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POTENTIAL OF RAINWATER HARVESTING IN IUT CAMPUS

BY

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Potential of Rainwater Harvesting in IUT Campus

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DECLARATION OF CANDIDATES

We hereby declare that the project/thesis work under the supervision of Dr. Md. Rezaul Karim entitled “Potential of Rainwater Harvesting in IUT Campus ", has been performed by us and this work has not been submitted elsewhere for reward of any degree or diploma.

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ABSTRACT

The exploration of alternate water sources and sustainable water management techniques is necessary due to the lack of available water and the rising demand for freshwater resources. A practical approach to increase water supply, ease pressure on current water sources, and encourage water conservation is rainwater harvesting (RWH). In evaluating the overall potential as a sustainable water management strategy, this thesis identifies how well it may work in a university environment.

The study starts off by looking at the patterns of water demand and usage on the university campus covering both the indoor and the outdoor water uses. For determining the possible availability of rainwater the information on local climate and rainfall patterns is gathered and reviewed. In order to determine which rainwater collecting techniques are best fit for the university's infrastructure and needs, a variety of methods including rooftop collection systems, surface runoff capture, and subterranean storage are studied. Then an equation based model was develop using catchment area, coefficient of runoff and rainfall intensity from which daily runoff was calculated. Rstudio was used for data assessing, finding trends and seasonal variations.

Examined as well are the environmental effects of rainwater collection, such as a decrease in the need for energy-intensive water treatment procedures and less stress on underground water supply.

From October to March that is in the dry season, the amount of supplementation ranges from 0.5% to 9% of the total water demand. In April and May it is close to 10-15%, whereas in August and September it is close to 20%. The most supplementation that can be achieved is in the months of June-July in which up to 25% of the total daily water demand can be supplemented.

The results of this study provide valuable insight on the possibilities of rainwater collection as a long-term water-management strategy for IUT. The findings support efforts to conserve water and encourage sustainable practices among campus residents by helping to develop guidelines and recommendations for the implementation of rainwater harvesting systems that take into account the unique qualities and needs of the university.

ACKNOWLEDGEMENTS

We would like to begin by expressing our deepest appreciation to Almighty Allah for enabling us to finish this research and finish the project and thesis.

We are highly indebted to the supervisor of our project/thesis, Dr. Md. Rezaul Karim, Professor, Department of Civil and Environmental Engineering (CEE), Islamic University of Technology (IUT), Bangladesh, who has helped us with his invaluable time for discussion, continuous advice and guidance for preparation and completion of this project/thesis.

We want to give thanks, to the office staffs and workers of Islamic University of Technology (IUT), Bangladesh, for giving us relevant required information regarding our thesis.

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CHAPTER I

INTRODUCTION

In this section, the background of the project which includes the current scenario of rainwater harvesting system, water supply system of IUT, outcome of the project and the study area is discussed.

1.1 About Rainwater Harvesting:

It is essential to look at alternative methods to meet water demands responsibly as the demand for sources of fresh water increases. Rainwater harvesting (RWH) is becoming more widely accepted as a practical approach to addressing water scarcity, conserving water, and easing the burden on conventional water sources. IUT has a vast built environment, which includes open areas and wide roof surfaces that may be used as possible rainwater collection locations. Universities are an intriguing example for determining the usability and impact of rainwater collecting systems because of the variety of water demands they have for academic buildings, residential facilities, landscaping, and recreational areas.

1.2 Water supply system of IUT:

The IUT water supply system is fully dependent groundwater supply system. Firstly, the water is pumped up by using submersible pump. Then it goes to two water reservoirs. After that it goes through 3 centrifugal pumps. The work for centrifugal pump is to push the water from the reservoir to the Air Vessels. Air Vessel is a type of pump, it has 50% water and 50% air. It maintains the water supply according to the needs of IUT by using the air pressure.

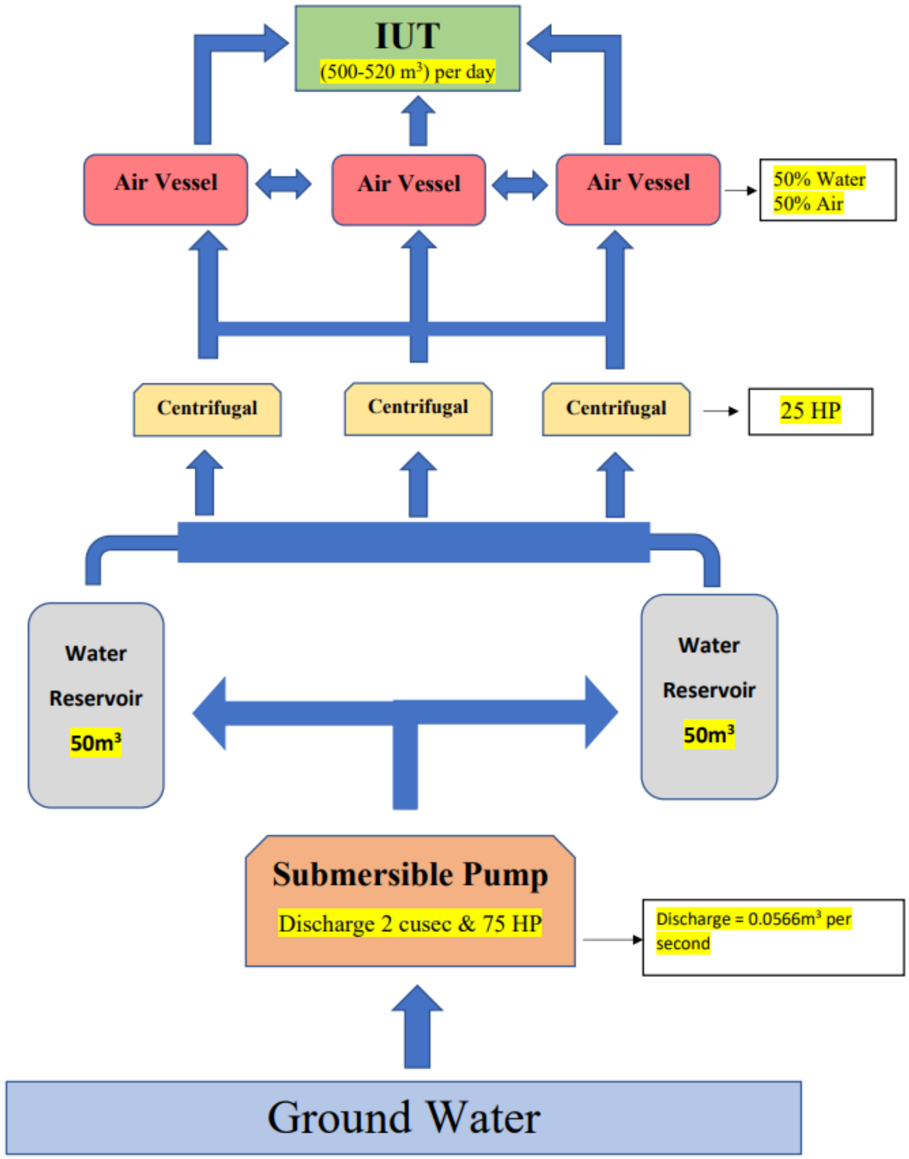


Figure 1 Water supply system of IUT

1.3 Study Area:

The study area, IUT, is situated in Gazipur district. From the area of around 30 acres, the buildings which have suitable roof area are taken into consideration for rainwater harvesting in order to get the maximum amount of catchment area. The most suitable building areas were taken into consideration for using as rainwater catchment area. The catchment area is 90% of the total roof area. The total available catchment area is about 10118 m^2.

Figure 2 Satellite View of IUT

Figure 3 IUT Campus

1.4 Problem Definition:

Universities are crucial in addressing sustainable water management strategies since water shortage is a significant worldwide concern. IUT now relies on underground water source to satisfy its water needs, which strains the local water supply and makes the institution more vulnerable to water shortages and rising water prices. The university's reliance on outside resources increases its carbon footprint since it requires more energy to pump and purify water. This thesis intends to evaluate the possibility of rainwater collection as a workable option for IUT in order to lessen these difficulties and enhance sustainable water management. In order to use rainwater for non-potable purposes like cooling systems, toilet flushing, and landscape irrigation, it must be collected, stored, and used in different forms. The institution can utilize the existing water resources more effectively and lessen its reliance on outside water sources by installing rainwater collecting devices on campus.

1.5 Objective:

In the context of an Islamic university of technology, this thesis aims to study the possibility of rainwater collection as a sustainable water management approach. The objectives of the thesis are:

- To supplement the water demand with available rainwater
- To Develop Rainwater Harvesting Model

CHAPTER II

LITERATURE REVIEW

In order to investigate the possibilities of rainwater collection in a university context, this study of the literature will look at earlier work, case studies, and best practices.

2.1 Water Scarcity and Sustainability:

Utilizing urban rainwater collecting to supplement the primary water supply can minimize total water use, water costs, and the amount of excess storm water that can burden the present drainage system (Mahmoud et al., 2014).

Utilizing urban rainwater collecting to supplement the primary water supply can minimize total water use, water costs, and the amount of excess storm water that can burden the present drainage system (Mahmoud et al., 2014). So for reducing dependency on local water sources, replenishing groundwater, and reducing stormwater runoff are all advantages of rainwater harvesting.

For a number of reasons, including water shortages and the requirement for water supply expansion, municipalities have expanded the installation of RWH systems. According to consolidated scientific and grey literature from the past 20 years, RWH actually belongs to the large family of detention-based Low Impact Development (LID) or Sustainable Drainage System (SuDS) approaches and can be used as a complementary measure to reduce frequency, peaks, and volumes of urban runoff if systems are properly designed. According to Burns et al. (2015) and Brodie (2008), increasing urban-catchment distributed detention by tank-based rainwater harvesting systems may lessen the effects of urbanization growth on the stormwater drainage system as well as potentially help mitigate environmental effects on receiving water bodies (e.g. Hamel and Fletcher, 2014).

2.2 Rainwater Harvesting Systems:

In the world, rainwater harvesting (RWH) is arguably the most popular method of supplying water to demand. Many countries currently promote the updated use of this strategy to address the needs of increased water demand caused by climatic, environmental, and social changes due to new technological capabilities. (Amos et al., 2016).

RWH systems were introduced globally to conserve potable water, and cities like Beijing and Berlin demonstrated reduction in water supply as 25%(Zhang et al.,2009), 70% (Nolde, 2007) respectively. Rainfall patterns, catchment area estimates, and storage tank sizing are key design factors for rain water harvesting. Types of rainwater harvesting systems, including rooftop catchment, surface runoff collection, and subterranean storage, that are appropriate for universities. As a result, installing RWH systems helps communities become more self-sufficient in water and may defer the need to build new centralized water infrastructure (Steffen et al., 2012).

2.3 Case Studies and Best Practices:

Due to natural arsenic poisoning of the groundwater, the usage of handpumps in Bangladesh has negatively impacted up to 70 million people with skin cancer and other health issues (Islam et al., 2010). By making space in the storage tank for future rain events, multiple-usage demands maximize rainwater collection by ensuring a reasonably continuous use of the water (Domènech and Saurí, 2011, Gardner and Vieritz, 2010). The effectiveness of the system in terms of stormwater mitigation may be significantly improved by including demands that are in line with regional rainfall patterns (Zhang et al., 2009).

Rainwater harvesting (RWH) is the process of gathering rainwater from roofs, terraces, courtyards, and other impervious building surfaces in order to concentrate, store, and treat it for use locally. Although the civil applications of collected rainwater vary (e.g., toilet flushing, washing clothes, gardening, cleaning terraces, and other occasional outside uses like vehicle washing), they all attempt to minimize use of drinking water from centrally provided sources. The technique of gathering, storing, and using runoff from roofs or other ground surfaces for useful purposes such as domestic water supply, agricultural use, and environmental management is known as rainwater harvesting (Anderson and Burton, 2009). According to GhaffarianHoseini et al. (2016), these applications might be responsible for 80–90% of total home water usage globally. They also show the enormous water-saving advantages of implementing RWH.

2.4 Institutional Policies and Regulations:

The rise of the environmental movement in the 1960s and the subsequent development and implementation of federal policies for conservation and environmental quality that had an impact on water resources [i.e. the National Wild and Scenic Rivers Act of 1968 (WSRA), the National Environmental Policy Act of 1969 (NEPA), and the 1973 Endangered Species Act (ESA)] were partially responsible for the decline of large reclamation project developments., 2003 (Pisani).

So for implementing rainwater harvesting systems in universities is hampered by a number of issues, including technical, economic, cultural, and legal ones. Techniques should be adopted for removing obstacles and incorporating rainwater collection into university policy and procedures.

2.5 Environmental and Educational Benefits:

Excess overflow water from RWH systems that would otherwise cause street runoff or enter the storm sewer network can be infiltrated for groundwater recharge when used in conjunction with infiltration-based solutions (often after preliminary treatment, as determined by national regulations) (Dillon, 2005). According to recent research (e.g. Hamel et al., 2012), infiltration techniques used in conjunction with RWH can also contribute to changing the urban microclimate by increasing moisture content and evapotranspiration, which reduces the effects of the heat island phenomenon (Furumai, 2008; Coutts et al., 2012).

Earlier research (e.g. Angrill et al., 2012) have examined the advantages of RWH system deployment for the environment in terms of emissions reduction and decreased resource use. In this regard, research in the scientific literature demonstrates that the type of implementation project (renovation or new construction) and the chosen use of rainwater in the building have a considerable impact on the system's economic feasibility (Devkota et al., 2015, Morales-Pinzón et al., 2015).

The literature clearly demonstrates the wide variety of applications of RWH systems in urbanized areas, but the outcomes and perception of the scope of potential benefits are varied and debatable, and methods for assessing the overall effectiveness of multiobjective (also competing) RWH systems are still in the early stages of development. In light of this, an in-depth analysis of the current state of the practice of application of RWH systems is carried out in this paper.

CHAPTER III

Methodology

3.1 Introduction

The Islamic University of Technology (IUT) is the subject of our study project's primary attention. We intended to determine the water demand segregation for residential and non-residential students and look into the catchment regions of particular buildings on the IUT campus. In order to do this, we measured water use manually and used the Bangladesh National Building Code (BNBC) of 2020 as a source of guidance. Additionally, we collected rainfall data for the last 21 years from NASA's website and the most recent demographic statistics for IUT from the institution's database.

3.2 Data Collection

3.2.1 Segregation of Water Demand

To segregate the water demand, we employed a manual measurement method by using water measurement containers and stopwatches. This approach allowed us to collect accurate data on water consumption by residential and non-residential students. By following the guidelines provided in the BNBC 2020 codes, which outline water usage norms for different types of buildings, we determined the specific water requirements for each category. This analysis facilitated a better understanding of the water demands of different student groups within IUT.

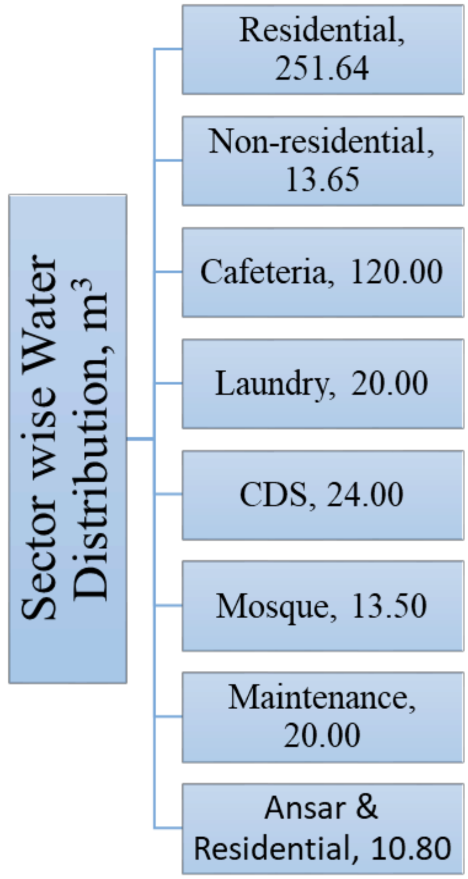


Figure 4 Sector Wise Water Distributions

3.2.2 Population Statistics

We gathered the most recent demographic statistics for IUT using the university's server in order to develop a thorough picture of water consumption. We were able to determine the community's total water needs using this data's useful insights into how many people live on campus.

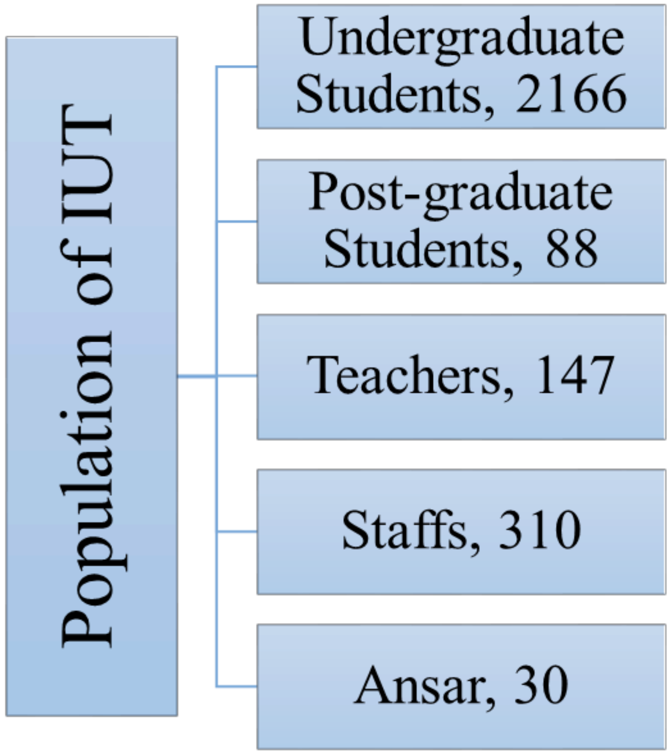


Figure 5 Population of IUT

3.2.3 Catchment Area:

We strategically selected buildings on the IUT campus that had good catchment areas for collecting water in order to enable a thorough investigation. The places from which rainfall water may be efficiently gathered are known as catchment areas. We figured out the catchment areas of the chosen buildings using inspections and measurements we conducted on the landscape. The prospective availability of water for different uses on campus is greatly influenced by its catchment areas.

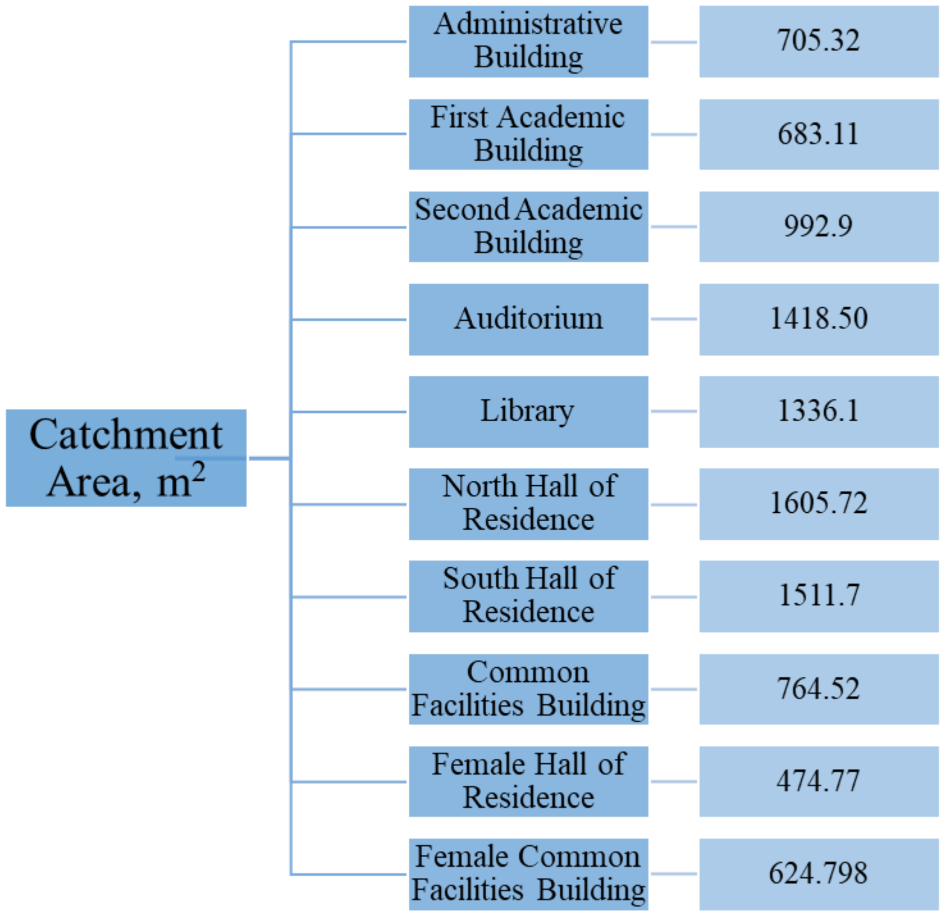


Figure 6 Catchment Area of IUT

3.2.4 Calculation Method:

Total monthly water demand = 500 m3 * 30 days = 15,000 m3/month
The available catchment area of the project, A = 108909.25 ft2 = 10118 m2

The quantity of potential Annual Rainwater Harvested, $Q_{rainwater}$ = CIA

Where,

C = Coefficient of Runoff (0.85-0.95)

I = Intensity of Rainfall, m/year
A = Catchment area,
m2

So, $Q_{rainwater}$ = 0.85 * 2.161 *10118 = 18,585 m3/year

C	0.85
A	10118 m^2

3.2.5 Rainfall Data Calculation

We gathered rainfall data covering the last 21 years to evaluate the region's water resource availability. A dependable source of meteorological data, NASA's website provided the information. We were able to find patterns, trends, and fluctuations in rainfall over time by analyzing this huge dataset. We learned more about the possible water supply and sustainability for the IUT campus by comparing the rainfall data with the catchment areas. Rainfall data with daily supplementation of the 2022 year is given:

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
1/1/2022	0	0	0	100
1/2/2022	0	0	0	100
1/3/2022	0	0	0	100
1/4/2022	0	0	0	100
1/5/2022	0	0	0	100
1/6/2022	0	0	0	100
1/7/2022	0	0	0	100
1/8/2022	0	0	0	100
1/9/2022	0	0	0	100
1/10/2022	0	0	0	100
1/11/2022	0.13	1.11804	0.22361	99.7764
1/12/2022	3.73	32.0791	6.41582	93.5842
1/13/2022	5.21	44.8076	8.96151	91.0385
1/14/2022	0.4	3.44012	0.68802	99.312
1/15/2022	0.1	0.86003	0.17201	99.828
1/16/2022	0.04	0.34401	0.0688	99.9312
1/17/2022	0	0	0	100
1/18/2022	0	0	0	100
1/19/2022	0	0	0	100
1/20/2022	0	0	0	100
1/21/2022	0	0	0	100
1/22/2022	0	0	0	100
1/23/2022	0.34	2.9241	0.58482	99.4152
1/24/2022	4.92	42.3135	8.4627	91.5373
1/25/2022	2.11	18.1466	3.62933	96.3707
1/26/2022	1.74	14.9645	2.9929	97.0071
1/27/2022	4.68	40.2494	8.04988	91.9501
1/28/2022	0.51	4.38615	0.87723	99.1228
1/29/2022	0	0	0	100
1/30/2022	0	0	0	100
1/31/2022	0	0	0	100

Table 1 Rainfall Data with daily supplementation for the month of January, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
2/1/2022	0.15	1.29005	0.25801	99.742
2/2/2022	0.21	1.80606	0.36121	99.6388
2/3/2022	0.16	1.37605	0.27521	99.7248
2/4/2022	11.35	97.6134	19.5227	80.4773
2/5/2022	12.5	107.504	21.5008	78.4993
2/6/2022	13.06	112.32	22.464	77.536
2/7/2022	0	0	0	100
2/8/2022	0	0	0	100
2/9/2022	0	0	0	100
2/10/2022	0.24	2.06407	0.41281	99.5872
2/11/2022	0.23	1.97807	0.39561	99.6044
2/12/2022	0.01	0.086	0.0172	99.9828
2/13/2022	0	0	0	100
2/14/2022	0	0	0	100
2/15/2022	0	0	0	100
2/16/2022	0	0	0	100
2/17/2022	0	0	0	100
2/18/2022	0	0	0	100
2/19/2022	0	0	0	100
2/20/2022	1.91	16.4266	3.28531	96.7147
2/21/2022	1.83	15.7385	3.14771	96.8523
2/22/2022	1.13	9.71834	1.94367	98.0563
2/23/2022	0.06	0.51602	0.1032	99.8968
2/24/2022	0.01	0.086	0.0172	99.9828
2/25/2022	1.96	16.8566	3.37132	96.6287
2/26/2022	0.86	7.39626	1.47925	98.5207
2/27/2022	0	0	0	100
2/28/2022	0.4	3.44012	0.68802	99.312

Table 2 Rainfall Data with daily supplementation for the month of February, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
3/1/2022	0.09	0.77403	0.15481	99.8452
3/2/2022	0	0	0	100
3/3/2022	0	0	0	100
3/4/2022	0	0	0	100
3/5/2022	0	0	0	100
3/6/2022	0	0	0	100
3/7/2022	0	0	0	100
3/8/2022	0	0	0	100
3/9/2022	0	0	0	100
3/10/2022	0	0	0	100
3/11/2022	0	0	0	100
3/12/2022	0	0	0	100
3/13/2022	0	0	0	100
3/14/2022	0	0	0	100
3/15/2022	0	0	0	100
3/16/2022	0	0	0	100
3/17/2022	0	0	0	100
3/18/2022	0	0	0	100
3/19/2022	0	0	0	100
3/20/2022	0	0	0	100
3/21/2022	0	0	0	100
3/22/2022	0	0	0	100
3/23/2022	0	0	0	100
3/24/2022	0.21	1.80606	0.36121	99.6388
3/25/2022	0.63	5.41819	1.08364	98.9164
3/26/2022	2.64	22.7048	4.54096	95.459
3/27/2022	1.31	11.2664	2.25328	97.7467
3/28/2022	2.91	25.0269	5.00537	94.9946
3/29/2022	6.09	52.3758	10.4752	89.5248
3/30/2022	4.89	42.0555	8.41109	91.5889
3/31/2022	1.21	10.4064	2.08127	97.9187

Table 3 Rainfall Data with daily supplementation for the month of March, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
4/1/2022	1.96	16.8566	3.37132	96.6287
4/2/2022	2.94	25.2849	5.05698	94.943
4/3/2022	0.68	5.8482	1.16964	98.8304
4/4/2022	1.29	11.0944	2.21888	97.7811
4/5/2022	3.88	33.3692	6.67383	93.3262
4/6/2022	2.32	19.9527	3.99054	96.0095
4/7/2022	0	0	0	100
4/8/2022	0	0	0	100
4/9/2022	0.23	1.97807	0.39561	99.6044
4/10/2022	3.43	29.499	5.89981	94.1002
4/11/2022	2.4	20.6407	4.12814	95.8719
4/12/2022	3.42	29.413	5.88261	94.1174
4/13/2022	3.22	27.693	5.53859	94.4614
4/14/2022	1.64	14.1045	2.8209	97.1791
4/15/2022	0.56	4.81617	0.96323	99.0368
4/16/2022	1.05	9.03032	1.80606	98.1939
4/17/2022	1.55	13.3305	2.66609	97.3339
4/18/2022	1.87	16.0826	3.21651	96.7835
4/19/2022	6.48	55.7299	11.146	88.854
4/20/2022	13.63	117.222	23.4444	76.5556
4/21/2022	8.56	73.6186	14.7237	85.2763
4/22/2022	7.62	65.5343	13.1069	86.8931
4/23/2022	22.72	195.399	39.0798	60.9202
4/24/2022	12.45	107.074	21.4147	78.5853
4/25/2022	0.72	6.19222	1.23844	98.7616
4/26/2022	2.21	19.0067	3.80133	96.1987
4/27/2022	7.05	60.6321	12.1264	87.8736
4/28/2022	0.59	5.07418	1.01484	98.9852
4/29/2022	1.25	10.7504	2.15008	97.8499
4/30/2022	3.3	28.381	5.6762	94.3238

Table 4 Rainfall Data with daily supplementation for the month of April, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
5/1/2022	0.57	4.90217	0.98043	99.0196
5/2/2022	1.82	15.6525	3.13051	96.8695
5/3/2022	11.52	99.0755	19.8151	80.1849
5/4/2022	12.6	108.364	21.6728	78.3272
5/5/2022	7.92	68.1144	13.6229	86.3771
5/6/2022	13.67	117.566	23.5132	76.4868
5/7/2022	4.54	39.0454	7.80907	92.1909
5/8/2022	1.97	16.9426	3.38852	96.6115
5/9/2022	8.4	72.2425	14.4485	85.5515
5/10/2022	18.99	163.32	32.6639	67.3361
5/11/2022	32.29	277.704	55.5407	44.4593
5/12/2022	17.57	151.107	30.2215	69.7785
5/13/2022	45.1	387.874	77.5747	22.4253
5/14/2022	22.6	194.367	38.8734	61.1266
5/15/2022	3.11	26.7469	5.34939	94.6506
5/16/2022	2.85	24.5109	4.90217	95.0978
5/17/2022	16.13	138.723	27.7446	72.2554
5/18/2022	19.02	163.578	32.7155	67.2845
5/19/2022	27.61	237.454	47.4909	52.5091
5/20/2022	27.51	236.594	47.3189	52.6811
5/21/2022	50.49	434.229	86.8458	13.1542
5/22/2022	12.27	105.526	21.1051	78.8949
5/23/2022	17.29	148.699	29.7398	70.2602
5/24/2022	4.35	37.4113	7.48226	92.5177
5/25/2022	4.95	42.5715	8.5143	91.4857
5/26/2022	16.71	143.711	28.7422	71.2578
5/27/2022	8.77	75.4246	15.0849	84.9151
5/28/2022	6.64	57.106	11.4212	88.5788
5/29/2022	22.87	196.689	39.3378	60.6622
5/30/2022	16.89	145.259	29.0518	70.9482
5/31/2022	8.46	72.7585	14.5517	85.4483

Table 5 Rainfall Data with daily supplementation for the month of May, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
6/1/2022	6.49	55.8159	11.1632	88.8368
6/2/2022	4.77	41.0234	8.20469	91.7953
6/3/2022	8.43	72.5005	14.5001	85.4999
6/4/2022	19.18	164.954	32.9908	67.0092
6/5/2022	7.71	66.3083	13.2617	86.7383
6/6/2022	7.86	67.5984	13.5197	86.4803
6/7/2022	16.08	138.293	27.6586	72.3414
6/8/2022	22.04	189.551	37.9101	62.0899
6/9/2022	34.68	298.258	59.6517	40.3483
6/10/2022	41.26	354.848	70.9697	29.0303
6/11/2022	0.82	7.05225	1.41045	98.5896
6/12/2022	4.73	40.6794	8.13588	91.8641
6/13/2022	7.96	68.4584	13.6917	86.3083
6/14/2022	10.42	89.6151	17.923	82.077
6/15/2022	7.5	64.5023	12.9005	87.0996
6/16/2022	17.99	154.719	30.9439	69.0561
6/17/2022	49.39	424.769	84.9538	15.0462
6/18/2022	53.5	460.116	92.0232	7.97679
6/19/2022	26.07	224.21	44.842	55.158
6/20/2022	19.8	170.286	34.0572	65.9428
6/21/2022	14.52	124.876	24.9753	75.0247
6/22/2022	2.83	24.3388	4.86777	95.1322
6/23/2022	14.93	128.402	25.6805	74.3195
6/24/2022	3.01	25.8869	5.17738	94.8226
6/25/2022	3.26	28.037	5.6074	94.3926
6/26/2022	4.17	35.8633	7.17265	92.8273
6/27/2022	2.48	21.3287	4.26575	95.7343
6/28/2022	4.62	39.7334	7.94668	92.0533
6/29/2022	8.25	70.9525	14.1905	85.8095
6/30/2022	13.82	118.856	23.7712	76.2288

Table 6 Rainfall Data with daily supplementation for the month of June, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
7/1/2022	4.55	39.1314	7.82627	92.1737
7/2/2022	3.37	28.983	5.7966	94.2034
7/3/2022	6.55	56.332	11.2664	88.7336
7/4/2022	7.25	62.3522	12.4704	87.5296
7/5/2022	0.92	7.91228	1.58246	98.4175
7/6/2022	22.11	190.153	38.0305	61.9695
7/7/2022	2.01	17.2866	3.45732	96.5427
7/8/2022	2.48	21.3287	4.26575	95.7343
7/9/2022	1	8.6003	1.72006	98.2799
7/10/2022	1.87	16.0826	3.21651	96.7835
7/11/2022	3.1	26.6609	5.33219	94.6678
7/12/2022	1.05	9.03032	1.80606	98.1939
7/13/2022	1.65	14.1905	2.8381	97.1619
7/14/2022	3.53	30.3591	6.07181	93.9282
7/15/2022	10.59	91.0772	18.2154	81.7846
7/16/2022	2.51	21.5868	4.31735	95.6826
7/17/2022	6.41	55.1279	11.0256	88.9744
7/18/2022	2.05	17.6306	3.52612	96.4739
7/19/2022	4.75	40.8514	8.17029	91.8297
7/20/2022	8.51	73.1886	14.6377	85.3623
7/21/2022	3.11	26.7469	5.34939	94.6506
7/22/2022	1.43	12.2984	2.45969	97.5403
7/23/2022	14.77	127.026	25.4053	74.5947
7/24/2022	3.91	33.6272	6.72543	93.2746
7/25/2022	13.61	117.05	23.41	76.59
7/26/2022	5.84	50.2258	10.0452	89.9548
7/27/2022	2.91	25.0269	5.00537	94.9946
7/28/2022	8.97	77.1447	15.4289	84.5711
7/29/2022	10.41	89.5291	17.9058	82.0942
7/30/2022	4.74	40.7654	8.15308	91.8469
7/31/2022	8.34	71.7265	14.3453	85.6547

Table 7 Rainfall Data with daily supplementation for the month of July, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
8/1/2022	19.94	171.49	34.298	65.702
8/2/2022	9.14	78.6067	15.7213	84.2787
8/3/2022	7.09	60.9761	12.1952	87.8048
8/4/2022	18.46	158.762	31.7523	68.2477
8/5/2022	12.77	109.826	21.9652	78.0348
8/6/2022	26.35	226.618	45.3236	54.6764
8/7/2022	13.73	118.082	23.6164	76.3836
8/8/2022	7.72	66.3943	13.2789	86.7211
8/9/2022	3.41	29.327	5.8654	94.1346
8/10/2022	1.53	13.1585	2.63169	97.3683
8/11/2022	1.85	15.9106	3.18211	96.8179
8/12/2022	1	8.6003	1.72006	98.2799
8/13/2022	9.62	82.7349	16.547	83.453
8/14/2022	17.9	153.945	30.7891	69.2109
8/15/2022	13.41	115.33	23.066	76.934
8/16/2022	3.77	32.4231	6.48463	93.5154
8/17/2022	4.45	38.2713	7.65427	92.3457
8/18/2022	3.89	33.4552	6.69103	93.309
8/19/2022	13.6	116.964	23.3928	76.6072
8/20/2022	21.35	183.616	36.7233	63.2767
8/21/2022	10.25	88.1531	17.6306	82.3694
8/22/2022	1.68	14.4485	2.8897	97.1103
8/23/2022	22.87	196.689	39.3378	60.6622
8/24/2022	5.51	47.3877	9.47753	90.5225
8/25/2022	3.85	33.1112	6.62223	93.3778
8/26/2022	0.84	7.22425	1.44485	98.5551
8/27/2022	3.54	30.4451	6.08901	93.911
8/28/2022	6.99	60.1161	12.0232	87.9768
8/29/2022	2.98	25.6289	5.12578	94.8742
8/30/2022	6.41	55.1279	11.0256	88.9744
8/31/2022	2.43	20.8987	4.17975	95.8203

Table 8 Rainfall Data with daily supplementation for the month of August, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
9/1/2022	9.67	83.1649	16.633	83.367
9/2/2022	10.08	86.691	17.3382	82.6618
9/3/2022	23.78	204.515	40.903	59.097
9/4/2022	28.11	241.754	48.3509	51.6491
9/5/2022	12.91	111.03	22.206	77.794
9/6/2022	15.83	136.143	27.2285	72.7715
9/7/2022	8.98	77.2307	15.4461	84.5539
9/8/2022	4.29	36.8953	7.37906	92.6209
9/9/2022	16.36	140.701	28.1402	71.8598
9/10/2022	9.87	84.885	16.977	83.023
9/11/2022	19.42	167.018	33.4036	66.5964
9/12/2022	14.13	121.522	24.3044	75.6956
9/13/2022	39	335.412	67.0823	32.9177
9/14/2022	44.14	379.617	75.9234	24.0766
9/15/2022	25.95	223.178	44.6356	55.3644
9/16/2022	12.38	106.472	21.2943	78.7057
9/17/2022	1.94	16.6846	3.33692	96.6631
9/18/2022	1.67	14.3625	2.8725	97.1275
9/19/2022	15.07	129.607	25.9213	74.0787
9/20/2022	3.16	27.1769	5.43539	94.5646
9/21/2022	3.35	28.811	5.7622	94.2378
9/22/2022	3.27	28.123	5.6246	94.3754
9/23/2022	2.46	21.1567	4.23135	95.7687
9/24/2022	2.58	22.1888	4.43775	95.5622
9/25/2022	6.24	53.6659	10.7332	89.2668
9/26/2022	3.49	30.015	6.00301	93.997
9/27/2022	13.3	114.384	22.8768	77.1232
9/28/2022	3.33	28.639	5.7278	94.2722
9/29/2022	1.33	11.4384	2.28768	97.7123
9/30/2022	0.71	6.10621	1.22124	98.7788

Table 9 Rainfall Data with daily supplementation for the month of September, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
10/1/2022	7.12	61.2341	12.2468	87.7532
10/2/2022	34.93	300.408	60.0817	39.9183
10/3/2022	21.14	181.81	36.3621	63.6379
10/4/2022	12.19	104.838	20.9675	79.0325
10/5/2022	10.22	87.8951	17.579	82.421
10/6/2022	2.15	18.4906	3.69813	96.3019
10/7/2022	2.09	17.9746	3.59493	96.4051
10/8/2022	1.41	12.1264	2.42528	97.5747
10/9/2022	6.19	53.2359	10.6472	89.3528
10/10/2022	7.11	61.1481	12.2296	87.7704
10/11/2022	12.47	107.246	21.4491	78.5509
10/12/2022	8.18	70.3505	14.0701	85.9299
10/13/2022	8.06	69.3184	13.8637	86.1363
10/14/2022	11.08	95.2913	19.0583	80.9417
10/15/2022	1.38	11.8684	2.37368	97.6263
10/16/2022	2.1	18.0606	3.61213	96.3879
10/17/2022	1.04	8.94431	1.78886	98.2111
10/18/2022	0.46	3.95614	0.79123	99.2088
10/19/2022	0.13	1.11804	0.22361	99.7764
10/20/2022	0.04	0.34401	0.0688	99.9312
10/21/2022	0	0	0	100
10/22/2022	0	0	0	100
10/23/2022	14.51	124.79	24.9581	75.0419
10/24/2022	144.77	1245.07	249.013	-149.01
10/25/2022	12.64	108.708	21.7416	78.2584
10/26/2022	3.6	30.9611	6.19222	93.8078
10/27/2022	0	0	0	100
10/28/2022	0	0	0	100
10/29/2022	0.08	0.68802	0.1376	99.8624
10/30/2022	2.99	25.7149	5.14298	94.857
10/31/2022	0.04	0.34401	0.0688	99.9312

Table 10 Rainfall Data with daily supplementation for the month of October, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
11/1/2022	0	0	0	100
11/2/2022	0	0	0	100
11/3/2022	0	0	0	100
11/4/2022	0	0	0	100
11/5/2022	0.02	0.17201	0.0344	99.9656
11/6/2022	3.08	26.4889	5.29778	94.7022
11/7/2022	0.01	0.086	0.0172	99.9828
11/8/2022	0	0	0	100
11/9/2022	0	0	0	100
11/10/2022	0	0	0	100
11/11/2022	0	0	0	100
11/12/2022	0	0	0	100
11/13/2022	0	0	0	100
11/14/2022	0.03	0.25801	0.0516	99.9484
11/15/2022	0	0	0	100
11/16/2022	0	0	0	100
11/17/2022	0	0	0	100
11/18/2022	0	0	0	100
11/19/2022	0	0	0	100
11/20/2022	0.07	0.60202	0.1204	99.8796
11/21/2022	0.92	7.91228	1.58246	98.4175
11/22/2022	0	0	0	100
11/23/2022	0	0	0	100
11/24/2022	0	0	0	100
11/25/2022	0	0	0	100
11/26/2022	0	0	0	100
11/27/2022	0	0	0	100
11/28/2022	0	0	0	100
11/29/2022	0	0	0	100
11/30/2022	0	0	0	100

Table 11 Rainfall Data with daily supplementation for the month of November, 2022

Date	Daily Rainfall	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
12/1/2022	0	0	0	100
12/2/2022	0	0	0	100
12/3/2022	0	0	0	100
12/4/2022	0	0	0	100
12/5/2022	0	0	0	100
12/6/2022	0	0	0	100
12/7/2022	0.01	0.086	0.0172	99.9828
12/8/2022	0	0	0	100
12/9/2022	0	0	0	100
12/10/2022	0	0	0	100
12/11/2022	0	0	0	100
12/12/2022	0	0	0	100
12/13/2022	0	0	0	100
12/14/2022	0	0	0	100
12/15/2022	0	0	0	100
12/16/2022	0	0	0	100
12/17/2022	0	0	0	100
12/18/2022	0	0	0	100
12/19/2022	0	0	0	100
12/20/2022	0	0	0	100
12/21/2022	0	0	0	100
12/22/2022	0	0	0	100
12/23/2022	0	0	0	100
12/24/2022	0	0	0	100
12/25/2022	0	0	0	100
12/26/2022	0.2	1.72006	0.34401	99.656
12/27/2022	3.32	28.553	5.7106	94.2894
12/28/2022	0.22	1.89207	0.37841	99.6216
12/29/2022	0	0	0	100
12/30/2022	0	0	0	100
12/31/2022	0	0	0	100

Table 12 Rainfall Data with daily supplementation for the month of December, 2022

CHAPTER IV

Data Analysis and Result Discussion

4.1 Monthly Rainwater Harvesting:

Month	Average Rainfall (mm)	Probable Harvested Rainwater(m^3)	% Harvested Rainwater	% Pumped Ground Water
January	8.701	74.83	0.499	99.50
February	15.8195	136.05	0.907	99.09
March	51.1515	439.92	2.933	97.067
April	167.9455	1444.38	9.629	90.371
May	309.3825	2660.78	17.74	82.26
June	385.595	3316.23	22.11	77.89
July	403.0575	3466.42	23.11	76.89
August	332.7725	2861.94	19.08	80.92
September	270.153	2323.40	15.49	84.51
October	167.809	1443.21	9.62	90.38
November	29.0995	250.26	1.668	98.332
December	19.622	168.76	1.125	98.875

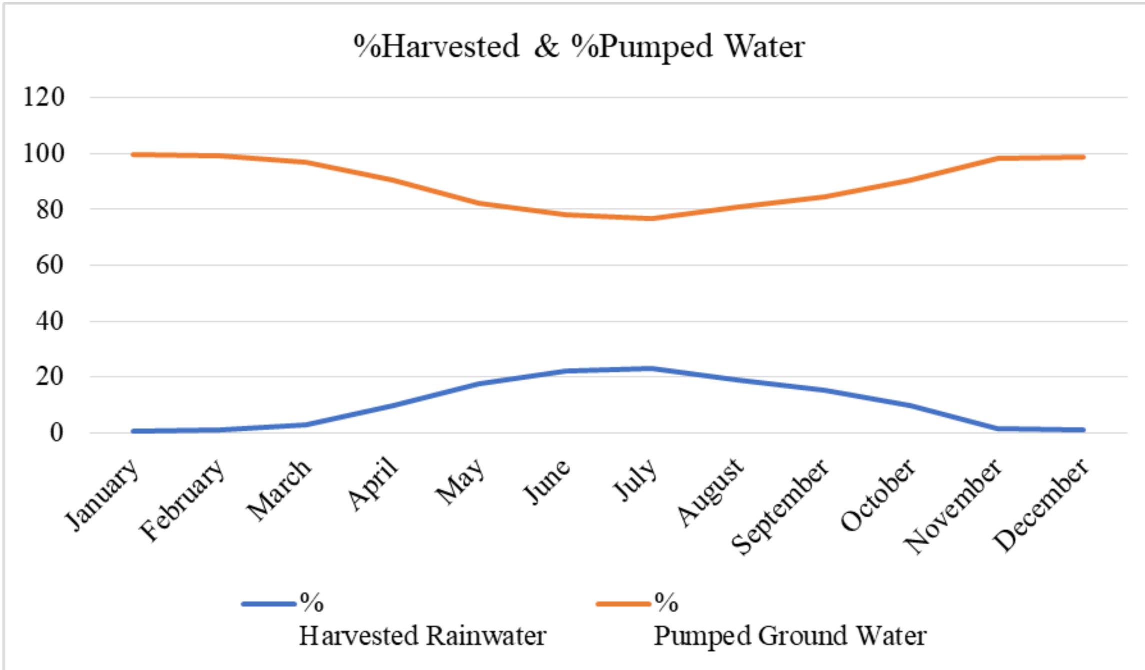


Figure 7 Harvested and Pumped Groundwater

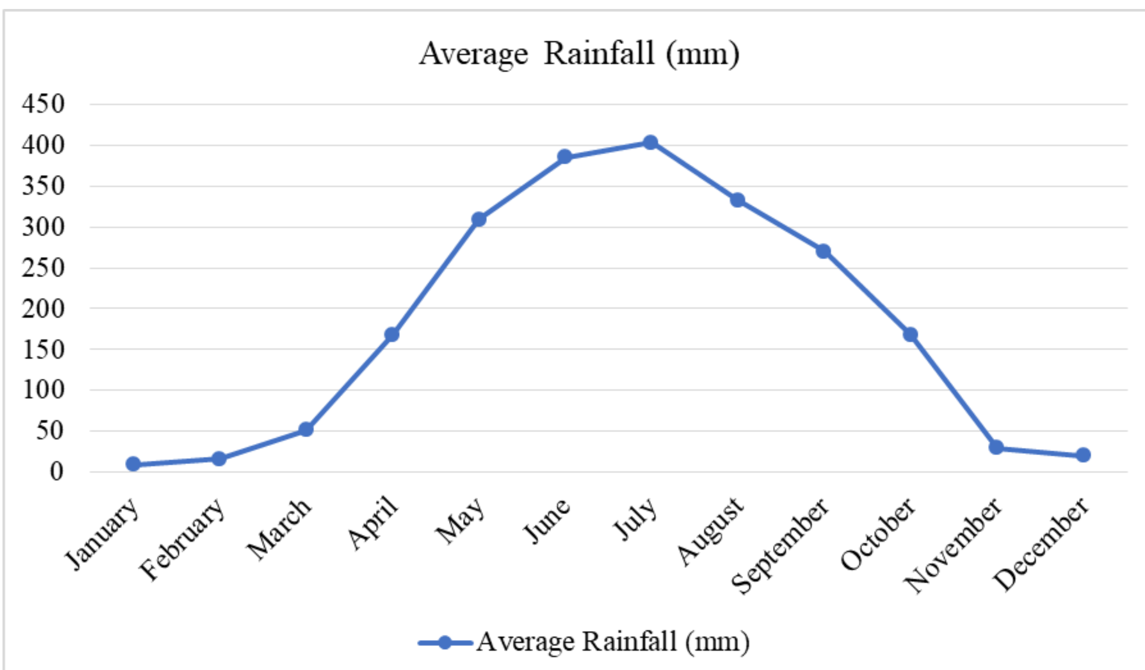


Figure 8 Average Rainfall (mm)

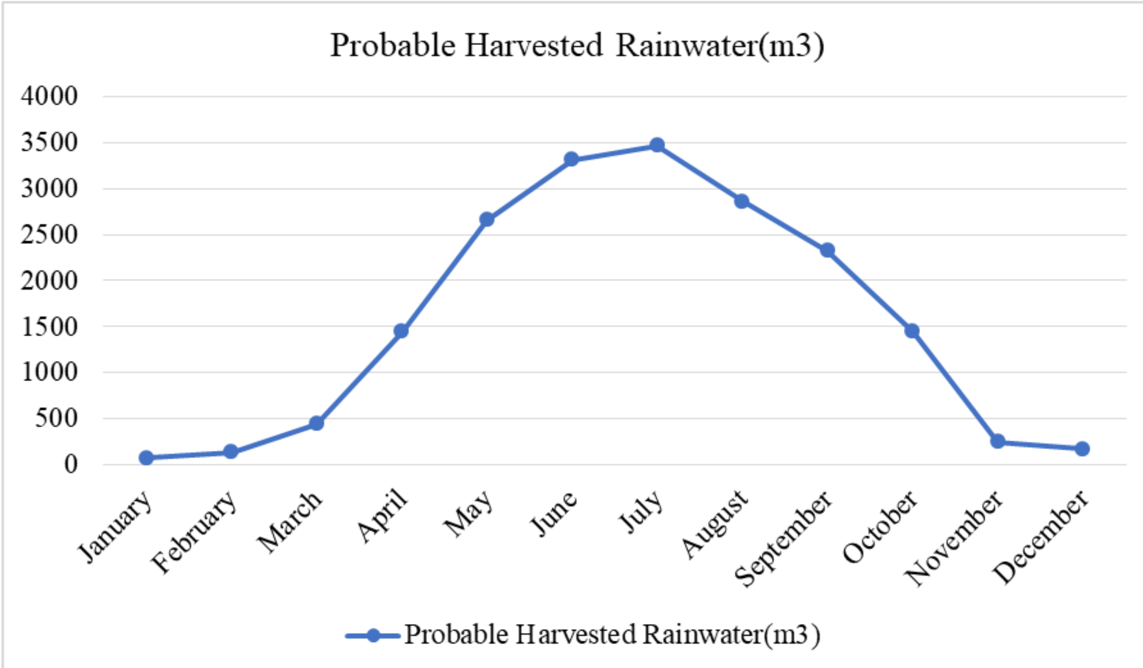


Figure 9 Probable Harvested Rainwater (m^3)

4.2 Daily Rainwater Harvesting:

A Particular Day in	Average Rainfall (mm)	Probable Harvested Rainwater(m3)	% Harvested Rainwater	% Pumped Ground Water
January	0.280677419	2.41391001	0.482782002	99.517218
February	0.564982143	4.859015923	0.971803185	99.02819682
March	1.650048387	14.19091114	2.838182229	97.16181777
April	5.598183333	48.14605612	9.629211224	90.37078878
May	9.980080645	85.83168757	17.16633751	82.83366249
June	12.85316667	110.5410893	22.10821786	77.89178214
July	13.00185484	111.8198522	22.36397043	77.63602957
August	10.73459677	92.32075264	18.46415053	81.53584947
September	9.0051	77.44656153	15.48931231	84.51068769
October	5.413193548	46.55508847	9.311017695	90.68898231
November	0.969983333	8.342147662	1.668429532	98.33157047
December	0.632967742	5.443712471	1.088742494	98.91125751

Table 13 Daily Rainwater Supplementation on any month

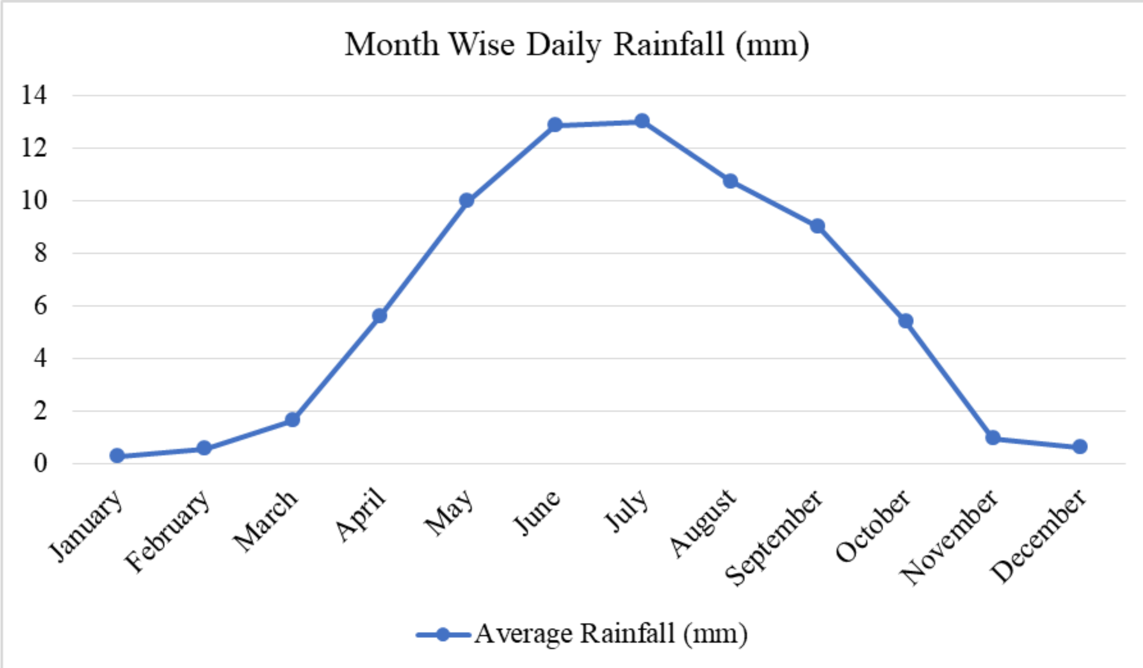


Figure 10 Month Wise Daily Rainfall (mm)

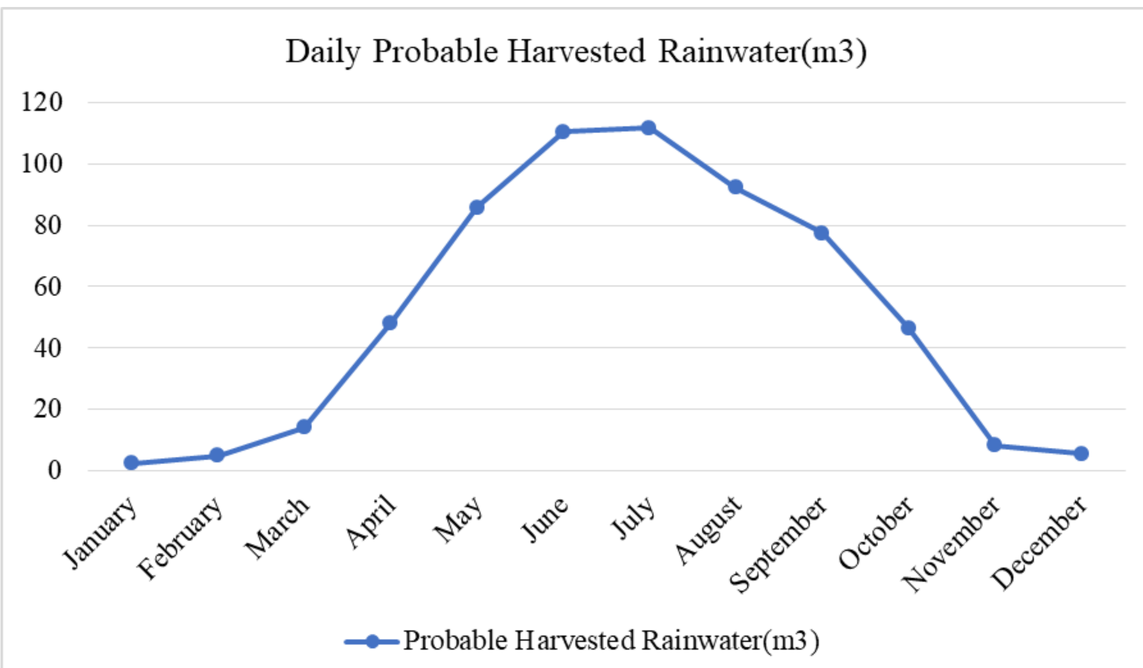


Figure 11 Daily Probable Harvested Rainwater (m^3)

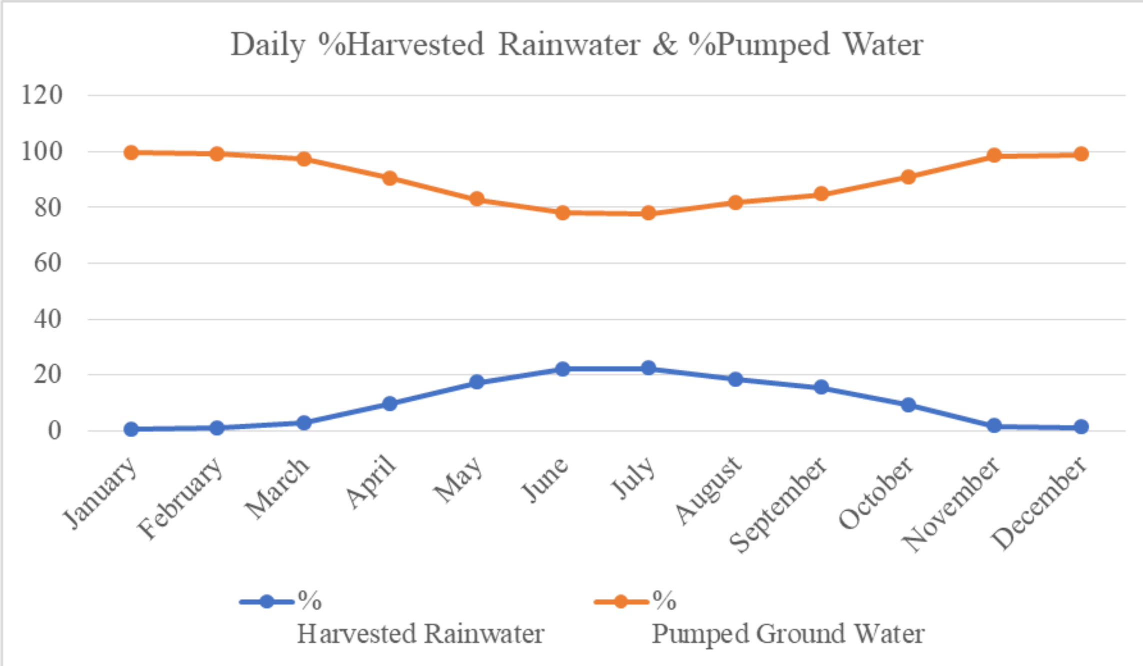


Figure 12 Daily Harvested Rainwater and Pumped Water (In Percentage)

4.3 R-Model Analysis:

Using daily rainfall data from RStudio, you would normally follow a basic data analysis and modeling procedure to create a rainwater collection model. An overview of the procedures is provided below:

1. Data Import: Enter into RStudio the daily rainfall data. The data may be in a database, CSV, Excel, or another format. To load the data into a suitable data structure, such as a data frame, use the necessary R functions or packages.

2. Data Preprocessing: Execute the required data cleaning and preparation preprocessing operations. This might entail addressing missing numbers, finding outliers, transforming the data, and performing data quality checks.

3. Exploratory Data Analysis (EDA): Analyze the data to learn more about it and discover its features. Identifying patterns, trends, and seasonality in the rainfall data may be done by using summary statistics, data visualization (plots, histograms, etc.), and pattern recognition software.

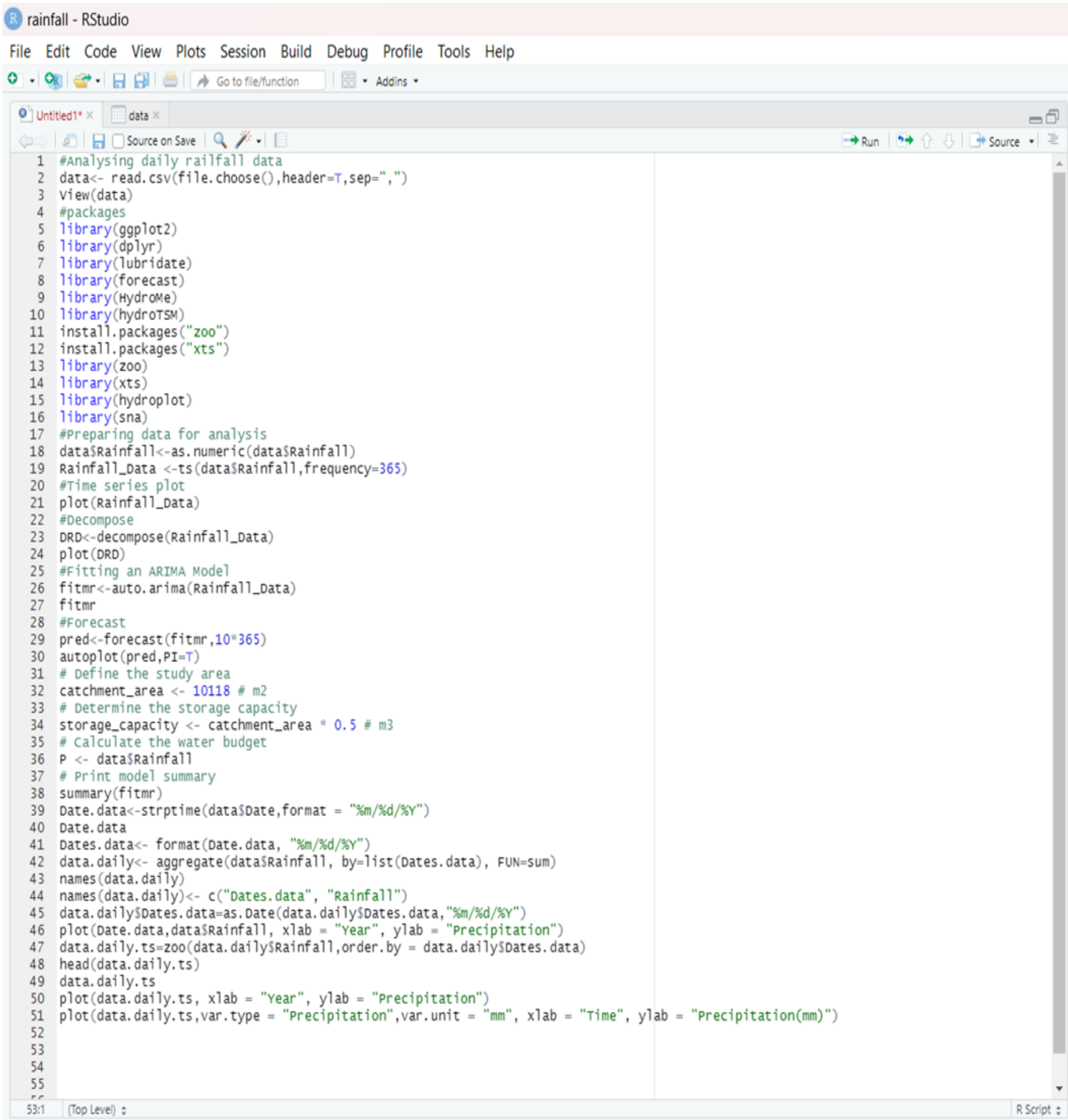
4. Feature Engineering: Determine any extra traits or variables that might improve our model's ability to forecast the future. Aggregating rainfall data over time, extracting temporal or geographical patterns, or factoring in outside factors like temperature or location are all examples of how to do this.

5. Model Selection: Depending on our unique goals and the qualities of our data, pick a suitable modeling approach. Simple regression models to more complex techniques like time series analysis or machine learning algorithms can be used.

6. Model Development: Using the given data, create and train our preferred model. This includes defining the model's structure, determining its parameters, and assessing the model's effectiveness.

7. Model Deployment and Prediction: Once we have a model that works well, we can use it to create forecasts based on fresh or previously unreported rainfall data. This helps us to predict future rainfall patterns or calculate pertinent metrics for rainwater collecting, including the amount of water available or the amount of storage needed.

4.3.1 Rainfall Data Coding and Analysis



```r
#Analysing daily railfall data
data<- read.csv(file.choose(),header=T,sep=",")
View(data)
#packages
library(ggplot2)
library(dplyr)
library(lubridate)
library(forecast)
library(HydroMe)
library(hydroTSM)
install.packages("zoo")
install.packages("xts")
library(zoo)
library(xts)
library(hydroplot)
library(sna)
#Preparing data for analysis
data$Rainfall<-as.numeric(data$Rainfall)
Rainfall_Data <-ts(data$Rainfall,frequency=365)
#Time series plot
plot(Rainfall_Data)
#Decompose
DRD<-decompose(Rainfall_Data)
plot(DRD)
#Fitting an ARIMA Model
fitmr<-auto.arima(Rainfall_Data)
fitmr
#Forecast
pred<-forecast(fitmr,10*365)
autoplot(pred,PI=T)
# Define the study area
catchment_area <- 10118 # m2
# Determine the storage capacity
storage_capacity <- catchment_area * 0.5 # m3
# Calculate the water budget
P <- data$Rainfall
# Print model summary
summary(fitmr)
Date.data<-strptime(data$Date,format = "%m/%d/%Y")
Date.data
Dates.data<- format(Date.data, "%m/%d/%Y")
data.daily<- aggregate(data$Rainfall, by=list(Dates.data), FUN=sum)
names(data.daily)
names(data.daily)<- c("Dates.data", "Rainfall")
data.daily$Dates.data=as.Date(data.daily$Dates.data,"%m/%d/%Y")
plot(Date.data,data$Rainfall, xlab = "Year", ylab = "Precipitation")
data.daily.ts=zoo(data.daily$Rainfall,order.by = data.daily$Dates.data)
head(data.daily.ts)
data.daily.ts
plot(data.daily.ts, xlab = "Year", ylab = "Precipitation")
plot(data.daily.ts,var.type = "Precipitation",var.unit = "mm", xlab = "Time", ylab = "Precipitation(mm)")
```

Figure 13 Coding used in Rstudio

4.3.2 Data Set:

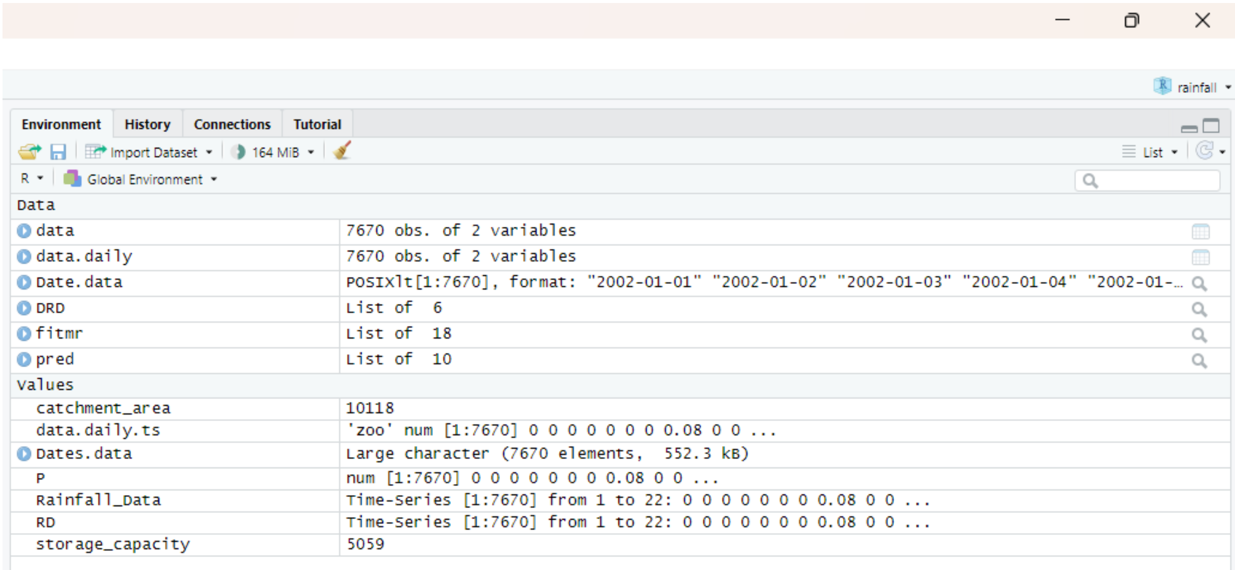


Figure 14 Data Set in Rstudio

4.3.2 Time Series Data Plot:

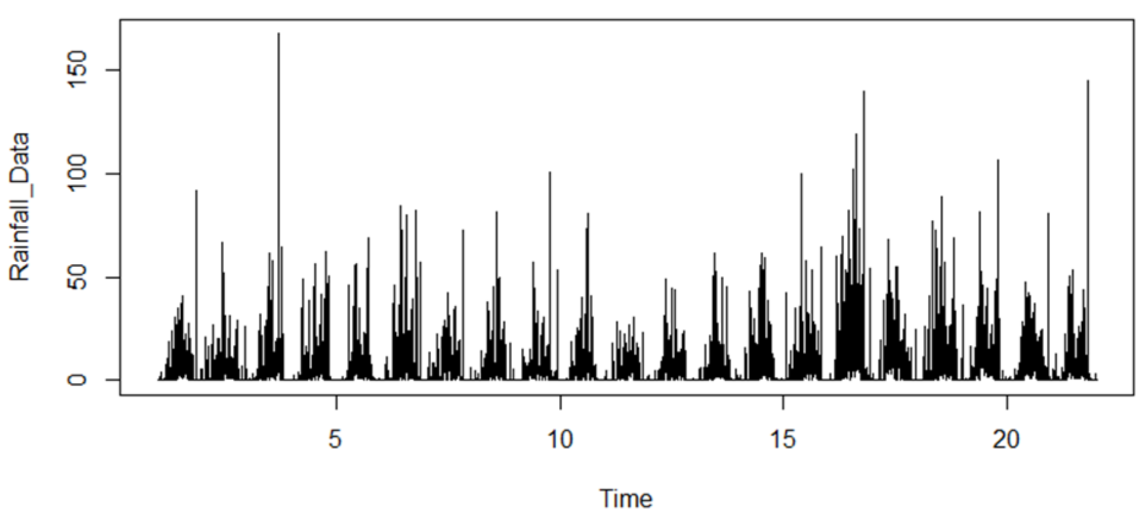


Figure 15 Time Series Data Plot

4.3.3 Decomposition of additive time series:

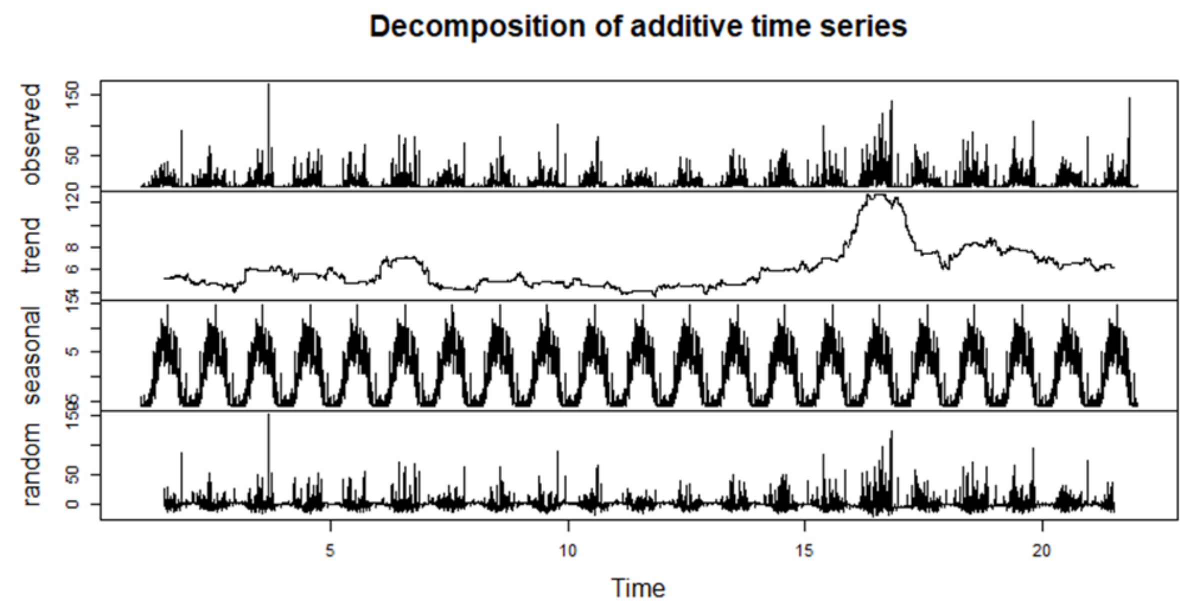


Figure 16 Decomposition of additive time series

4.3.4 Precipitation Data Chart:

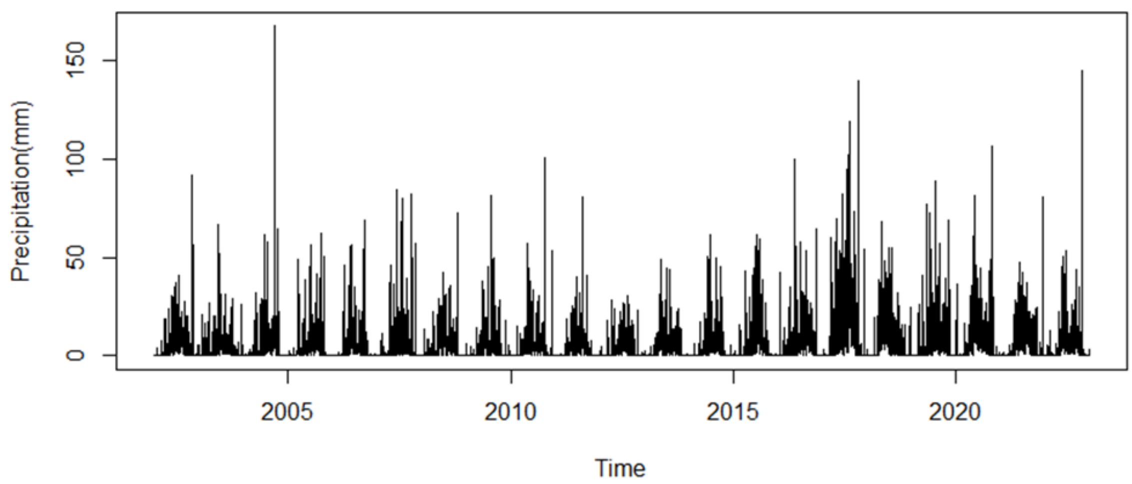
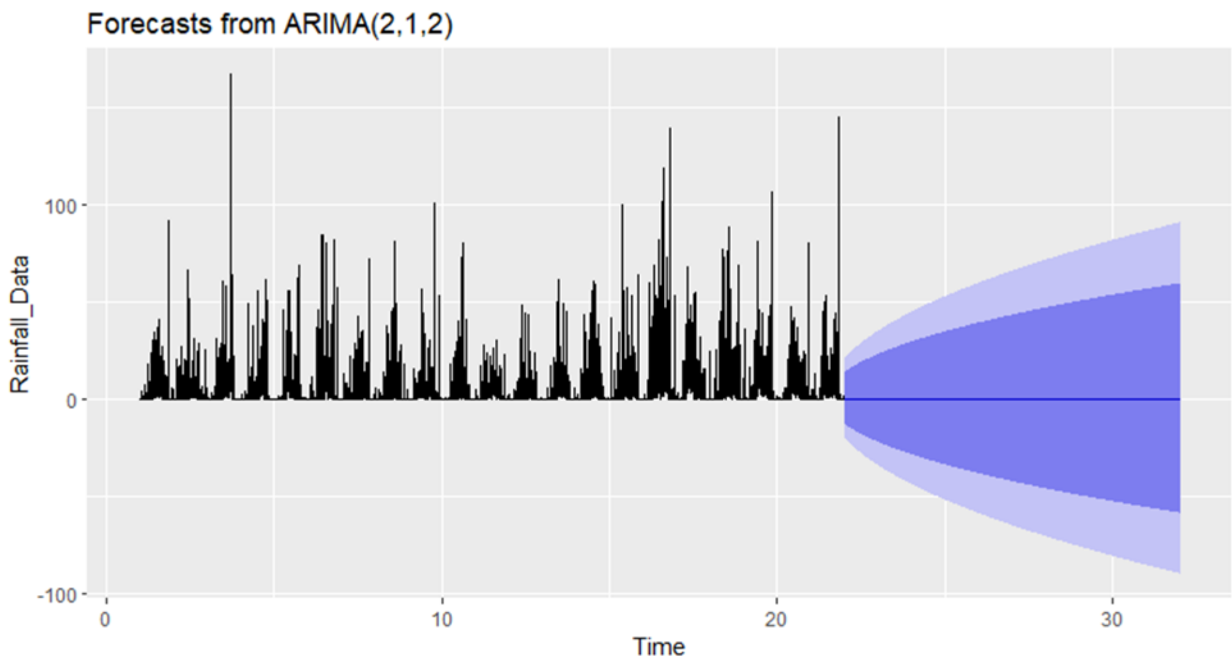


Figure 17 Precipitation Data Chart

4.3.5 Rainfall Forecast for Next 10 Years:



For carrying out these stages, RStudio offers a comfortable environment that enables you to develop and run R code, visualize data and findings, and arrange your research in a repeatable way. Additionally, it provides a number of tools and packages that may help with data pretreatment, modeling, and visualization.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The study describes the variation in rainfall and its impact on water supplementation throughout the year on a daily basis in IUT. During the dry season which could be a period of little rainfall the supplementation of water is relatively low. This suggests that the natural rainfall may not be sufficient to meet the daily water demand, and additional supplementation is required for most of the use case. November through December sees virtually little supplementing to the actual demand. The supplementation amount during April and October is low. In May, August and September months moderate amount of supplementation ranging upto 20% to the daily water demand. In the months of June and July up to one-fourth of total water demand can be supplemented using harvested rainwater as plenty of rainfall occurs in this time period.

In summary, research on rainwater harvesting model development demonstrates its potential as a sustainable water management solution. However, further studies and practical applications are necessary to refine the models, address challenges, and promote widespread adoption to realize the full benefits of rainwater harvesting.

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