU, decreasing further in subsequent tanks. In Figure 21, the pH of harvested rainwater ranges between 7 and 8. In Figure 22, alkalinity is less than 50 mg/L, decreasing continually in subsequent tanks. And in Figure 23, hardness is less than 40 mg/L of $CaCO_3$. Microbiological contamination was detected in all the samples according to Zaheer & Shah (2016).

	Rainwater Quality at NUST	WAPDA Standards	Treatment Option
Electrical Conductivity	✓	1500 us/cm	No Action Required
Total Dissolved Solids	✓	1000 mg/L	No Action Required
Sodium Adsorption Ratio	✓	10	No Action Required
Residual Sodium Carbonate	✓	2.5 meq/L	No Action Required

Figure 24: Quality of rainwater samples evaluated against irrigation standards by WAPDA

If the harvested rainwater is to be used for irrigation, then according to these guidelines, values for all four parameters in harvested rainwater are well under the maximum limit. This suggests that roof-harvested rainwater at NUST is safe to be used for irrigation without any prior treatment.

For making conclusions about rainwater for drinking, data of heavy metals is needed. For information regarding heavy metals in harvested rainwater, in the study conducted by (Zdeb, 2020), it was found that the samples of rainwater had values that are under the maximum acceptable limit of NEQS. In a similar study conducted in northern cities of Vietnam (Tran et. Al, 2020), it was found that all heavy metals were under the maximum acceptable limit except for Cadmium.

	Rainwater Quality at NUST	NEQS Standards	Treatment Option
Turbidity	✓	< 5 NTU	No Action Required
pH	✓	6.5-8.5	No Action Required
Alkalinity	✓		No Action Required
Hardness	✓	< 500 mg/L	No Action Required
Microbial Contamination	✗	E-coli should not be present	Chlorination or UV disinfection
Heavy Metals			

Figure 25: Quality of rainwater samples evaluated against NEQS for drinking water

4.4 Suggested Treatment Options

Treatment for harvested rainwater is suggested according to the intended end use. If the end use is irrigation and watering plants, then only sedimentation in the storage tank is enough since all parameters are under maximum acceptable limit.

If the end use is non-potable indoor use, then along-with sedimentation, disinfection with chlorination is required. Chlorination is a relatively cheaper, yet effective disinfection technology. This will make the water safe to be used indoors.

If the end use is drinking, then a complex filtration assembly is required after sedimentation. This filtration assembly is suggested to include a 50-micron fiber filter, activated carbon cartridge filter, and ultra-filtration membrane. This is followed by disinfection with Ultraviolet sterilizer. Using this treatment options, roof-harvested rainwater was observed to be clean with all quality parameters under acceptable maximum value. (Tran et al., 2020)

50-micron filter removes relatively larger, suspended particles. Activated Carbon has been proven to be effective in removing heavy metals to a large extent. In experimental trials, activated carbon filter will contribute in removing heavy metals, organic contaminants, and also in improving smell and taste. 0.1-micron filter will remove bacteria and UV sterilizer will kill the pathogenic micro-organisms.

4.5 Model Simulations

4.5.1 Manipulation of monthly rainfall data

Figure 26,Figure *27*

Figure 28Figure 29 shows the different results obtained with manipulating average monthly data differently. The results using monthly rainfall data divided on first 10 days of the month gives closes result to daily resolution data. Therefore, this method was adopted to turn average monthly rainfall data of 38 years into daily rainfall data.

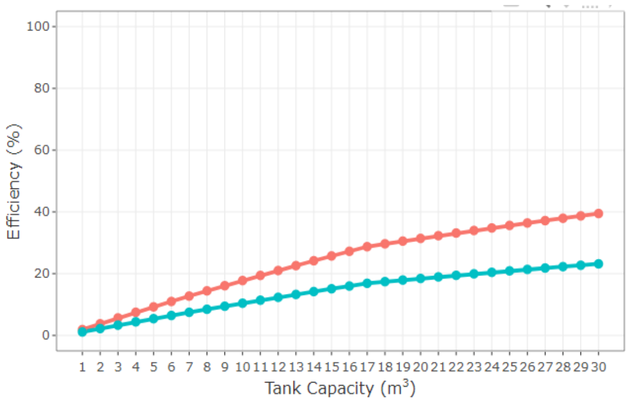

Figure 26: Result using daily rainfall data of 2020

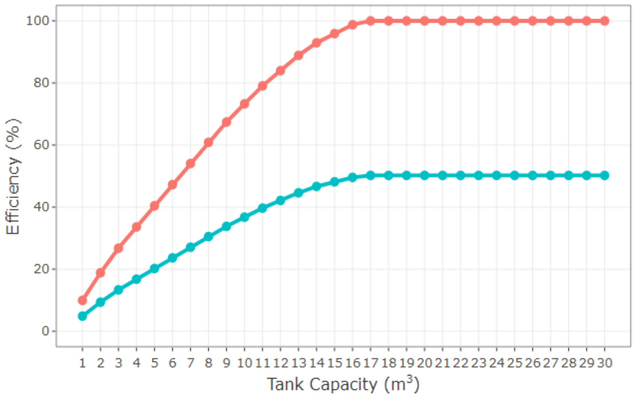

Figure 27: Result using average monthly rainfall divided equally

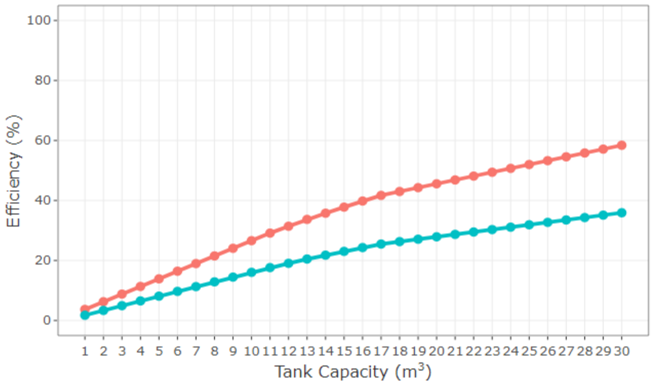

Figure 28: Result using monthly data divided on random 10 days of the month

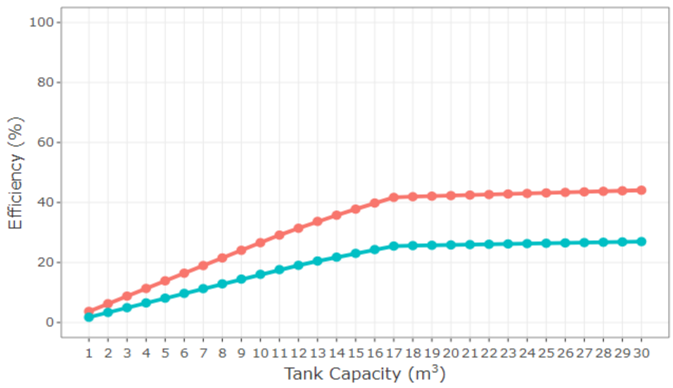

Figure 29: Result using monthly rainfall data divided on first 10 days of the month

4.5.2 Zainab Hostel Potable Demand – Case Study

Determining an optimum tank size for a building depends upon maximum water saving efficiency and storage efficiency but is limited by cost and land availability. In this section, Zainab Hostel model results for potable demand scenario are discussed.

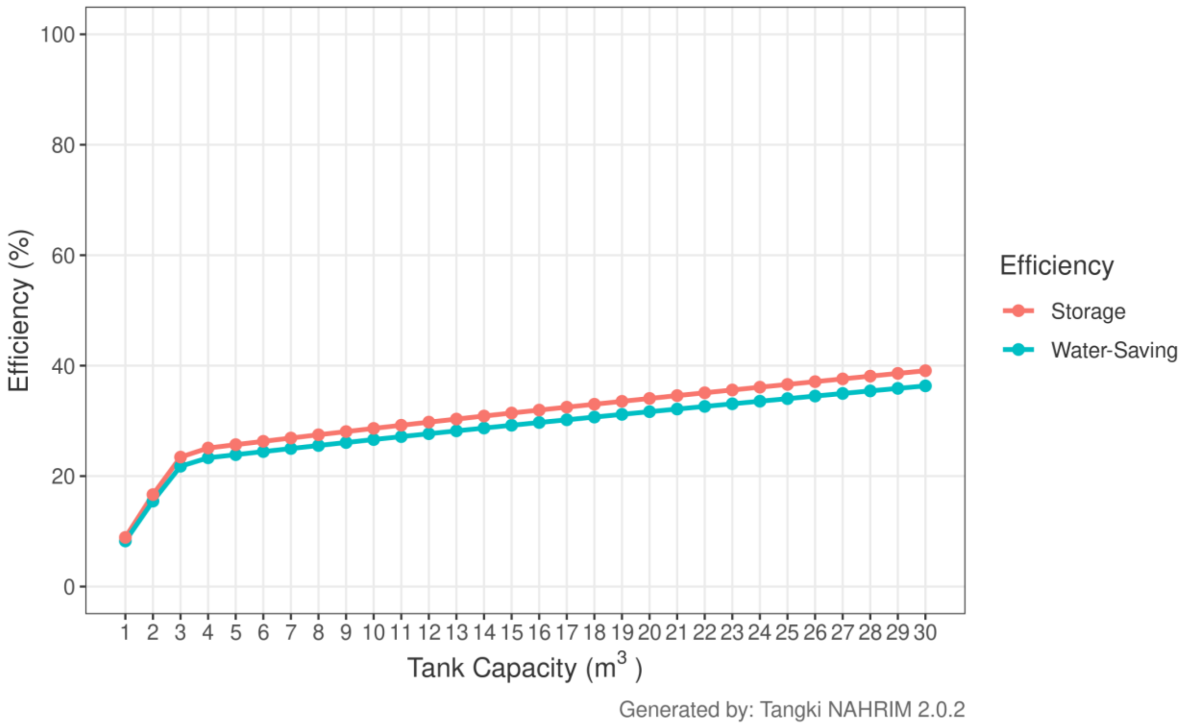

Figure 30: Efficiency graph for Zainab Hostel - Potable Demand

Figure 30 shows that there is sharp increase in both storage and water saving efficiency uptil 3 m^3, beyond this point there is slight increase up till 30 m^3. Maximum water saving efficiency that can be reached within 1 to 30 m^3 of tank capacity is 36.3 percent. The optimum tank size here depends upon the space available and need to meet the demand.

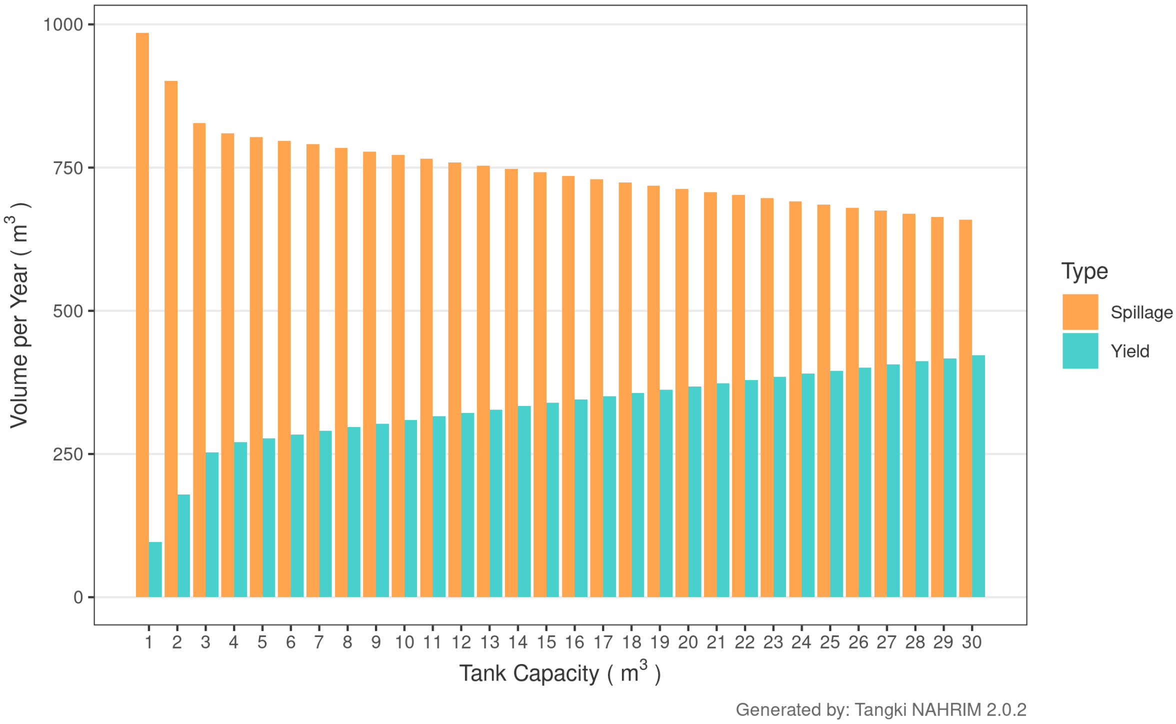

Figure 31: Yield vs Spillage Volume per year - Zainab Hostel - Potable Demand

Figure 31 shows that the spillage per year for potable demand scenario is higher than yield at any tank capacity between 1 to 30 m^3. This implies that a tank size above 30 m^3 with reduce spillage and increase yield. This trend was also observed in Figure 30 which showed increasing water saving efficiency i.e., higher demand being met and increasing storage efficiency i.e., less spillage.

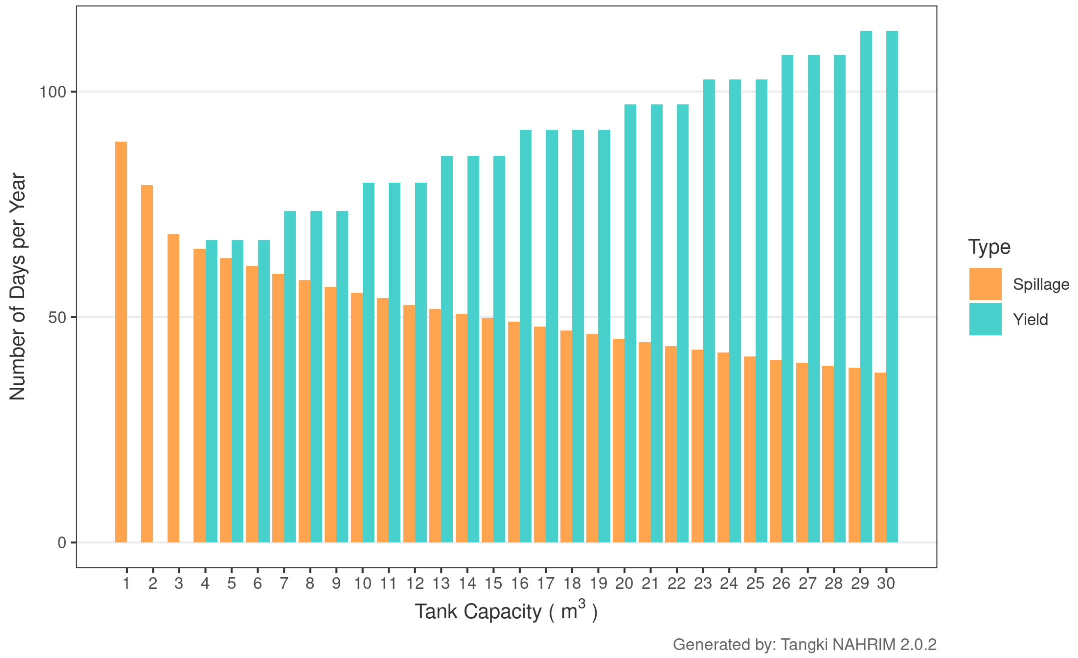

Figure 32: Yield vs Spillage by Day - Zainab Hostel - Potable Demand

For temporal reliability, Figure 32 shows the number of days per year spillage occurred vs the number of days the yield fulfilled the demand. As the tank size increases, the temporal reliability increases. However, the highest tank capacity of 30 m^3 can fulfil the demand only 113 days/year on average.

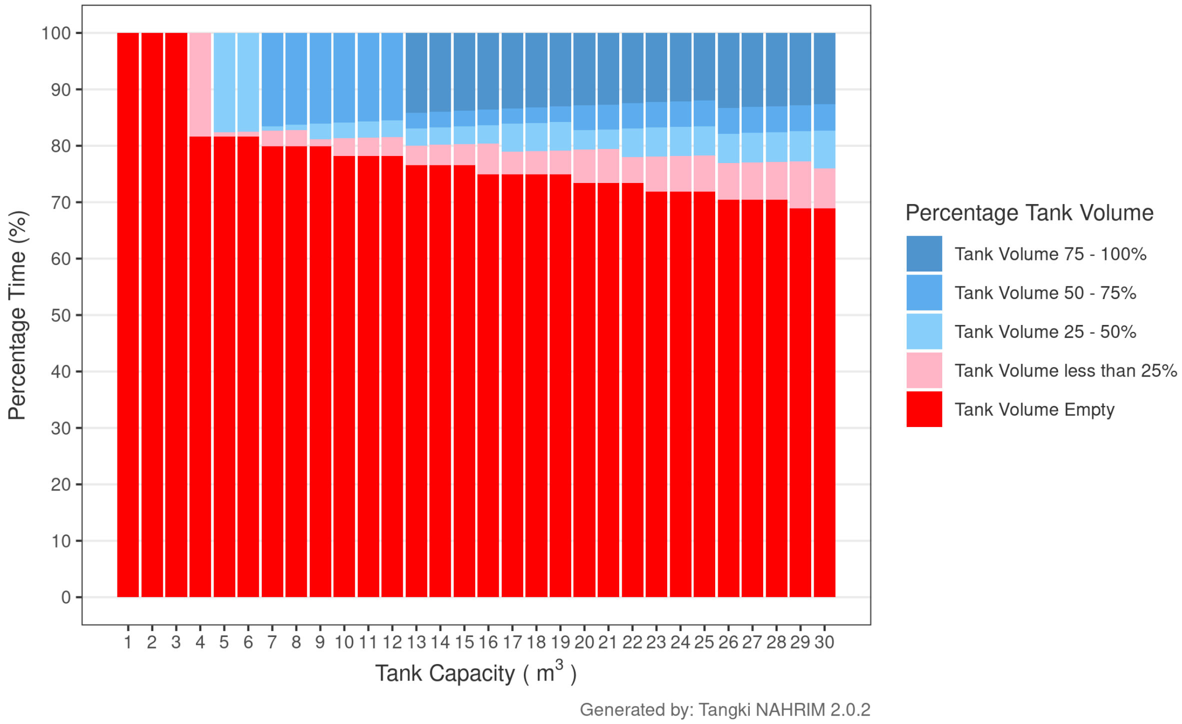

Figure 33: Percentage Tank Volume - Zainab Hostel - Potable Demand

To present the percentage time the tank is at specific volume for different tank size considered, the tank volume is divided into 5 classes. This is shown in Figure 33. Then, the model calculates the percentage of time the water in tank is at each class. For tank size 1 to 3 m^3, the tank remains empty 100 percent of the time. For tank size 4 m^3, the tank volume is less than 25 percent 19 percent of the time and tank is empty 81 percent of the time. At 13 m^3, at least 14 percent of the time, the tank capacity is between 75 to 100 percent. However, such scenario is required when huge fluctuation in demand is expected.

Such graphs were created and stored in a database for 35 building for 3 demand scenarios; total demand scenario, potable demand scenario and non-potable demand scenario. Scan the QR code below to get access to MS Excel database of every building.

4.5.3 Simulation output summary

4.5.3.1 Water Saving Efficiency

Figure 35 shows the maximum water saving efficiency for each of 35 buildings. The figure shows that the potable demand scenario has the highest efficiency in all buildings and there is negligible difference in total and non-potable demand scenario. Press Building has the highest water saving efficiency in potable demand scenario. For total demand and non-potable demand scenario, Exam center has the highest water saving efficiency of 28.2 percent and 29.7 percent respectively.

Figure 34 shows that 78.78 percent of the time, the maximum water saving efficiency was achieved at highest tank capacity considered. This implies that in majority of simulations reliability threshold was not achieved within the range of 1 to 30 m^3. Reliability threshold is at tank capacity beyond which there is none or negligible increase in efficiency. 11.11 percent of the time, the maximum water saving efficiency was achieved for tank capacity greater than 25 m^3 and 8.8 percent of the time the maximum efficiency value was between 20 to 25 m^3.

More detail table of maximum efficiencies can be found in **Appendix 4**

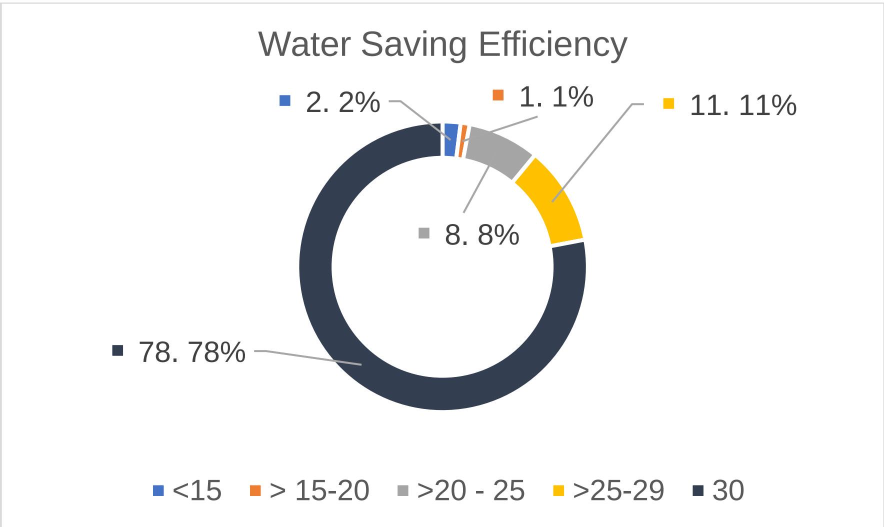

Figure 34: Tank capacity at maximum water saving efficiency for all 3 usage scenar

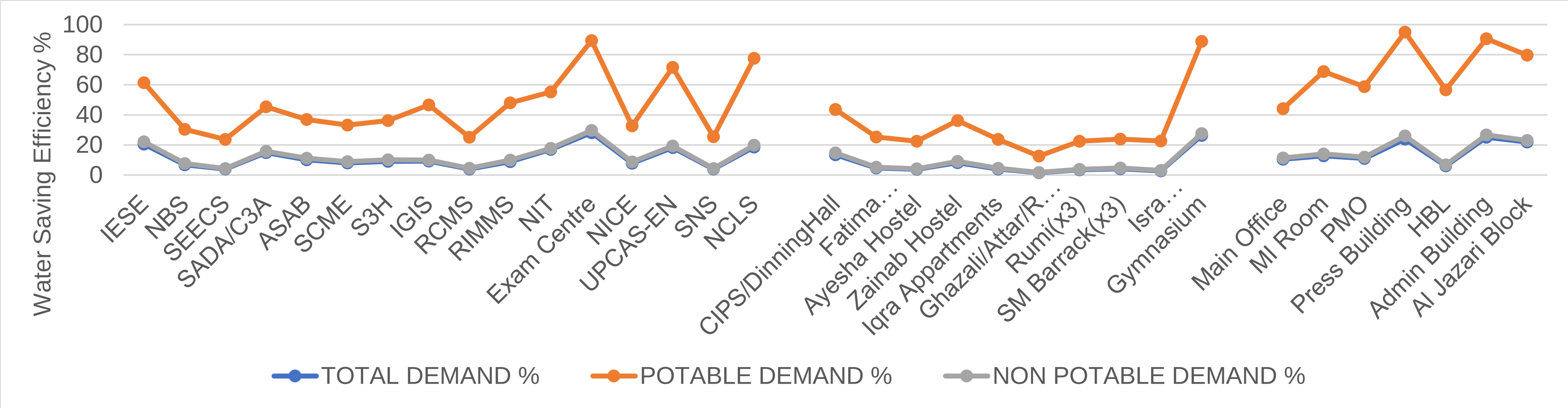

Figure 35: Maximum Water Saving Efficiency for 3 usage scenarios

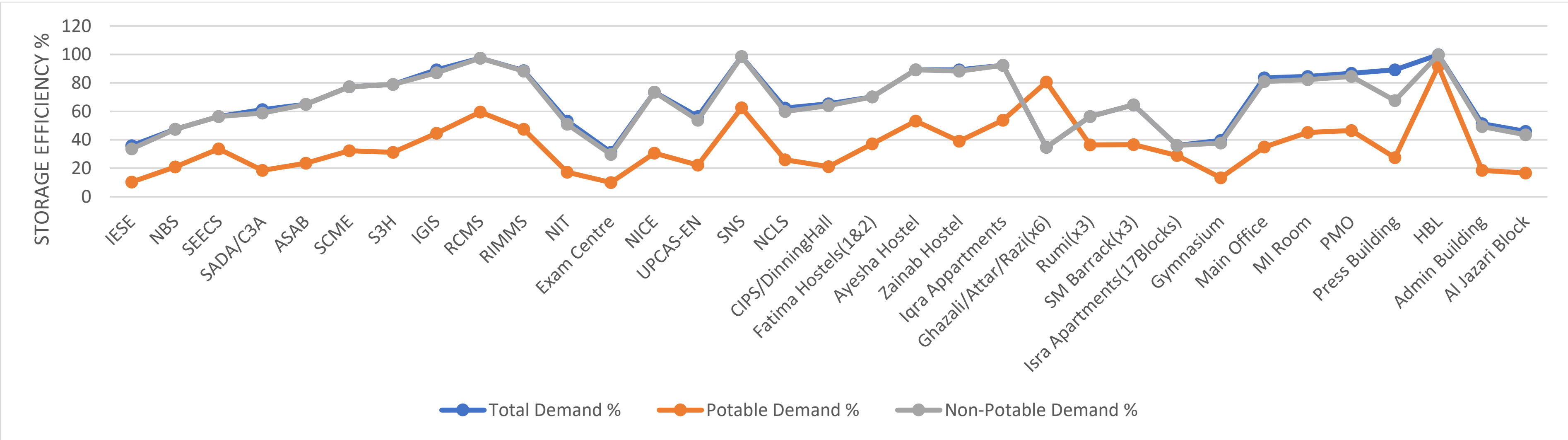

Figure 36: Maximum Storage Efficiency for 3 usage scenarios

4.5.3.2 Storage efficiency

Figure 36 shows the maximum storage efficiency achieved in range of 1 to 30 m^3. Here, the potable scenario has lower storage efficiency than non-potable and total demand scenario. The highest storage efficiency is achieved by Habib Bank Limited is total demand, non-potable demand and potable demand scenario at 99.8 percent, 99.7 percent, and 91.8 percent respectively.

Figure 37 shows that 93.94 percent of the time, maximum storage efficiency was achieved at 30 m^3 tank capacity and 4.4 percent of the time highest storage efficiency was achieved in greater than 25 - 29 m^3 tank capacity.

A more detail table of which building reached highest storage efficiency at what tank capacity can be found in **Appendix 4**

Table 3 summarizes the name of buildings with maximum water saving and storage efficiencies.

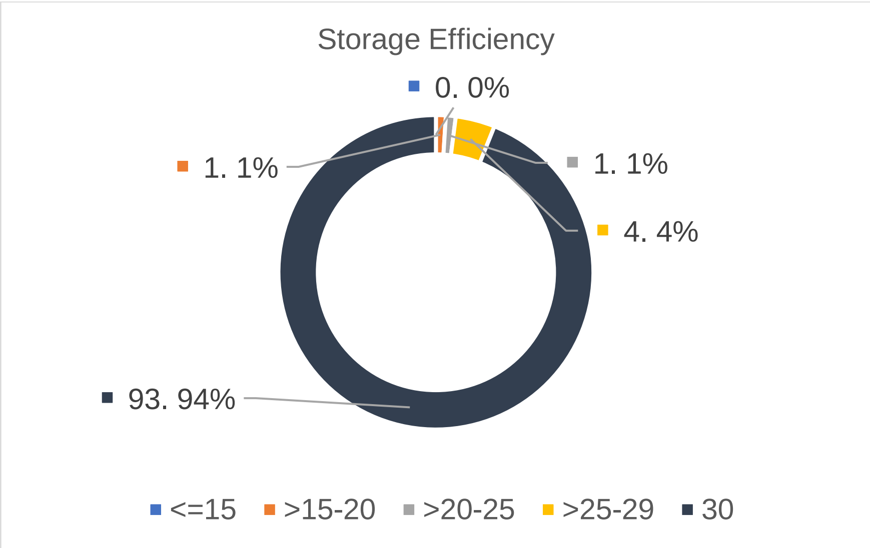

Figure 37: Tank capacity at maximum storage efficiency

Usage Scenario	Name of the building	Maximum water saving efficiency (%)	Name of the building	Maximum storage efficiency (%)
Total Demand	Exam Center	28.2	HBL	99.8
Non-potable Demand	Exam Center	29.7	HBL	99.7
Potable Demand	Press Building	95	HBL	91.8

Table 3: Maximum water saving and storage efficiency – summary

Chapter 5

5 Conclusion and Recommendations

5.1 Conclusion

5.1.1 Time series analysis

We performed time series analysis on the meteorological data in R- Studio to check the seasonal variation and trend of rainfall. We saw a sharp increase in 5-year rainfall data after 2018 with high seasonal strength of 0.8. The Wettest month was July and August, and driest period was September to December. The temperature and Humidity had opposite trends.

5.1.2 Simulation and Modelling

We used Historical rainfall data of 38-year, roof area, water demand, Runoff co-efficient 0.8 for Concrete and first flush 1mm as input in the Tangki NAHRIM Website based simulation app and got water saving efficiency, storage efficiency and tank capacity for all water usage scenarios like Potable, non-potable and outdoor usage as outcome.

5.1.3 Outcome

Overall results were, Potable Demand Scenario, overall gave better water saving efficiency in almost all NUST Buildings considered. Non-potable demand scenario and Total Demand scenario had very little variation in performance parameters. Due to high water demands, a very few buildings reached reliability threshold within 1 to 30 cubic meter tank capacity.

5.1.4 Quality Analysis and Treatment options

Paper of (Zaheer & Shah, 2011) provided experimental data on water quality for NUST rainwater. Additional Parameters were also explored from literature of similar climate. We proposed some Treatment option for all water usage scenario. For instance, Potable water use requires sedimentation, multistage-filtration, and UV disinfection. For non- portable, we suggested sedimentation and disinfection by chlorination and for agricultural Scenario-only settling in Sedimentation tank is required if the water is used for irrigation. In the end, we developed a VBA based Spreadsheet solution of all NUST buildings by using results of simulation ran in Tangki NAHRIM 2.0.

5.2 Recommendations

We recommended some important and valuable points which may improve the efficiency and reliability of rainwater system.

- NUST has no working rain gauge for measuring rainfall. So, we suggested the maintenance of weather data for NUST.

- Secondly, we did not do any experiment work on quality due to lockdown imposed by Covid-19 pandemic. We recommended, Quality analysis of roof rainwater thorough experimental data.
- Thirdly, Cost Analysis for different sizes of Tank and for Treatment interventions because due to some uncertain circumstances we could not did cost analysis. It is the main part of any project. The reason is that, on the basis of cost analysis, we check the feasibility of Project.
- In the last, we recommended, Incorporation of uncertainty due to Climate Change.

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Appendix 1

Raw data from Project Management Office (PMO), NUST

Name of the building	Auth Scale (Gln/Head/Day)	Population	Total Demand (Gln/day)
SEECS	15	1800	27000
NBS	15	1150	17250
IGIS	15	275	4125
IAEC	15	280	4200
RIMMS	15	250	3750
SADA/C3A	15	450	6750
ASAB/RCMS	15	625	9375
IESE	15	300	4500
S3H	15	550	8250
SCME	15	650	9750
Fatima Hostels (I & II)	50	368	18400
Ayesha Hostel	50	307	15350
Zainab Hostel	50	306	15300
Khadija Hostel	50	306	15300
Hostel Staff Accomodation x2	50	60	3000
Iqra Appartments	50	256	12800
Main office	15	350	5250
CIPS/Dinning Hall	20	350	7000
Gymnasium	15	100	1500
Ghazali/Attar/Razi (x6)	50	1668	83400
Rumi (x3)	50	618	30900
Hostel Staff Accomodation	50	120	6000
Nursery/Mali Living	50	4	200
SM Barrack (x3)	50	452	22600
NIT	15	325	4875
NICE	15	700	10500
SMME (3 wings)	15	450	6750
MRC	15	100	1500
SNS	15	550	8250
USPCAS-EN	15	200	3000
HBL	15	50	750
Admin Building	15	80	1200
Exam Centre	15	100	1500
Al Jazari Block	15	150	2250
Press Building	15	50	750
PMO	15	176	2640
Isra Apartments (13 blocks)	N/A	N/A	47600
MI Room	10	178	1780
NCLS	10	193	1930

Ground floor Area

Name of the Buildings	Ground Floor
Location 1	**Area(Sft)**
IESE	49536.5
NBS	46750
SEECS	35456
SADA/C3A	30616.83
ASAB	27296.33
CIPS/DinningHall	26938
Fatima Hostels(1&2)	23200
SCME	18694.67
Gymnasium	18456
S3H	17796
Main Office	12332.75
Ayesha Hostel	12100
Zainab Hostel	12100
Khadija Hostel	12100
Iqra Appartments	10525
IGIS	8019.67
RCMS	7333.33
RIMMS	7068.33
Bhattai Mess	2833.75
Location 2	
Ghazali/Attar/Razi(x6)	72600
Rumi(x3)	35475
NIT	29051
SM Barrack(x3)	27518
SMME(3 Wings)	26914
Exam Centre	26276
NICE	20981
Al Jazari Block	20042
UPCAS-EN	18034
MRC	15253
Admin Building	10912
SNS	6240
PMO	6200
Press Building	4838
HBL	861

Location 3

Isra Apartments(17Blocks)	69265.67
NCLS	10710
MI Room	5044

Appendix 2

Meteorological Data (Pakistan Meteorological Department):

5 Year monthly Rainfall Data:

Month	2016	2017	2018	2019	2020
Jan	54.4	148.5	1.0	141.3	111.6
Feb	83.6	19.0	78.0	126.1	65.5
Mar	199.0	13.4	39.6	74.2	231.8
Apr	11.0	100.6	85.0	91.0	115.0
May	27.2	21.0	65.0	52.0	132.0
Jun	47.0	138.9	63.0	31.0	89.0
Jul	344.8	191.0	373.6	252.4	219.5
Aug	265.0	160.8	532.5	535.5	398.7
Sept	3.0	92.0	105.0	97.6	95.0
Oct	9.0	7.0	31.0	42.2	0.0
Nov	0.0	24.0	24.0	54.6	92.8
Dec	0.0	58.0	30.4	16.0	26.1

Temperature Data:

Month	2016	2017	2018	2019	2020
Jan	10.7	10.7	11.2	9.2	9.1
Feb	14	14.5	13.7	11.6	13.3
Mar	17.8	17.1	19.1	15.4	16.3
Apr	22.5	23.2	23	23.1	21.1
May	28.6	28.1	26.5	25.5	25.6
Jun	31.4	29.4	30.8	29.3	28.6
Jul	29.8	29.4	29.5	29.1	30.1
Aug	28.6	28.5	28.8	28	29.2
Sept	28.3	27	27.1	26.8	27.1
Oct	23.7	23.3	20.9	20.8	22.2
Nov	16.8	16	15.6	16.4	15.2
Dec	13.8	12.1	10.7	10.3	11.725

Appendix 2:

Humidity data:

Month	2016	2017	2018	2019	2020
Jan	65	65	40	62	58.3
Feb	44	47	42	56	44.6

Mar	52	36	37	43	60.1
Apr	38	34	35	39	47.5
May	32	30	29	29	42.1
Jun	36	40	33	29	42.1
Jul	59	61	54	52	52.6
Aug	58	61	63	60	67.7
Sept	52	51	55	60	57.6
Oct	41	41	45	58	48
Nov	51	56	53	64	62.6
Dec	49	52	58	61	55

Historical monthly rainfall Data:

Islamabad	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Average**
1983	130.6	73.9	67.3	231.5	29.4	46.5	245	531.2	203.4	37.6	2.8	0.5	133.3083
1984	1.5	89.4	99.2	43.8	14.2	222.3	326.4	426.6	98.2	1.3	11.4	10	112.025
1985	50	5.3	17.5	35.3	22	5.1	553.1	213	55.7	45.3	14.5	141.8	96.55
1986	12.6	142.4	120.2	64.3	63.4	58.3	155.4	260.1	132.7	33.5	42.8	46.1	94.31667
1987	1.8	111.6	89.5	49.9	186.4	41.1	81.1	263.1	6.3	115.7	0	13.2	79.975
1988	24.3	50.3	166.9	9.9	9.6	77.7	769.5	369.7	106.1	23.3	0.01	78.4	140.4758
1989	86.2	18.5	93.2	18.3	11.9	46.6	472.8	229.4	32.3	10.2	4.1	57.7	90.1
1990	41.9	123.3	177.3	59.7	2.3	42.2	288	578.9	118.8	29.9	7.9	161.7	135.9917
1991	13.6	98.9	103.1	135.6	35.1	58.1	229.5	300.8	258.3	10.5	13.1	25.8	106.8667
1992	218.9	158.5	150.6	51.7	68.6	24	135.3	266	418.3	6	40.5	9.7	129.0083
1993	32.3	39.9	174.8	30.4	38.7	119.1	234.3	199.6	162.9	0.01	1	0	86.08417
1994	41.9	53.4	38.7	66.5	59	56.8	828.6	618.9	58.1	52.8	2.6	120.2	166.4583
1995	28.9	75.3	86.6	72.8	36.8	22.2	551.4	440.4	31.5	33.2	28.4	34.4	120.1583
1996	80.5	135.9	143	36.3	43.4	138.3	199.9	411.7	118.3	57.8	3.4	7.6	114.675
1997	34.8	16.7	87.5	189.6	82.1	63.6	356.8	476.8	234.8	103.9	21	23.9	140.9583
1998	33	251.6	96.5	106.9	20.7	37.9	289.5	407.7	84.8	41.8	0	0	114.2
1999	121.3	33.3	60.7	1.1	24.5	21	279.5	319.2	112.9	4	31.4	0	84.075
2000	119.1	75.2	14.2	2.3	11	68.4	180.8	369.4	90.9	0	0.01	16.5	78.98417
2001	0.01	0.2	31.3	15.4	37.8	118.2	1038.6	192.2	15.8	18.5	3.1	1	122.6758
2002	6.5	30.6	48.3	19.5	4.8	147	75.7	359.8	139.5	35.2	0.01	18.5	73.78417

2003	37.7	235.4	105.9	22.3	18.2	90.2	407.1	212.8	292.5	5.3	27	48.9	125.275
2004	126.2	49.1	0.01	87	23.4	212.6	147.8	301.9	46.1	90.3	17.4	37.4	94.93417
2005	97.8	236.9	108.3	12.4	20.7	10.4	289.9	246.8	111.7	75	7.8	0	101.475
2006	93.4	32.7	55.8	25.3	73	91.5	535.2	420.9	38.6	36.5	12.3	148.7	130.325
2007	0.8	125.5	192.7	18.2	54.6	85.5	295.2	382.8	232	0	13	14	117.8583
2008	124.5	47.5	19.2	114	15.6	230.4	525	237	44	17.2	15.1	86.6	123.0083
2009	74.5	75.3	63.4	126.5	27.6	14.5	84.4	120.7	63.6	9	15.6	1	56.34167
2010	17.5	105.6	43.8	22.4	35.6	41.4	344.8	214.5	142.9	22.2	1	26.2	84.825
2011	7	118.1	51.2	76.4	16.2	128.4	292.5	215.4	130.8	37.6	6	0.01	89.9675
2012	50.4	47.5	15.8	24.9	16	24	162.2	283.1	356.1	6.2	3	87.2	89.7
2013	9	297.9	54.4	39.1	13.8	94	334.4	664	176.6	38.6	7.6	3	144.3667
2014	6	71.7	277.2	11	95	52.2	309	208.4	444.8	23	9	0	125.6083
2015	34.3	112.1	298.1	196.1	27.5	34.1	380.2	198.5	134.8	190.2	18.7	25.9	137.5417
2016	54.8	86.9	149	12.1	27.4	47.5	341.9	265.3	3.3	25	0	0.1	84.44167
2017													#DIV/0!
2018	1.01	59	39.21	85.02	64	64.23	322.28	434.5	105.01	31.01	12	20	103.1058

Appendix 3

R Script for Time Series Analysis

Rainfall

```
###########################################################
library(lubridate)
library(ggplot2)
library(tidyverse)
library(dplyr)
library(astsa)
library(forecast)
library(readxl)
library(urca)
library(ggfortify)
library(tsutils)

#########################################################################

ISB_Rainfall <- read_excel("F:/MET_DATA_ISB.xlsx", sheet = 'RAINFALL')
View(ISB_Rainfall)

###################################################################################################

Isb_rain1 <- ISB_Rainfall %>% gather(key= 'year', value= 'Rainfall', c(-Month))
View(Isb_rain1)

##############################################################################

Isb_rain1_ts <- ts(Isb_rain1[,3], frequency= 12, start=c(2016,1))

###############################################################################

Isb_rain1_ts <- window(Isb_rain1_ts, start= c(2016,1))
Isb_rain1_ts

###############################################################################

options(repr.plot.width = 14, repr.plot.height = 8)
autoplot(Isb_rain1_ts) + ylab("Rainfall (mm2)") + xlab("Year") +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year', minor_breaks = '1 month') +
  theme_bw() + ggtitle("Islamabad Rainfall 2016 - 2020")

######################################################################################

decomp <- stl(Isb_rain1_ts[,1], s.window = 'periodic')
autoplot(decomp) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
               minor_breaks = '2 month') +
  ggtitle("Decomposed Rainfall Time Series")

DecomposedIsb_ts <- decompose(Isb_rain1_ts)

autoplot(DecomposedIsb_ts$seasonal) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
               minor_breaks = '2 month') +
  ggtitle("Seasonal")

autoplot(DecomposedIsb_ts$trend) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
               minor_breaks = '2 month') +
  ggtitle("Trend")

###################################################################################
```

```
Tt <- trendcycle(decomp)
St <- seasonal(decomp)
Rt <- remainder(decomp)
Ft <- round(max(0,1 - (var(Rt)/var(Tt + Rt))),1)
Fs <- round(max(0,1 - (var(Rt)/var(St + Rt))),1)
data.frame('Trend Strength' = Ft , 'Seasonal Strength' = Fs)

#  Trend.Strength Seasonal.Strength
#1          0.2              0.8

######################################################################################

seasonplot(Isb_rain1_ts, year.labels = TRUE, col = 1:13,
         main = "Seasonal Plot", ylab= "Rainfall (mm2)")

seasplot(Isb_rain1_ts, outplot = 2, trend = FALSE, main = "Seasonal Box Plot",
        ylab= "Rainfall (mm2)")

seasplot(Isb_rain1_ts, outplot = 3, trend = FALSE, main = "Seasonal Subseries Plot",
        ylab= "Rainfall (mm2)")

########################################################################################
```

Temperature

```
############################################################################

ISB_temp <- read_excel("F:/MET_DATA_ISB.xlsx", sheet = 'TEMPERATURE')
View(ISB_temp)

#############################################################################

Isb_temp1 <- ISB_temp %>% gather(key= 'year', value= 'Temperature', c(-Month))
View(Isb_temp1)

#################################################################################

Isb_temp1_ts <- ts(Isb_temp1[,3], frequency= 12, start=c(2016,1))

##################################################################################

Isb_temp1_ts <- window(Isb_temp1_ts, start= c(2016,1))
Isb_temp1_ts

##################################################################################

options(repr.plot.width = 14, repr.plot.height = 8)
autoplot(Isb_temp1_ts) + ylab("Temperature (˚C)") + xlab("Year") +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year', minor_breaks = '1 month') +
  theme_bw() + ggtitle("Average Temperature 2016 - 2020")

##########################################################################################

decompt <- stl(Isb_temp1_ts[,1], s.window = 'periodic')
autoplot(decompt) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
             minor_breaks = '2 month') +
  ggtitle("Decomposed Temperature Time Series")

DecomposedT_ts <- decompose(Isb_temp1_ts)

autoplot(DecomposedT_ts$seasonal) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
             minor_breaks = '2 month') +
  ggtitle("Seasonal")
```

```
autoplot(DecomposedT_ts$trend) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
             minor_breaks = '2 month') +
  ggtitle("Trend")

##################################################################################

Ttt <- trendcycle(decompt)
Stt <- seasonal(decompt)
Rtt <- remainder(decompt)
Ftt <- round(max(0,1 - (var(Rtt)/var(Ttt + Rtt))),1)
Fss <- round(max(0,1 - (var(Rtt)/var(Stt + Rtt))),1)
data.frame('Trend Strength' = Ftt , 'Seasonal Strength' = Fss)

#  Trend.Strength Seasonal.Strength
#1           0.2              0.8

##################################################################################

seasonplot(Isb_temp1_ts, year.labels = TRUE, col = 1:13,
         main = "Seasonal Plot", ylab= "Temperature (˚C)")

seasplot(Isb_temp1_ts, outplot = 2, trend = FALSE, main = "Seasonal Box Plot",
        ylab= "Temperature (˚C)")

seasplot(Isb_temp1_ts, outplot = 3, trend = FALSE, main = "Seasonal Subseries Plot",
        ylab= "Temperature (˚C)")
```

Relative Humidity

```
########################################################################

ISB_hum <- read_excel("F:/MET_DATA_ISB.xlsx", sheet = 'HUMIDITY')
View(ISB_hum)

##################################################################################################

Isb_hum1 <- ISB_hum %>% gather(key= 'year', value= 'Humidity', c(-Month))
View(Isb_hum1)

#############################################################################

Isb_hum1_ts <- ts(Isb_hum1[,3], frequency= 12, start=c(2016,1))

##############################################################################

Isb_hum1_ts <- window(Isb_hum1_ts, start= c(2016,1))
Isb_hum1_ts

##############################################################################

options(repr.plot.width = 14, repr.plot.height = 8)
autoplot(Isb_hum1_ts) + ylab("Humidity (%)") + xlab("Year") +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year', minor_breaks = '1 month') +
  theme_bw() + ggtitle("Monthly Relative Humidity at 1200 UTC (%)")

#####################################################################################

decomph <- stl(Isb_hum1_ts[,1], s.window = 'periodic')
autoplot(decomph) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
             minor_breaks = '2 month') +
  ggtitle("Decomposed Relative Humidity Time Series")
```

```
DecomposedH_ts <- decompose(Isb_hum1_ts)

autoplot(DecomposedH_ts$seasonal) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
             minor_breaks = '2 month') +
  ggtitle("Seasonal")

autoplot(DecomposedH_ts$trend) + theme_bw() +
  scale_x_date(date_labels = '%b - %Y', breaks = '1 year',
             minor_breaks = '2 month') +
  ggtitle("Trend")

##################################################################################

Tth <- trendcycle(decomph)
Sth <- seasonal(decomph)
Rth <- remainder(decomph)
Fth <- round(max(0,1 - (var(Rth)/var(Tth + Rth))),1)
Fsh <- round(max(0,1 - (var(Rth)/var(Sth + Rth))),1)
data.frame('Trend Strength' = Fth , 'Seasonal Strength' = Fsh)

#  Trend.Strength Seasonal.Strength
#1           0.4               0.8

##################################################################################

seasonplot(Isb_hum1_ts, year.labels = TRUE, col = 1:13,
          main = "Seasonal Plot", ylab= "Relative Humidity (%)")

seasplot(Isb_hum1_ts, outplot = 2, trend = FALSE, main = "Seasonal Box Plot",
        ylab= "Relative Humidity (%)")

seasplot(Isb_temp1_ts, outplot = 3, trend = FALSE, main = "Seasonal Subseries Plot",
        ylab= "Relative Humidity (%)")
```

VBA code

Code to create csv file (insert multiple rows for daily data at once)

```
Option Explicit
'*************************************************************
'
' Macro to insert rows in the same location acroos all worksheets
'
Sub insertRowsSheets()
    'Disable Excel Propertities before macro name
    With Application
        .Calculation = xlCalculationManual
        .EnableEvents = False
        .ScreenUpdating = False
    End With

        'Declare object variables
        Dim ws As Worksheet, iCountRows As Integer
        Dim activeSheet As Worksheet, activeRow As Long
        Dim startSheet As String

            'State activeRow
            activeRow = ActiveCell.Row

                'Save initial active sheet selection
                startSheet = ThisWorkbook.activeSheet.Name

                    'Trigger input message to appear - in terms of how many rows to insert
                    iCountRows = Application.InputBox(Prompt:="How many rows do you want to insert, starting with row" _
                    & activeRow & "?", Type:=1)

                        'Error handling - end the macro if a zero, negative integer or non-integer value is entered
```

```
            If iCountRows = False Or iCountRows <= 0 Then End

                'Loop through the worksheets in active workbook
                For Each ws In ActiveWorkbook.Sheets

                    ws.Activate
                    Rows(activeRow & ":" & activeRow + iCountRows - 1).Insert Shift:=xlDown

                Next ws

        ' Move cursor back to intial worksheet
        Worksheets(startSheet).Select
        Range("A1").Select

    'Re-enable Excel propertities once macro is complete
    With Application
        .Calulation = xlCalculationAutomatic
        .EnableEvents = True
        .ScreenUpdating = True
    End With
End Sub
```

VBA code to merge 105 files to create database

```
Sub MergeExcelFiles()
    Dim fnameList, fnameCurFile As Variant
    Dim countFiles, countSheets As Integer
    Dim wksCurSheet As Worksheet
    Dim wbkCurBook, wbkSrcBook As Workbook

    fnameList = Application.GetOpenFilename(FileFilter:="Microsoft Excel Workbooks (*.xls;*.xlsx;*.xlsm),*.xls;*.xlsx;*.xlsm",
Title:="Choose Excel files to merge", MultiSelect:=True)

    If (vbBoolean <> VarType(fnameList)) Then

        If (UBound(fnameList) > 0) Then
            countFiles = 0
            countSheets = 0

            Application.ScreenUpdating = False
            Application.Calculation = xlCalculationManual

            Set wbkCurBook = ActiveWorkbook

            For Each fnameCurFile In fnameList
                countFiles = countFiles + 1

                Set wbkSrcBook = Workbooks.Open(Filename:=fnameCurFile)

                For Each wksCurSheet In wbkSrcBook.Sheets
                    countSheets = countSheets + 1
                    wksCurSheet.Copy after:=wbkCurBook.Sheets(wbkCurBook.Sheets.Count)
                Next

                wbkSrcBook.Close SaveChanges:=False

            Next

            Application.ScreenUpdating = True
            Application.Calculation = xlCalculationAutomatic

            MsgBox "Processed " & countFiles & " files" & vbCrLf & "Merged " & countSheets & " worksheets", Title:="Merge Excel
files"
        End If

    Else
        MsgBox "No files selected", Title:="Merge Excel files"
    End If
End Sub
```

Appendix 4

Total Demand Scenario

Building Name	roof area (sqft)	Roof Area (sqm)	TWD Gallon/day	TWD(Liters/day)	WSE(max)Maximum Water Saving Efficiency	Tank capacity max (WSE)	SE (max) Storage Efficiency %	(TC(max)) (SE)	Water saved/per year (max) m3
IESE	49536.5	4602.05314	4500	20457	20.6	21	35.9	30	1540
NBS	46750	4343.180974	17250	78418.5	6.9	30	47.5	30	1982.4
SEECS	35456	3293.942772	27000	122742	4	30	56.4	30	1786.3
SADA/C3A	30616.83	2844.37291	6750	30685.5	14.9	30	61.2	30	1673.8
ASAB	27296.33	2535.890933	9375	42618.75	10.2	30	64.9	30	1582.2
SCME	18694.67	1736.77722	9750	44323.5	8	30	77.3	30	1291.8
S3H	17796	1653.28874	8250	37504.5	9.2	30	78.9	30	1254.6
IGIS	8019.67	745.0455221	4125	18752.25	9.3	23	89.3	30	633.7
RCMS	7333.33	681.2829803	9375	42618.75	4.1	27	97.5	30	630.9
RIMMS	7068.33	656.6638796	3750	17047.5	9	17	88.6	17	559.4
NIT	29051	2698.903753	4875	22161.75	17	23	53.3	24	1378.4
Exam Centre	26276	2441.099963	1570	7137.22	28.2	30	31.3	30	734.2
NICE	20981	1949.18246	10500	47733	7.9	30	73.6	30	1379.1
UPCAS-EN	18034	1675.39948	3000	13638	18.3	30	56.4	30	909.1
SNS	6240	579.7101449	8250	37504.5	4	25	98.5	30	542.7
NCLS	10710	994.9832776	1930	8773.78	18.6	30	62.4	30	597.1
CIPS/DinningHall	26938	2502.601263	7000	31822	13.5	30	65.3	30	1571.8
Fatima Hostels(1&2)	23200	2155.33259	18400	83646.4	4.8	30	70.2	30	1455.4

Ayesha Hostel	12100	1124.117428	15350	69781.1	3.8	30	89.3	30	965.4
Zainab Hostel	12100	1124.117428	7000	31822	8.3%	30	89.3%	30	965.4
Iqra Appartments	10525	977.7963582	12800	58188.8	4.1%	29	92.3%	30	867.5
Ghazali/Attar/Razi(x6)	72600	6744.704571	83400	379136.4	1.6%	29	34.8%	30	2253.6
Rumi(x3)	35475	3295.707915	30900	140471.4	3.5%	30	56.4%	30	1786.7
SM Barrack(x3)	27518	2556.484578	22600	102739.6	4.2%	29	64.6%	30	1588.6
Isra Apartments(17Blocks)	69265.67	6434.937755	47600	216389.6	2.8%	30	36.0%	30	2225.9
Gymnasium	18456	1714.604236	1500	6819	26.3%	30	39.7%	30	654.1
Main Office	12332.75	1145.740431	5250	23866.5	10.6%	29	83.7%	30	922.3
MI Room	5044	468.5990338	1780	8091.88	12.9%	30	84.5%	30	380.6
PMO	6200	575.9940543	2640	12001.44	11.0%	30	86.7%	30	480.4
Press Building	4838	449.4611669	750	3409.5	24.0%	30	89.2%	30	299.1
HBL	861	79.98885173	750	3409.5	6.2%	23	99.8%	28	76.8
Admin Building	10912	1013.749535	1200	5455.2	25.1%	30	51.3%	30	500.4
Al Jazari Block	20042	1861.947232	2250	10228.5	22.0%	30	45.9%	30	821.2

Non-Potable Demand Scenario

Building Name	roof area (sqft)	Roof Area (sqm)	NP Water Demand (Liters/day)	WSE(max)Maximum Water Saving Efficiency	Tank Capacit	SE (max) Storage	(TC(max)) Tank Capacity	Water saved/pe

					y WSE max	Efficiency %		r year (max) m3
IESE	49536.5	4602.05314	18411.3	22.1	30	33.6	30	1487.5
NBS	46750	4343.180974	70576.65	7.7	30	47.5	30	1982.4
SEECS	35456	3293.942772	110467.8	4.4	30	56.4	30	1786.3
SADA/C3A	30616.83	2844.37291	27616.95	15.9	30	58.8	30	1607.2
ASAB	27296.33	2535.890933	38356.875	11.3	30	64.9	30	1582.2
SCME	18694.67	1736.77722	39891.15	8.9	30	77.3	30	1291.8
S3H	17796	1653.28874	33754.05	10.2	30	78.9	30	1254.6
IGIS	8019.67	745.0455221	16877.025	10	24	87.2	30	624.6
RCMS	7333.33	681.2829803	38356.875	4.6	30	97.5	30	638.9
RIMMS	7068.33	656.6638796	15342.75	10	30	88.3	30	557.7
NIT	29051	2698.903753	19945.575	17.7	21	51	29	1291.2
Exam Centre	26276	2441.099963	6423.498	29.7	30	29.7	30	695.9
NICE	20981	1949.18246	42959.7	8.8	30	73.6	30	1379.1
UPCAS-EN	18034	1675.39948	12274.2	19.3	30	53.7	30	864.7
SNS	6240	579.7101449	33754.05	4.4	23	98.5	30	536.9
NCLS	10710	994.9832776	7896.402	19.9	30	60	30	573.7
CIPS/DinningHall	26938	2502.601263	28639.8	14.7	29	64	30	1539.9
Fatima Hostels(1&2)	23200	2155.33259	75281.76	5.3	30	70.2	30	1455.4
Ayesha Hostel	12100	1124.117428	62802.99	4.2	30	89.3	30	965.4
Zainab Hostel	12100	1124.117428	28639.8	9.1	28	88.3	30	954.7
Iqra Appartments	10525	977.7963582	52369.92	4.5	28	92.3	30	867.5
Ghazali/Attar/Razi (x6)	72600	6744.704571	341222.76	1.8	30	34.8	30	2253.6
Rumi(x3)	35475	3295.707915	126424.26	3.9	30	56.4	30	1786.7
SM Barrack(x3)	27518	2556.484578	92465.64	4.7		64.6	30	1588.6
Isra Apartments(17Blocks)	69265.67	6434.937755	194750.64	3.1	29	36	30	2225.9
Gymnasium	18456	1714.604236	6137.1	27.7	30	37.7	30	621.8
Main Office	12332.75	1145.740431	21479.85	11.4	29	81	30	892.9
MI Room	5044	468.5990338	7282.692	14	30	82.4	30	371.2
PMO	6200	575.9940543	10801.296	11.9	29	84.6	30	468.9
Press Building	4838	449.4611669	3068.55	26	30	67.5	30	291.7

HBL	861	79.98885173	3068.55	6.8	13	99.7	28	76.7
Admin Building	10912	1013.749535	4909.68	26.8	30	49.3	30	480.4
Al Jazari Block	20042	1861.947232	9205.65	23.1	30	43.5	30	778.4

Potable Demand Scenario

Building Name	roof area (sqft)	Roof Area (sqm)	Potable Water Demand (Liters/day)	WSE(max)Maximum Water Saving Efficiency	Tank Capacity (max WSE) m3	SE (max) Storage Efficiency %	(TC(max)) Tank Capacity	Water saved/per year (max) m3
IESE	49536.5	4602.05314	2045.7	61.4	30	10.4	30	458.8
NBS	46750	4343.180974	7841.85	30.4	30	20.9	30	870.8
SEECS	35456	3293.942772	12274.2	23.8	30	33.7	30	1067
SADA/C3A	30616.83	2844.37291	3068.55	45.4	30	18.6	30	509.1
ASAB	27296.33	2535.890933	4261.875	37	30	23.6	30	575.8
SCME	18694.67	1736.77722	4432.35	33.3	30	32.3	30	538.7
S3H	17796	1653.28874	3750.45	36.3	30	31.3	30	496.8
IGIS	8019.67	745.0455221	1875.225	46.7	30	44.6	30	319.6
RCMS	7333.33	681.2829803	4261.875	25.1	30	59.6	30	390.2
RIMMS	7068.33	656.6638796	1704.75	48.1	30	47.5	30	299.7
NIT	29051	2698.903753	2216.175	55.2	30	17.2	30	446.7
Exam Centre	26276	2441.099963	713.722	89.5	30	10	30	233.2
NICE	20981	1949.18246	4773.3	32.8	30	30.6	30	572.7
UPCAS-EN	18034	1675.39948	1363.8	71.6	30	22.2	30	356.6
SNS	6240	579.7101449	3750.45	25.5	30	62.5	30	348.7
NCLS	10710	994.9832776	877.378	77.6	30	26	30	248.8
CIPS/DinningHall	26938	2502.601263	3182.2	43.6	30	21.1	30	506.7
Fatima Hostels(1&2)	23200	2155.33259	8364.64	25.3	30	37.2	30	771.6
Ayesha Hostel	12100	1124.117428	6978.11	22.5	30	53.2	30	574.7
Zainab Hostel	12100	1124.117428	3182.2	36.3	30	39.1	30	422.4
Iqra Appartments	10525	977.7963582	5818.88	23.8	30	53.8	30	506.2
Ghazali/Attar/Razi(x6)	72600	6744.704571	37913.64	12.6	30	80.6	30	580.6

Rumi(x3)	35475	3295.707915	14047.14	22.5	30	36.5	30	1155.1
SM Barrack(x3)	27518	2556.484578	10273.96	24	30	36.7	30	902.1
Isra Apartments(17Blocks)	69265.67	6434.937755	21638.96	22.7	30	29	30	1793.1
Gymnasium	18456	1714.604236	681.9	88.8	30	13.4	29	221.2