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2. Acknowledgment:

We would like to express our heartfelt gratitude to **WWF-Pakistan** and **PepsiCo-Pakistan** for their invaluable support and sponsorship of our final year project at UET Taxila on the "Design and Installation of Groundwater Recharging Wells." Their generous funding and collaboration enabled us to undertake this crucial initiative aimed at conserving and enhancing groundwater resources in our region.

We are deeply indebted to our project supervisor, **Engr. Babar Abbas**, for his unwavering guidance, expertise, and mentorship throughout the project. His dedication and knowledge have been instrumental in shaping our research and ensuring its successful completion.

Additionally, we extend our sincere thanks to the Department of **Environmental engineering** for their support and encouragement. This project would not have been possible without the collective efforts of our department and their commitment to environmental sustainability.

3. Abstract

In many places of the world, shortages of water and the depletion of groundwater reserves are serious challenges. As a result, solutions including groundwater recharge and other forms of sustainable groundwater management are being considered. An installation of a replenishment of groundwater well is currently under way to ensure the continuance of water supply. Water quality, aquifer characteristics, and the feasibility of refilling were just few of the hydrogeological factors that were carefully examined in this study. Well construction methods were also dissected for this study. All aspects of the well's construction were considered.

The importance of selecting a proper location for the replenishment of groundwater well is highlighted by the study's findings. In addition, different recharge strategies, including basins for infiltration and injection wells, were evaluated to find the most appropriate method for the site. It was also looked into how putting in the replenishment of groundwater well could affect the ecosystem. Mitigation measures, such as proper sealing of the well casing and monitoring of water quality parameters, were recommended to minimize potential risks and ensure the sustainability of the recharge operation. Taxila, is Hilly area of Pakistan, poses unique challenges for groundwater management and sustainability. The water table is lower as compared to other areas. In response to diminishing groundwater resources and increasing water stress, this research project aimed to design and install two groundwater recharging wells in the Taxila area. The study's primary objectives were to assess the effectiveness of these wells in recharging groundwater, evaluate their environmental impact, and provide insights into their potential for sustainable water resource management in hilly regions.

The research involved comprehensive site selection, hydrogeological investigations, and the design and construction of two recharge wells. Detailed monitoring and data collection were carried out before, during, and after the installation of these wells to evaluate their impact on groundwater levels and quality.

4. Keywords

Groundwater replenishment, Recharging well, Water filtration, Water quality, Conservation, SDGs, Clean water, sustainability.

5. Introduction

Water is an essential element to sustain all life. Globally, one-third of the freshwater resources on earth are found in groundwater[1]. However, the global overexploitation of surface water resources has put enormous pressure on terrestrial resources, leading to their depletion in many parts of the world[2].

There has been a lot of pressure put on both the quantity and quality of Pakistan's water resources due to the country's fast population growth, urbanization, and unsustainable freshwater-use practices both in rural & modern areas[3]. There has been a significant rise in water availability in Pakistan, with the number of cubic meters of water available per year per person rising from 5,000 on 1951 to 1,100 in 2006 (SCEA 2006)[4]. There are significant water shortages in nearly all locations due to the widening disparity in the natural water market. The Population Growth Rate in Pakistan in 2004 was 1.9%, as recorded by the Climate Service. 173 million in 2010 and 221 million in 2025 are the increased estimates[5].

These evaluations indicate that, since 2010, the country has been consistently falling short of the target annual water supply of one thousand cubic meters per inhabitant[6]. Outside the Indus River basin, where yearly flows are presently below one thousand cubic meters per individual (SOE 2005), the situation may deteriorate[7]. For Pakistan's people to thrive in the long run, water is a must. As a result of water shortage and rising demand for it in other sectors, water pollution has emerged as a major issue in Pakistan[8]. It's common knowledge at this point that polluted water is at the root of most reported ailments. Water scarcity (WB) will be eradicated in Pakistan, which is now one of the world's most water stressed countries[9]. The remarkable research illustrates the connection among the quality of water and its effect on well-being and details the current situation of both quantity and quality of water in Pakistan[10]. The overall situation is improved by describing certain harmful actions.

5.1. Current Situation / Issues of Water in Pakistan

There are a number of stresses on the nation's water supply. Rapid urbanization increased industrial activity, and this increasing use of fertilizers and chemicals polluted water supplies[11]. Water pollution from declining water quality causes an increase in waterborne illnesses and their harmful impact on human health[12].

5.2. Water Availability in Pakistan

There has been a worrying decline in the quantity of water accessible per person. From about 5,000 cubic meters in 1951 per capita to about 1,100 cubic meters today, a reduction of almost 80% is evident[13]. Fewer than 700 cubic meter of fresh water per person is projected to be available in 2025 (Pak-SCEA, 2006)[14].

Most people in Pakistan get their water from underground sources. Most rural locations and many large cities, including Islamabad, Karachi, and Hyderabad, derive their water from completely different sources[15]. About 80% of the land in Punjab is covered by fresh groundwater; the remaining 20% is either brackish water or desert[16]. High region levels of either fluoride or arsenic have also been detected in some areas of Punjab[17]. As an added bonus, many areas have been polluted due to the industrialization's practice of discharging wastewater underground. There is less than 30% potable groundwater in Sindh[18].

The water throughout the majority of the region is extremely salty, and there have been reports of slightly higher fluoride levels[19]. Wells in KPK have sunk to the saltwater level due to excessive pumping of groundwater[20]. The groundwater in much of Baluchistan is salty (Pak-SCEA, 2006). Punjab is home to the country's best water supply in rural regions system, according to the government[21].

Most people in rural areas have access to running water or can use a hand or power pump to get water. The report found that just 7% of rural residents relied on surface water sources such as water from rivers, canals, streams, and wells[22]. The situation is most dire in Sindh, where around 24 percent of the rural residents relies on these resources for survival. It would imply that conditions in rural Sindh are worsening as well. Baluchistan and KPK (Khyber Pakhtunkhwa) have the poorest rural water supply situations in Pakistan[23].

About 46% and 72% of the rural population in both of these provinces, respectively, get their water from a drilled well or a river, canal, or stream (SOE 2005)[24].

5.3. Per Capita Water Availability

As for Draft State of Environment Report 2005, water availability in Pakistan per capita has reduced from 5300 m^3 in 1951 to 850 m^3 in 2013 and it will reduce further to 659 m^3 in 2025[25]. The decline in water availability in Pakistan primarily stems from three factors; these include mismanagement on behalf of the government, lack of awareness, and politics between provinces.

Table 1 shows the water availability in Pakistan per capita.

Table 1: water availability in Pakistan per capita

Year (Annually)	Population (million)	Per capita water availability
1951	34	5300 m^3
1961	46	3950 m^3
1971	65	2700 m^3
1981	84	2100 m^3
1991	115	1600 m^3
2000	148	1200 m^3
2013	207	850 m^3
2025	267	659 m^3

Source: Draft State of Environment Report 2005 ministry of environment Pakistan[26]

Irrigation accounts for almost 93 percent of Pakistan's current water consumption, per the NWP[27]. The remainder is distributed to urban and suburban industries and farms. A 221 million increase in Pakistan's population is forecast by 2025, as was previously indicated. There will be a significant increase in demand for water, especially in metropolitan areas. This action will place even more of a strain on water supplies that are already inadequate[28].

Table 2:Pakistan's water scenario

Annually	2004	2025
Availability	104 MAF	104 MAF
Requirement (including drinking water)	115 MAF	135 MAF
Overall Shortfall	11 MAF	31 MAF

Source: Ten Year Perspective Development Plan 2001-2011, Planning commission govt of Pakistan [29]

From literature review we find out that, rainwater is fresh source for groundwater recharging Well, and proactive approach to deal with urban flooding[30]. The project primarily consists of surface rainwater harvesting to cope with stormwater in Taxila. The key objective of this research is to reuse the rainwater for groundwater recharge and other several activities such as to prevent rainwater discharge in municipal drains, devise and develop policy for rainwater harvesting in Taxila. Study and design techniques for rainwater harvesting (collection, storage, groundwater, recharge) under diverse local condition, and to devise a solution to deal with the ponding of stormwater in UET Taxila. To the best of our knowledge, this is the first project of rainwater harvesting to cope with storm water in Taxila which will be helpful for policy makers and water stewardship managers who are working for groundwater replenishment. The designing and workflow methodology for groundwater recharging well are comprised of (i) site visits to select suitable catchment area (ii) point out the ponding sites during the peak (Monsoon) season (iii) data analysis for groundwater quality and rainwater quality monitoring (iv) Estimation for potential rainwater harvesting at Library top and multipurpose Hall top. (v) pre-installation measures for the design of recharge well (vi) post-installation measures for recharge well.

6. Methodology:

Before adopted suitable methodology for groundwater recharging Well, the past data of groundwater table in Taxila were collected to check the current groundwater table. The ground strata were also checked before construction of Recharging Well. The data was taken from the planning department of UET Taxila. The installation of a groundwater recharge well involves a systematic methodology to ensure its effectiveness and long-term functionality. A study was conducted in UET Taxila by using the following methodology. Firstly, suitable catchment areas have been selected for groundwater recharging well through several sites visits. Then we performed the data analysis for groundwater quality, rainwater and hydrological studies to check feasibility of groundwater recharge Wells. After that we designed and installed the filtration assembly and recharge well according to the designed dimension and then check and evaluate the performance of groundwater recharge Wells through monitoring Well.

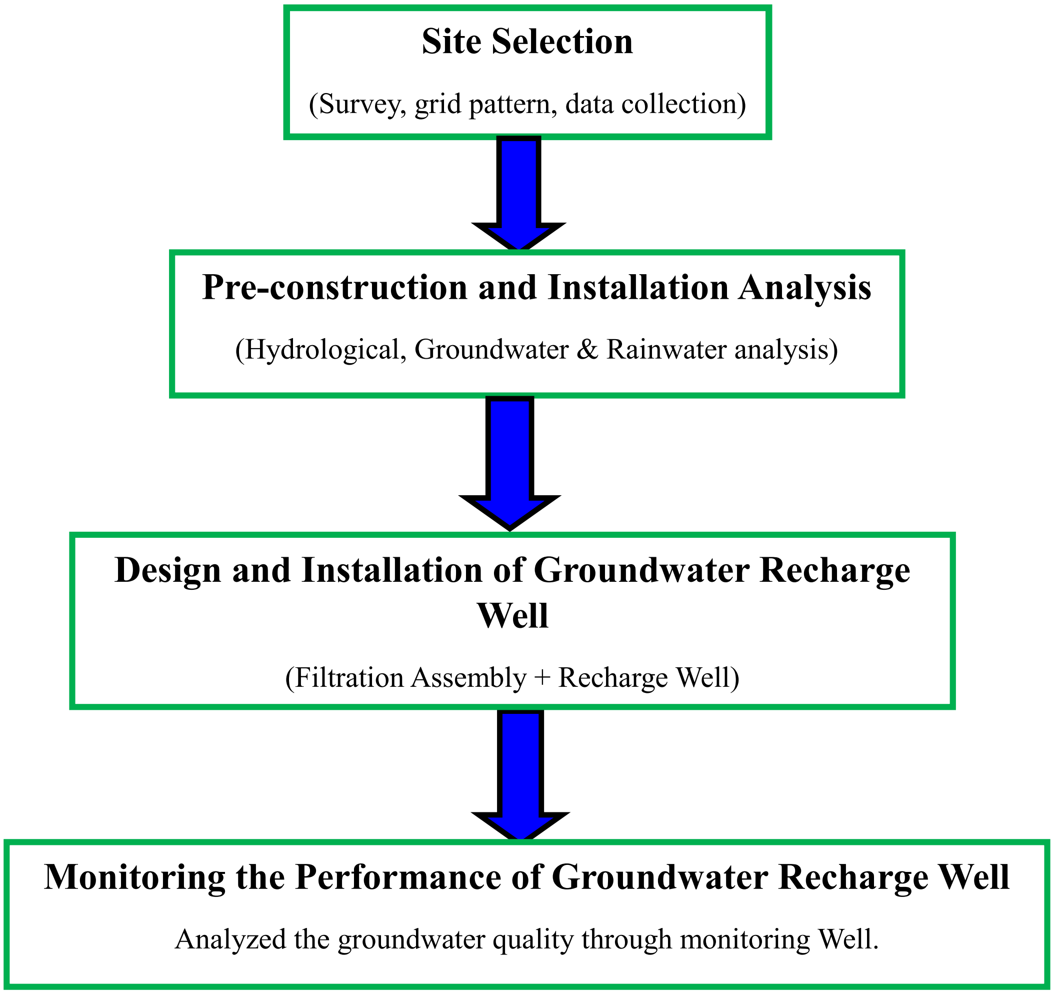

Figure 1:methodology

6.1. Site Selection:

A general survey was conducted in UET Taxila to select suitable catchment area for the installation of ground water recharge well. Those areas were selected, where the accumulation of rainwater is in excessive amount. Various field visits have been made after every rainfall to identify the potential areas for groundwater recharging well. After detailed site visits and meeting two areas were selected, one is near the library of university and the other one is near the multipurpose hall.

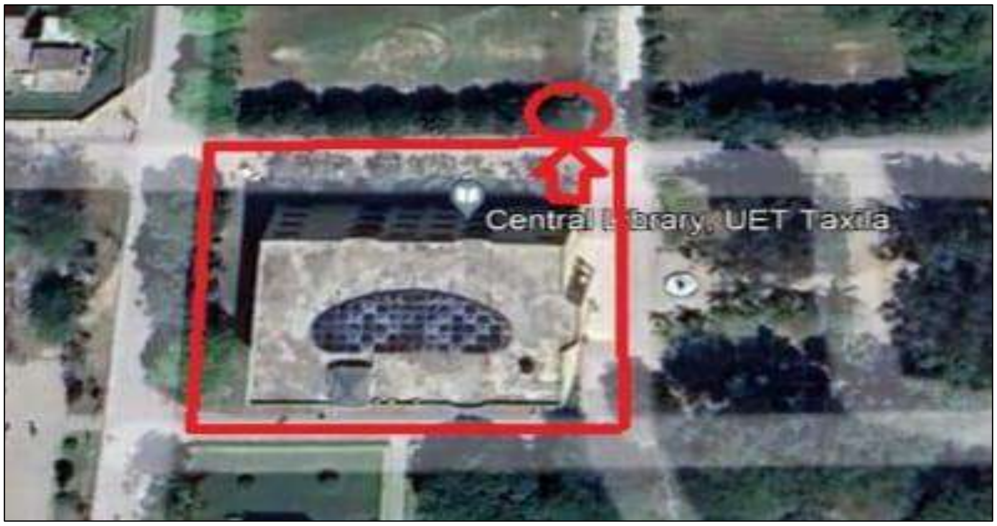

Figure 2:Library Site Catchment Area

Figure 3:MP Hall Site Catchment Area

6.2. Hydrogeological Investigation:

We performed the hydrogeological investigation to analyze the local groundwater system, including aquifer characteristics, groundwater flow direction, and recharge potential by Laboratory analysis. water quality parameters have been checked. Also, soil tests have been analyzed to check the water percolation rate, infiltration capacity, soil composition and compaction. The tests that performed for soil analysis is classification, grading and permeability.

Figure 4:working in soil Analysis lab.

6.3. Design & Construction:

Based on the site assessment and hydrogeological investigation, design the groundwater recharge well system, including well depth, diameter, screen placement, and filter materials. Mobilize drilling equipment and personnel to the site. The depth of borehole of recharge well is 80 ft down and monitoring well depth is 150ft down. The technique used for drilling is rotary drilling. The well casing is installed and screen to prevent collapse and allow water to enter while filtering out sediments. Seal the annular space between the casing and borehole walls with a suitable sealing material to prevent contamination.

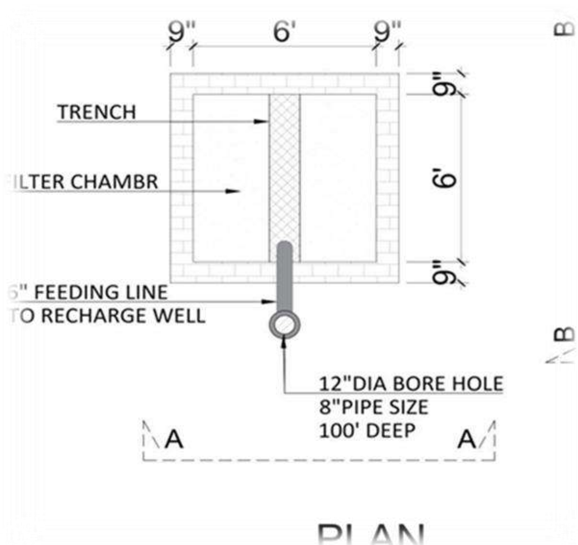

Figure 5:Plan of Recharge Well

6.4. Filter Media:

A layer of filter media, such as graded sand and gravel, has been installed in recharge pits to filter the rainwater. The use of activated carbon for more removal efficiency has also been introduced in filter media.

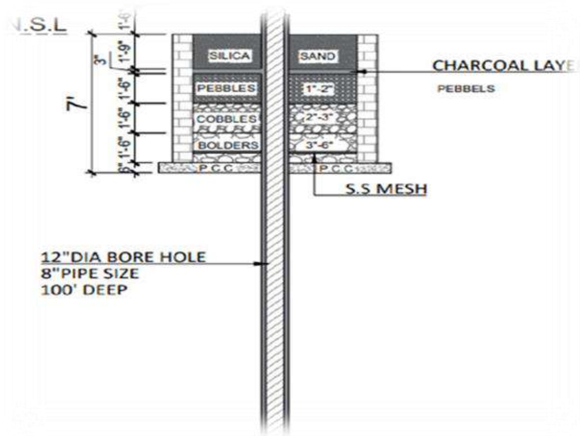

Figure 6:Filter Media Design

6.5. Analysis and Monitoring:

Pumping tests have been conducted to assess the well's performance, including water yield and drawdown. We analyzed the groundwater quality before filter media and after placing the filter media. A monitoring program during the rainfall and after the rainfall has been done to monitor water levels, water quality, and overall system performance.

6.6. Operation and Maintenance:

To ensure the ongoing functionality and efficiency of the groundwater recharge well. Regularly inspected and maintain the well, including cleaning, disinfection, and repairs as needed.

7. Groundwater Analysis

Groundwater analysis is the process of evaluating the depth, composition, and quality of groundwater. The chemical composition, physical characteristics, and presence of contaminants in groundwater are examined to determine its quality. The study sheds light on the reliability and value of groundwater for numerous applications, including agriculture and industry. The following are some of the cornerstones of groundwater analysis:

7.1. Water Sampling:

Groundwater is sampled at various sites, such as wells, and then examined with the appropriate tools and techniques. The samples must be representative of the aquifer, so they should be collected in clean, sterile containers to avoid contamination.

7.2. Physical Parameters:

Groundwater's basic characteristics can be described by measuring its physical parameters including pH, humidity, the conductivity of electricity, and the amount of total dissolved solids (TDS).

7.3. Chemical Analysis:

Chemical examination of groundwater can reveal a wide variety of ions and nutrients, including calcium, magnesium, chloride, sodium, and sulfate. The chemical makeup may be evaluated, and the origins of any impurities can be tracked down, with the use of these analyses.

7.4. Water Quality Standards:

Water quality criteria and guidelines provided by regulatory bodies or organizations like world health organization (WHO) are compared with the assessed data. These guidelines establish maximum levels for a variety of criteria, guaranteeing that the water is fit for its intended purposes.

7.5. Contaminant Identification:

During a groundwater study, contaminants such as metals, organic chemicals, and VOCs (volatile organic compounds) can be detected and removed. Methods like chromatography and mass spectrometry can be employed for very accurate identification and quantification.

7.6. Water Quantity Assessment:

For a precise evaluation of groundwater, measurements of freshwater stages, flow rates, and recharge rates are required. Using this information, water management can be optimized.

7.7. Data Interpretation:

The information is analyzed to discover trends, identify potential threats, and track changes over time in groundwater quality. This understanding can be used to better safeguard water supplies, improve water quality, and prepare for water shortages. You may figure out how much water was put back into the earth by utilizing the Captures and the infiltration of water method, which takes into account the available supply (i.e., the volume dropping from the drainage), the volume obtained by the actions taken, and the losses linked with evaporation (if any) and consumption

8. Results and Discussion:

8.1. Groundwater Quality Analysis

The examination of groundwater is essential to check the water quality in given study area. Three samples of groundwater have been collected from the water pump from the vicinity of the study area. The sample has been tested in environmental chemistry lab in our department. After analyzing of sample in lab its showed that all the parameters of groundwater are within the permissible limit with world health organization (WHO) guidelines. The groundwater sample were collected on daily basis and analyses regularly in laboratory.

Table 3: Groundwater analysis

Groundwater Analysis on monthly basis								
Sr.no.	Parameter	Unit	Nov,2023	Dec,2023	Jan,2023	Feb,2023	Mar,203	April,2023
1	**pH**	-	7.52	7.8	7.76	7.69	7.56	7.71
2	**Turbidity**	NTU	1.8	0.55	0.87	1.12	1.2	0.9
3	**TDS**	mg/l	550	150	200	300	199	224
4	**TSS**	mg/l	120	101	131	117	99	112
5	**Alkalinity**	ml	454	389	407	417	398	402
6	**Hardness**	mg/l	208	436	280	308	331	319
7	**Calcium Hardness**	mg/l	428	512	588	509	498	501
8	**Magnesium Hardness**	mg/l	220	76	308	201	199	88
9	**Sulphate**	mg/l	5.2	7.8	7.3	6.7	5.9	6.2
10	**Chloride**	mg/l	139	184.5	211	196.9	201.22	177.9
11	**Nitrate**	mg/l	33.5	41.0	29.8	30.43	39.8	33
12	**Nitrite**	mg/l	1.8	1.2	1.34	2.67	1.87	1.99
13	**Residual chlorine**	mg/l	0.23	0.12	0.45	0.36	0.25	0.46

The number of samples were collected on monthly basis and then each parameter of groundwater was compared to the WHO guidelines to check its deviation from the World health organization (WHO) guidelines. In the following graphs each parameter was compared to WHO guidelines to check that the parameter is within WHO guidelines.

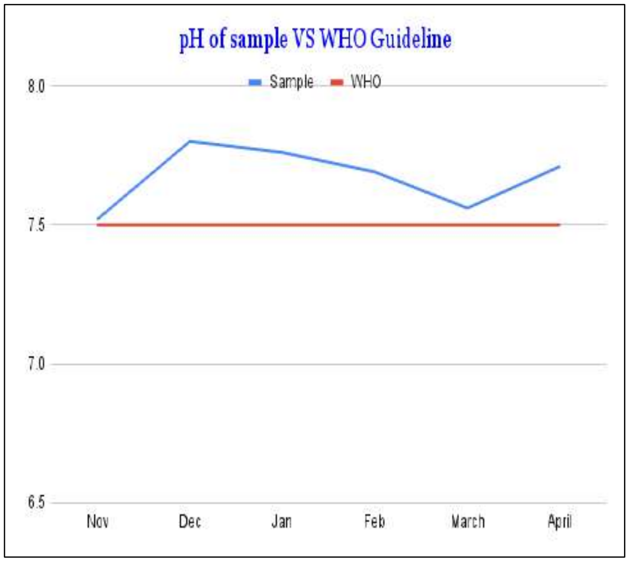

Figure 7: pH of sample VS WHO guidelines

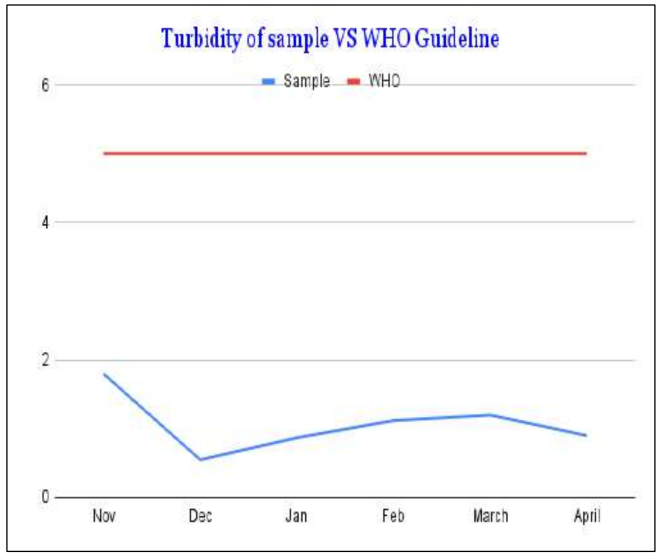

Figure 8:turbidity of sample VS WHO guideline

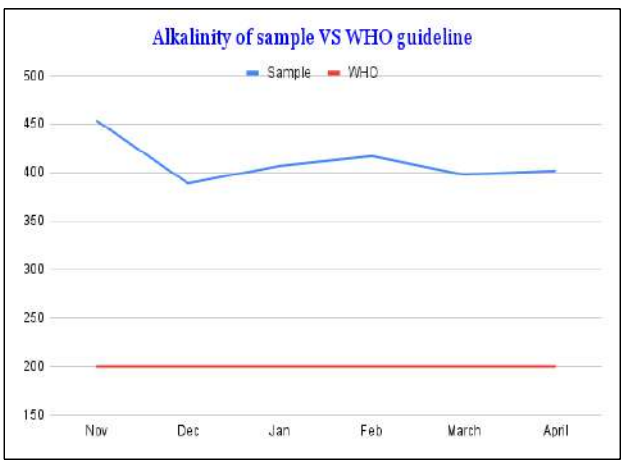

Figure 9: Alkalinity of sample VS WHO guideline

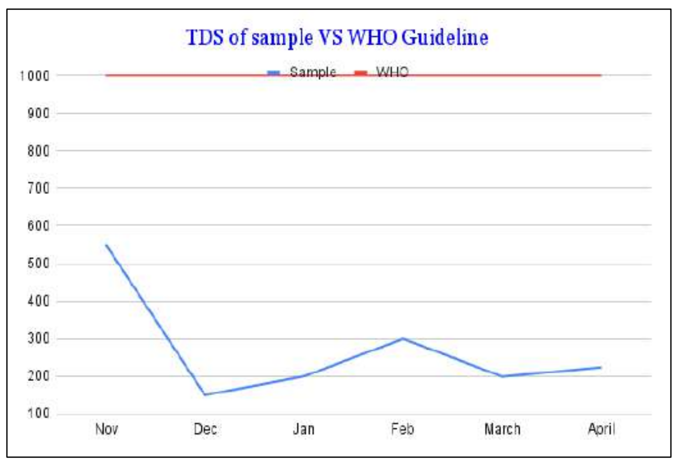

Figure 10: TDS od sample VS WHO guideline.

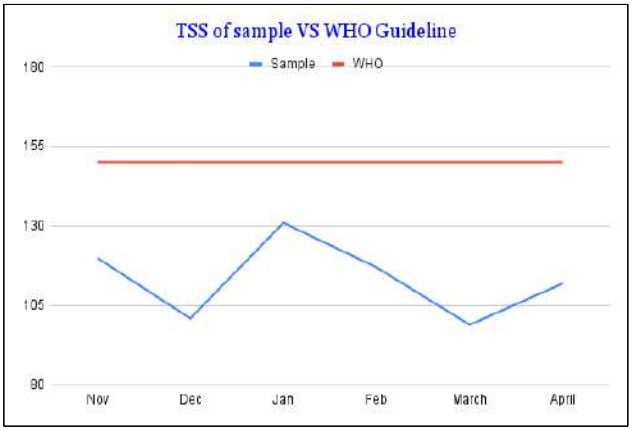

Figure 11:TSS of Sample VS WHO guideline

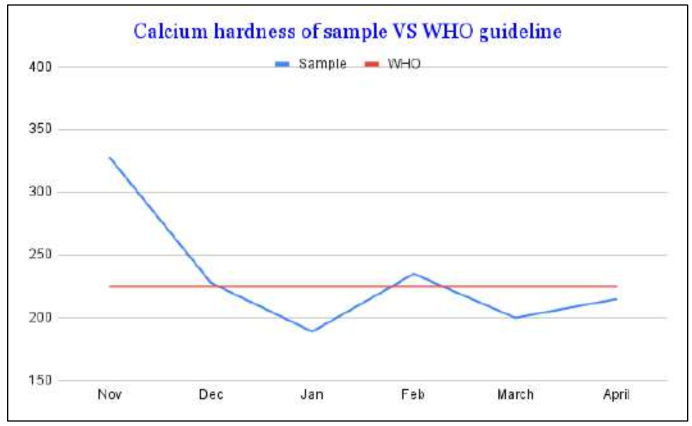

Figure 12: Calcium hardness VS WHO guideline

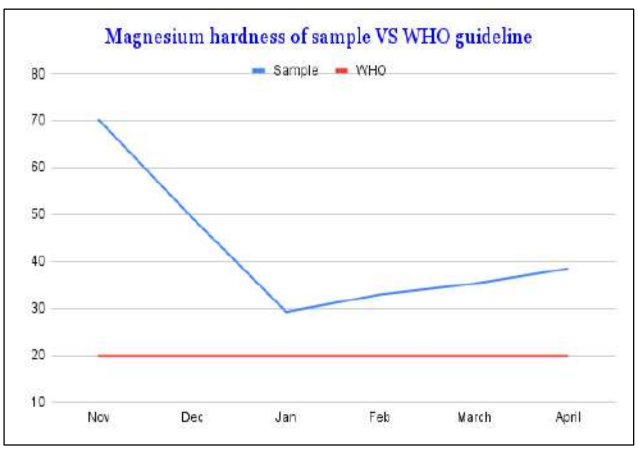

Figure 13: Magnesium hardness VS WHO guideline

Figure 12, The value of calcium hardness in pre-installation groundwater quality analysis was higher than that of WHO guideline. This is because that the Taxila region is hilly area and the calcium hardness found in groundwater was often higher than the normal.

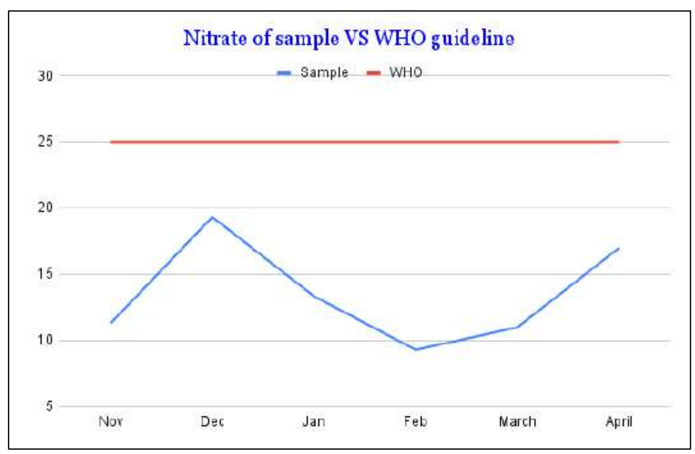

Figure 14: Nitrate sample VS WHO guideline

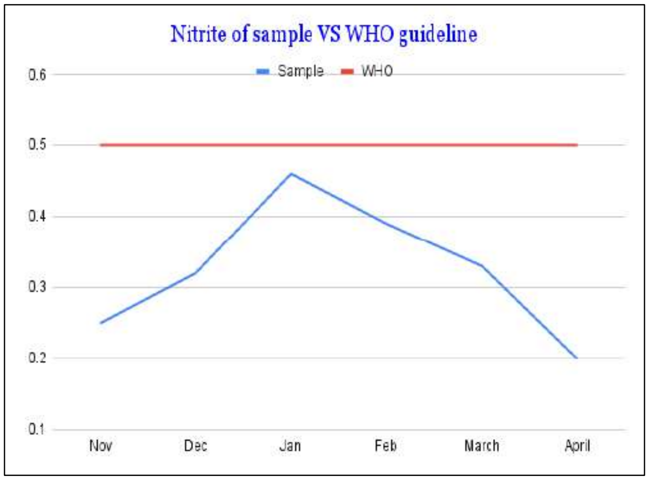

Figure 15:Nitrite sample VS WHO guideline

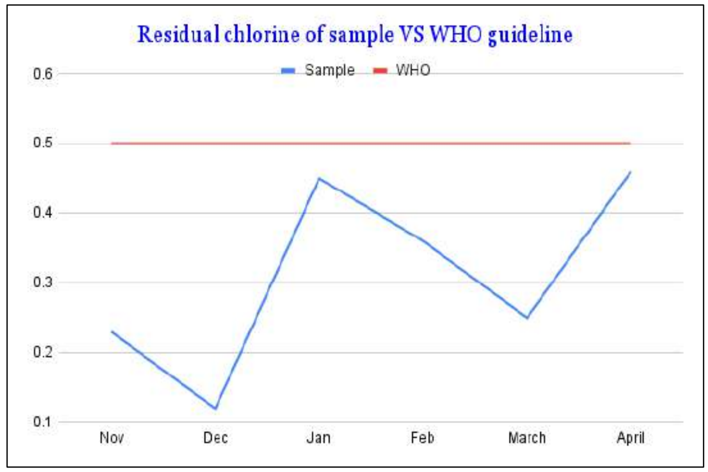

Figure 16: Residual chlorine

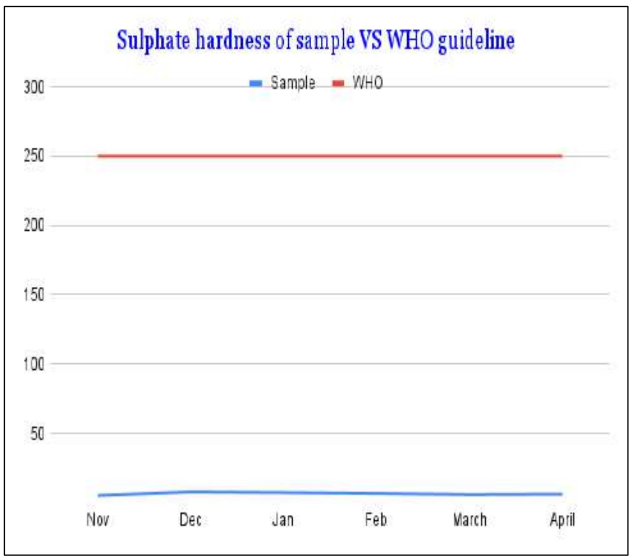

Figure 17: Sulphate hardness of sample VS WHO guideline

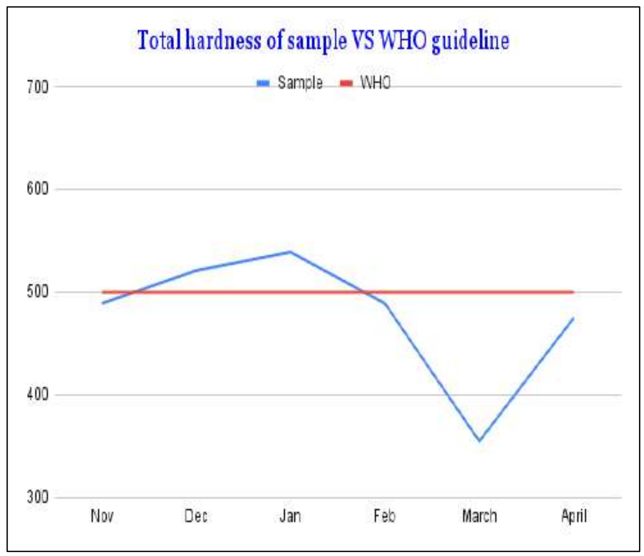

Figure 18: total hardness of sample VS WHO guideline

In figure 18, The total hardness found in some samples of groundwater was higher that that of the normal, this is because of hilly region of Taxila. The total hardness in groundwater of most of hilly region was found to be higher than that of WHO guidelines.

8.2. Rainwater Quality Analysis:

This was deemed necessary to maintain the purity of the groundwater as rainwater was used for recharging. One of the most significant actions that may be performed to protect and encourage public health is to ensure that everyone has access to clean drinking water, as both poor sanitation and water pollution are major contributors to the global health crisis. Therefore, the water supply must be of high quality and unpolluted. The personnel who take the rainwater samples have the necessary training and competence. Three samples of rainwater have been collected and analyzed in the sample environmental chemistry lab. It shows that all the rainwater parameters are within permissible limit and can be recharged well. The table below shows different parameters of rainwater.

Table 4: Rainwater Analysis

Rainwater Analysis on monthly basis							
Sr.no	**Parameters**	**Unit**	**15/12/2022**	**4/1/2023**	**12/3/2023**	**2/4/2023**	**25/5/2023**
1	**pH**	-	6.3	7.4	6.2	6.9	6.2
2	**Turbidity**	NTU	6.65	6.56	6.89	6.81	6.7
3	**TDS**	mg/l	74	69	62	71	68
4	**TSS**	mg/l	76	72	68	72	72
5	**Alkalinity**	ml	166	112	120	165	132
6	**Hardness**	mg/l	302	210.4	250	301	254
7	**Calcium Hardness**	mg/l	0	0	0	0	0
8	**Magnesium Hardness**	mg/l	302	210.4	250	301	254
9	**E-coli**	-	0	0	0	0	0
10	**Chloride**	mg/l	22	29	19	34	30
11	**Nitrate**	mg/l	11.2	16.3	9.37	15	10.89
12	**Nitrite**	mg/l	0.23	0.2	0.25	0.2	0.28
13	**Residual chlorine**	mg/l	0.39	0.36	0.33	0.34	0.29

The number of samples were collected after every rainfall event and then each parameter of rainwater was compared to the WHO guidelines to check its deviation from the World health organization (WHO) guidelines. In the following graphs each parameter was compared to WHO guidelines to check that the parameter is within WHO guidelines or not.

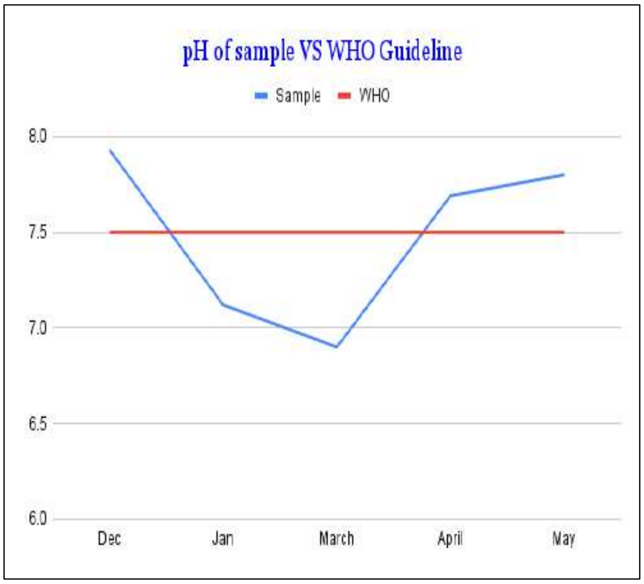

Figure 19: pH of sample VS WHO guideline

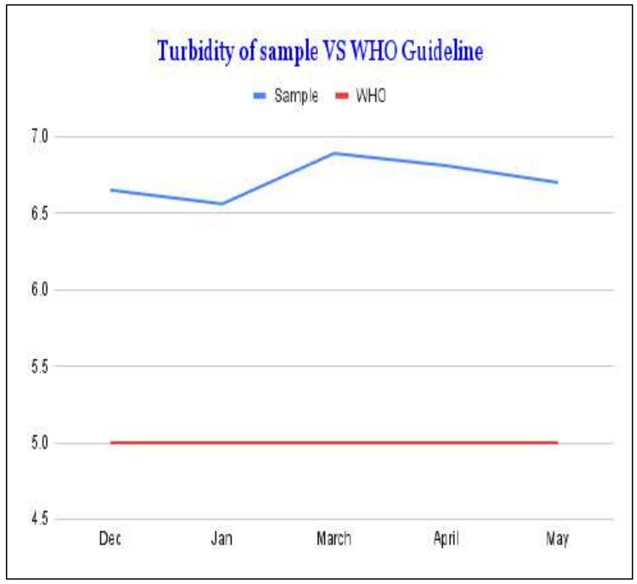

Figure 20: Turbidity of sample VS WHO guideline

In figure 19 of rainwater quality analysis, the pH of rainwater was higher than that of WHO guideline. Most of the rainwater is acidic and to be treated before it discharges to groundwater.

In figure 20, the turbidity of rainwater was higher that of WHO guideline. In most of the rainwater, the turbidity found is higher than that of WHO guideline and need to treated before they discharges to groundwater.

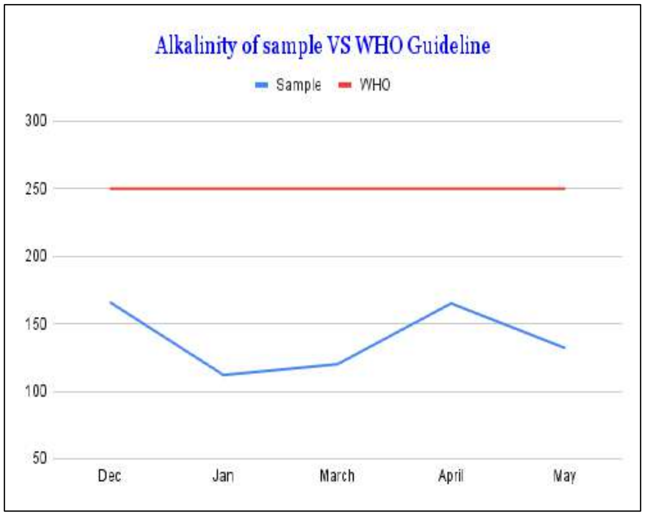

Figure 21: Alkalinity of sample VS WHO guideline

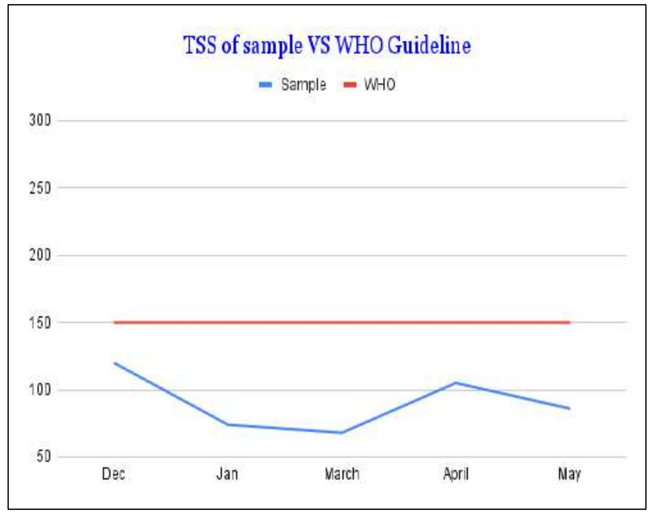

Figure 22: TSS of sample VS WHO guideline

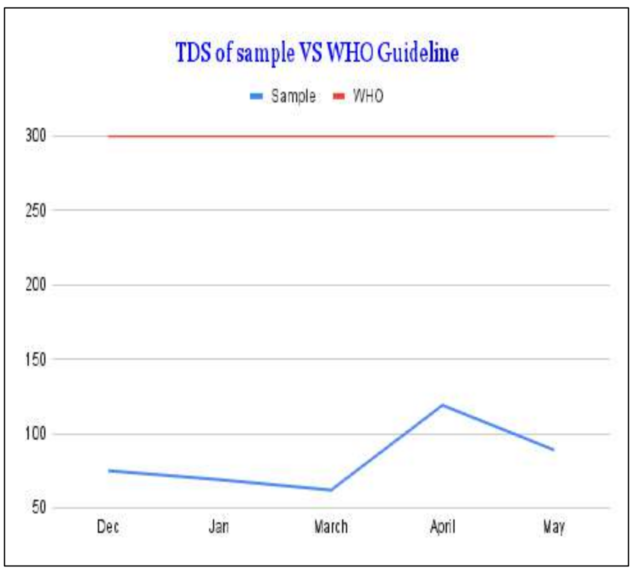

Figure 23: TDS of sample VS WHO guideline

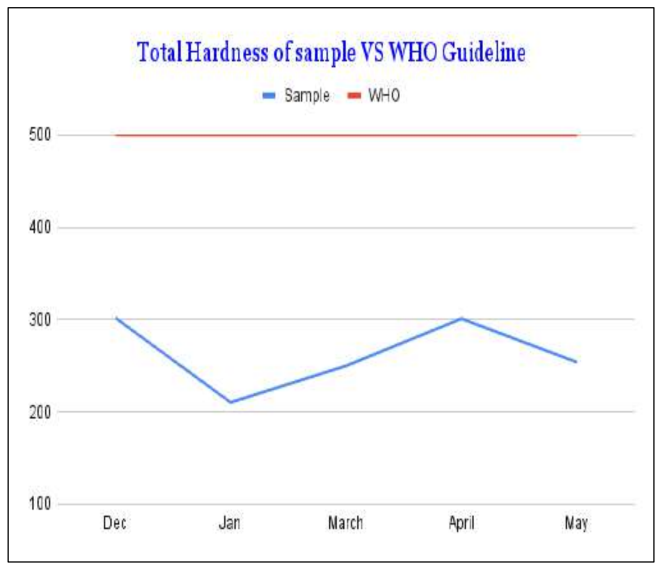

Figure 24: Total hardness of sample vs WHO guideline

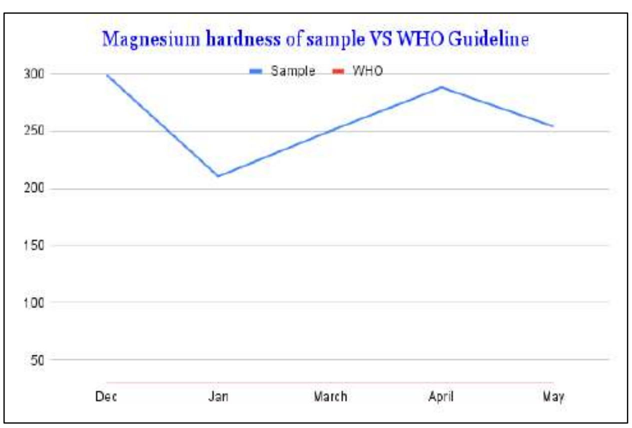

Figure 25:Magnesium hardness of sample VS WHO guideline

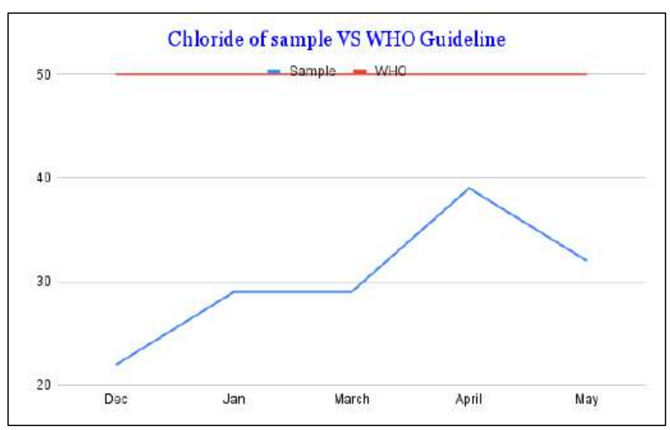

Figure 26:Chloride of sample VS WHO guideline

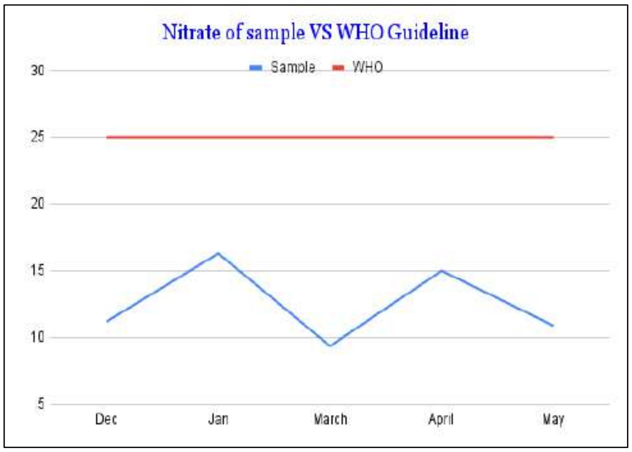

Figure 27: Nitrate of sample VS WHO guideline

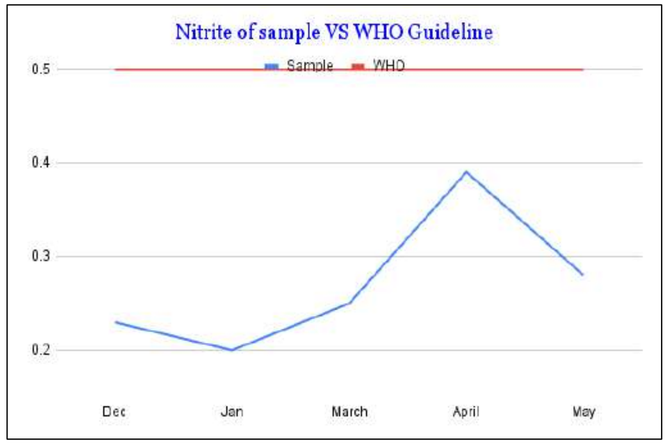

Figure 28: Nitrite of sample VS WHO guideline

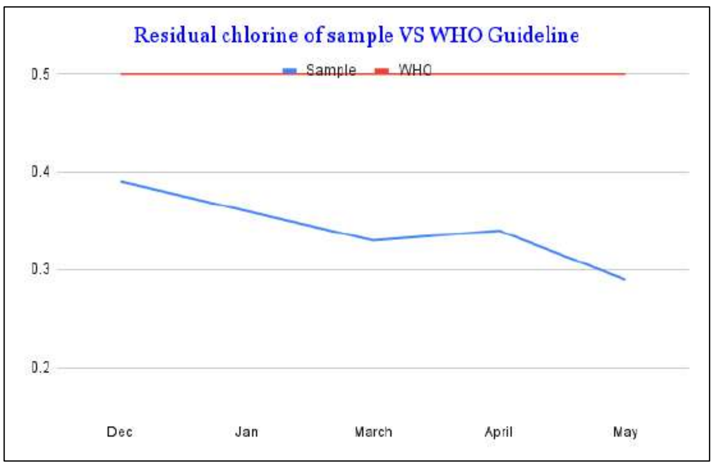

Figure 29: Residual chlorine of sample VS WHO guideline

8.3. Post-installation Groundwater quality Analysis

The post groundwater quality of recharge well has been checked whether the groundwater has been contaminated by the rainwater or not. So, from the below table it shows that the groundwater has not been affected by the rainwater and groundwater quality parameter are within the acceptable range and within World health Organization (WHO) guidelines. Two samples of groundwater have been collected through monitoring Well to check the effectiveness and efficiency of recharge well. From the result of analysis of groundwater, it shows that all the parameter of groundwater are within the range of WHO guidelines.

Table 5: Post-installation Groundwater Quality Analysis

Post-installation Groundwater Analysis					
Sr.no	**Parameters**	**Unit**	**6/5/2023**	**2/6/2023**	**15/7/2023**
1	**pH**	-	7.7	7.69	7.53
2	**Turbidity**	NTU	4.3	4.8	4.1
3	**TDS**	mg/l	289	322	280
4	**TSS**	mg/l	131	119	109
5	**Alkalinity**	ml	155	179	169
6	**Hardness**	mg/l	410	483	425
7	**Calcium hardness**	mg/l	189	212	203
8	**Magnesium hardness**	mg/l	12.33	17.5	15.78
9	**Sulphate**	mg/l	7.8	11.2	19.22
10	**chloride**	mg/l	20.3	25	31
11	**Nitrate**	mg/l	11.2	17	9.46
12	**Nitrite**	mg/l	0.33	0.49	0.37
13	**Residual chlorine**	mg/l	0.30	0.27	0.3

The number of samples were collected after every rainfall event and then each parameter of rainwater was compared to the WHO guidelines to check its deviation from the World health organization (WHO) guidelines. In the following graphs each parameter was compared to WHO guidelines to check that the parameter is within WHO guidelines or not.

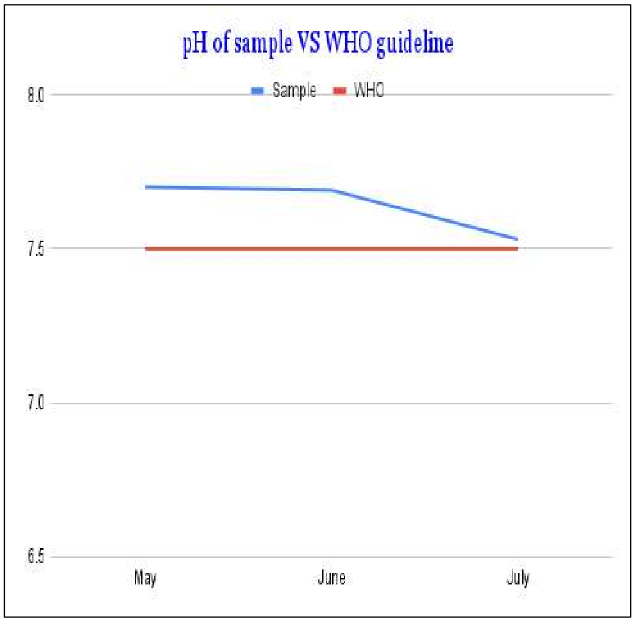

Figure 30: pH of sample VS WHO guideline

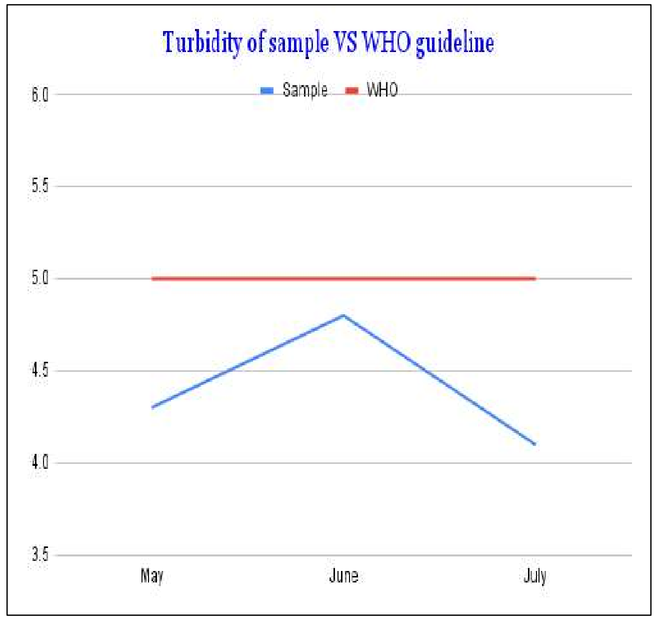

Figure 31: Turbidity of sample VS WHO guideline

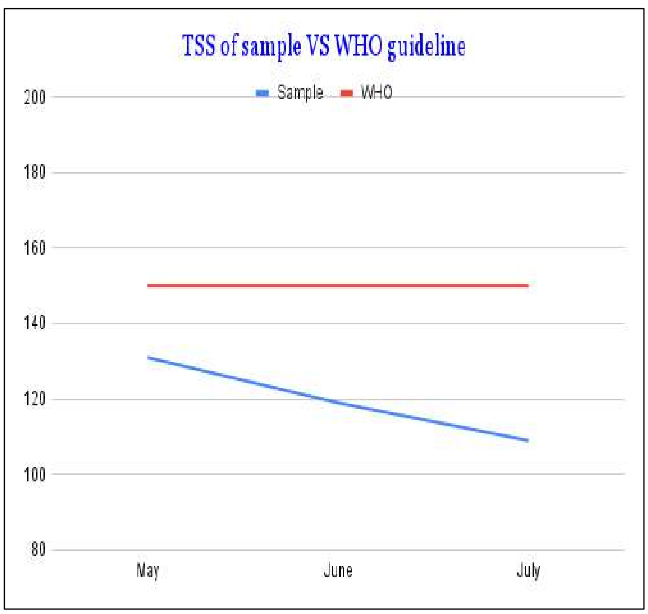

Figure 32: TSS of sample VS WHO guideline

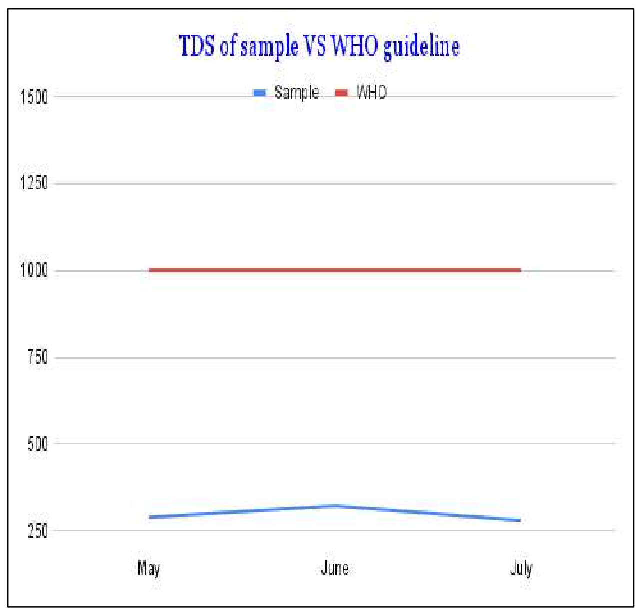

Figure 33: TDS of sample VS WHO guideline

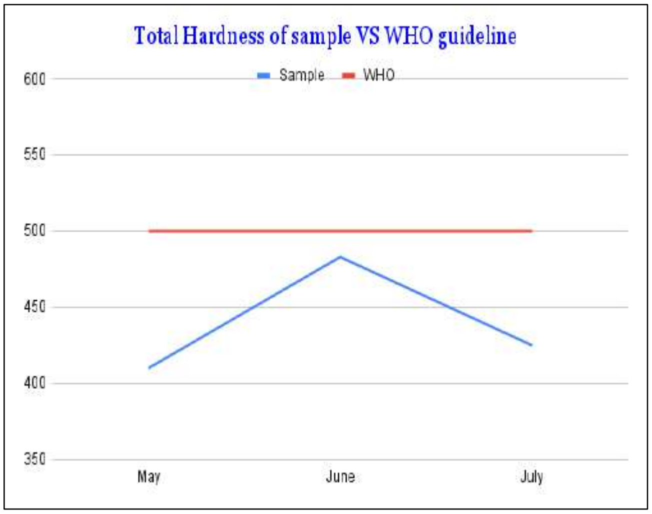

Figure 34: Total hardness of sample VS WHO guideline

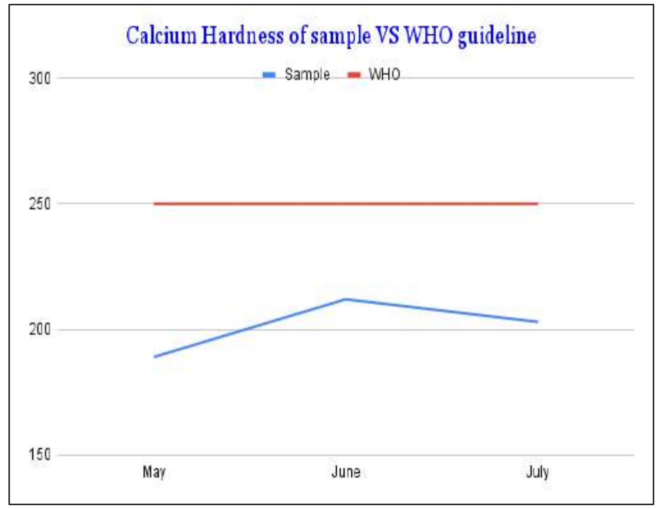

Figure 35: Calcium hardness VS WHO guideline

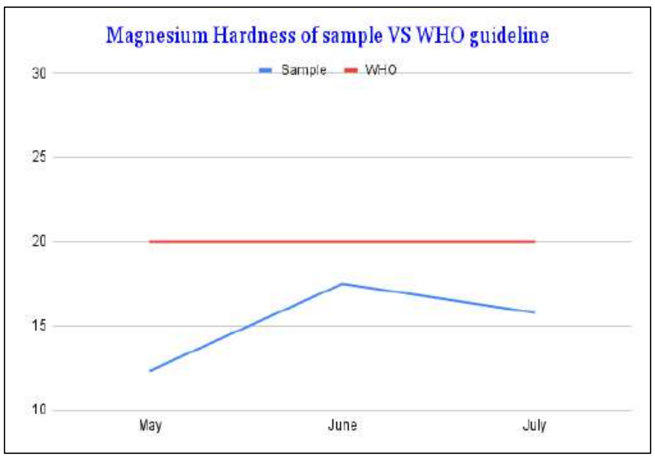

Figure 36: Magnesium hardness of Sample VS WHO guideline

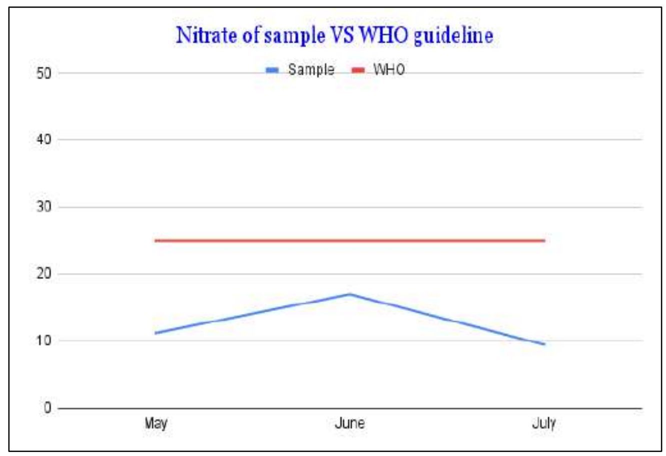

Figure 37: Calcium hardness of sample VS WHO guideline

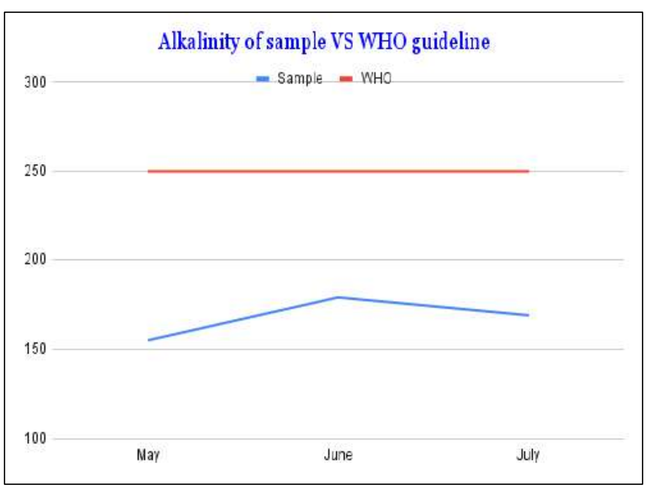

Figure 38: Alkalinity of sample VS WHO guideline

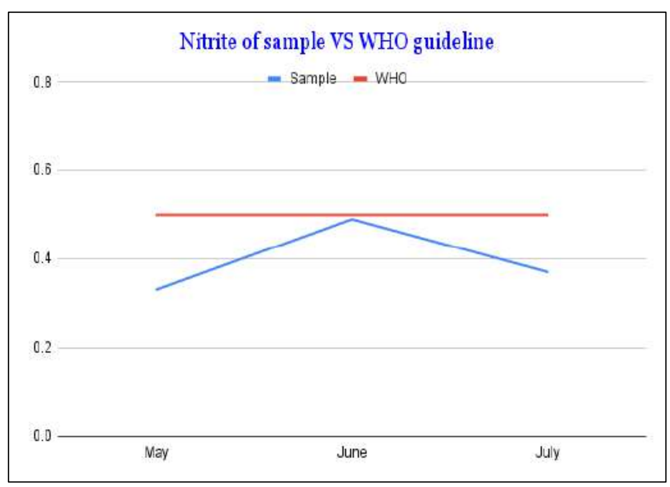

Figure 39: Nitrite of sample vs WHO guideline

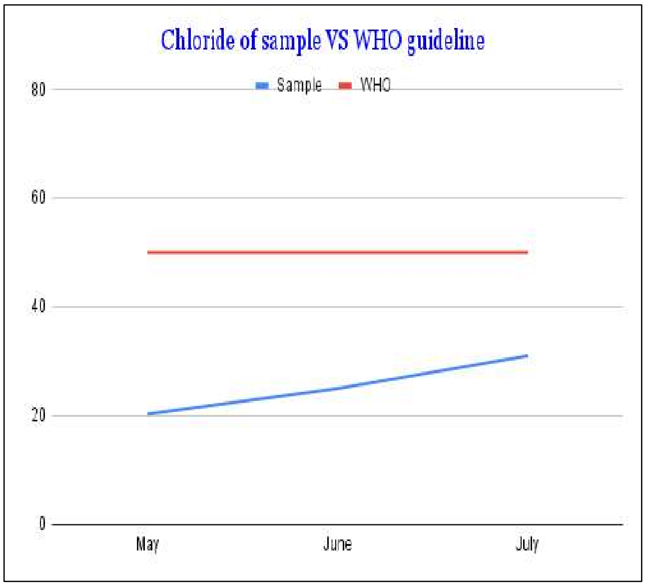

Figure 40:Chloride of sample VS WHO guideline

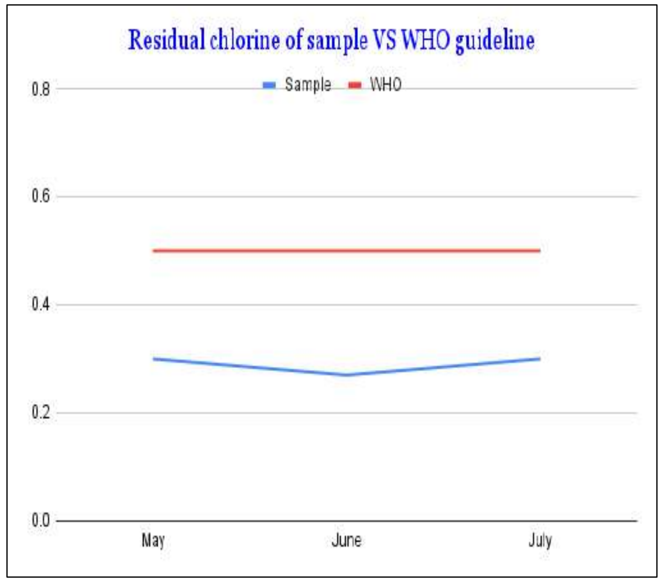

Figure 41: Residual chlorine of sample VS WHO guideline

Discussion:

So, by analyzing the rainwater in lab, we found that few parameters were exceeded the WHO guidelines. According to the WHO guidelines the pH of drinking water must be in the range of 6.5 to 8.5, but by analyzing the rainwater we found that the pH of rainwater was less than the range of WHO guidelines. Similarly, the Turbidity and total suspended solids (TSS) were also exceeded the WHO guidelines. Now to check the effectiveness and efficiency of filtration of groundwater recharging Wells, some samples of groundwater were collected after the installation of groundwater recharging Wells. We collected three samples of groundwater of recharging Wells and analyzed them in laboratory. After lab analysis we see those significant changes in the value of pH, Turbidity. The white charcoal, as we placed in the filtration system shows its effectiveness in neutralizing the acid rainwater. Similarly, the turbidity of rainwater which was high in amount was decreased by the sand we used in the filtration system of Recharge Wells.

In similar way, the total suspended solids (TSS) of rainwater were high in amount of rainwater that WHO guidelines, which was removed by the pebbles and boulders, which we placed in the filtration system of recharge Wells. So, by comparing both the results of rainwater analysis and post -installation analysis of groundwater. We found that the filtration system, we placed for groundwater recharging Wells shows its effectiveness and performing well in removing certain impurities from rainwater.

7.4. Comparison with WHO guidelines

All the analysis which we performed for the pre-installation groundwater quality analysis, post-installation groundwater quality analysis of recharge Well and rainwater quality analysis are compared with the world health organization (WHO) to check that whether the given result or within the WHO guidelines. By comparing we analyzed that all the results are within the WHO guidelines

Table 6: comparison of results with WHO guidelines

Parameters	Unit	WHO Guidelines	Laboratory Result
pH	-	6.5-8.5	7.69
Turbidity	NTU	<5	1.07
TDS	mg/l	<1000	300
TSS	mg/l	150	117.3
Alkalinity	ml	20-200	416.6
Total Hardness	mg/l	<500	308
Calcium hardness	mg/l	75-22	509
Magnesium hardness	mg/l	2-20	201
Sulphate	mg/l	250	6.7
Chloride	mg/l	50	37.8
Residual chlorine	mg/l	0.5	0.34
Nitrate	mg/l	25	13.67
Nitrite	mg/l	0.5	0.22

7.5. Soil Analysis of Recharge and Monitoring Wells.

Rotary drilling method is used for construction of recharge well and monitoring well, and the soil samples have been collected at various depths.

7.5.1. Soil Permeability Analysis (MP Hall & Library Site)

Before construction of groundwater recharging Wells, soil permeability test was performed at different depths of recharge Wells. The soil sample has been collected from both recharge Wells. Soil permeability tests are conducted to assess the ability of soil to transmit water, helping engineers and geologists in various applications. One primary purpose is to evaluate the suitability of soil for construction projects, such as groundwater recharging Wells by determining that how easily water can flow through it. Based on the results in the given table it shows that the soil has the potential to pass water easily.

Table 7: Permeability test results of recharge well

Serial No	**Sample**			
	70ft	**80ft**	**90ft**	**100ft**
1.	K= 0.0293 cm/min	K=0.0386 cm/min	K=0.0762 cm/min	K=0.0863 cm/min

Table 8:Permeability test results of monitoring Well

Serial No	**Sample**					
	90ft	**100ft**	**110ft**	**120ft**	**130ft**	**140ft**
1.	K= 0.0378 cm/min	K= 0.0478 cm/min	K= 0.0597 cm/min	K= 0.0674 cm/min	K= 0.0832 cm/min	K= 0.0921 cm/min

Soil Gradation Test Analysis:

As an indicator of engineering qualities like compressibility, hydraulic conductivity, and shear strength, soil gradation testing is a crucial tool in geotechnical engineering. Soil gradation plays a role in groundwater studies by influencing how water moves through the soil. It helps determine the hydraulic conductivity of soil, which is essential for modeling groundwater flow and contamination transport.

The results of soil gradation test are given below.

- **Library catchment site:** The sample has been collected at depths of 90ft, 100ft, 110ft, 120ft, 130ft, 140ft, and 150 from library sit recharge well.
- **MP Hall catchment site:** the sample has been collected from 80 ft, 90ft, 100 ft and 110 ft.

7.5.2 Soil Gradation Analysis (Library Site)

The soil gradation test table reveals a composition of soil that is indicative of excellent quality and remarkable hydraulic conductivity. With a well-balanced distribution of particle sizes, this soil exhibits optimal engineering characteristics. The presence of a diverse range of sand, silt, and clay particles allows for efficient water movement, making it highly permeable. The weight of sample taken for the test was 200mg. For sieve analysis the sample were passed from sieve sizes of 20mm, 10mm, 5mm, 2mm, 1mm, 0.5mm, 0.16mm, 0.08mm, and then from Pan size.

Table 9: Soil analysis of library catchment recharge Well

Sieve No	Weight of Retained from Sieve						Weight Passing (gm)						%Passing					
	90ft	110ft	120ft	130ft	140ft	150ft	90ft	110ft	120ft	130ft	140ft	150ft	90ft	110ft	120ft	130ft	140ft	150ft
20mm					41.1						158.9						79.5	
10mm	9.3	36.2	6.6	72.9	28.5	92.1	190.1	164.8	193.2	127.1	130.4	107.9	95.3	82.1	96.7	63.5	65.2	53.5
5mm	12.1	3.6	4.1	3.8	13.8	4.2	178.7	160.4	189.3	123.3	116.6	103.7	89.5	80.2	94.5	61.5	58.3	51.5
2mm	17.8	3.9	3.7	2.7	2.6	3.4	160.9	156.5	185.6	120.6	114.7	100.3	80.5	78.5	92.8	60.3	57.4	50.5
1mm	8.4	1.8	1.7	0.6	0.7	0.4	152.5	154.7	183.9	120.2	113.3	99.9	76.5	77.5	91.5	60.9	56.5	49.5
0.5mm	10.5	1.5	2.1	0.1	0.1	1.1	142.4	153.2	181.8	120.4	113.3	98.9	71.3	76.6	90.9	60.8	56.5	49.5
0.25mm	10.5	2.7	2.3	0.9	0.6	1.5	131.5	150.5	179.5	119.1	112.7	97.4	65.5	75.5	89.5	59.5	56.5	48.7
0.16mm	1.8	1.1	0.7	0.2	0.1	0.7	129.7	149.4	178.8	119.1	112.7	96.7	64.5	74.7	89.4	59.5	56.5	48.5
0.08mm	1.2	0.4	0.4	0.2	0.1	0.4	128.5	149.4	178.4	119.1	112.7	96.3	64.5	74.5	89.2	59.5	56.5	48.5
Pan	0.4	0	0	0	0	0	128.1	149.1	178.4	119.1	112.7	96.3	64.5	74.5	89.2	59.5	56.5	48.5

The graph of soil gradation is given below.

The green line in the curve shows that the %passing at 150ft depth and the dark blue line shows the %passing at 90ft. the same remaining lines shows the %passing at their respective depths. From this table, we concluded that from the curve that %passing at 150ft depth was maximum and minimum at 90ft depth. From the below curves the %passing at 150ft depth is maximum which shows that the soil is more granular and coarse-grained in nature. Soils with a higher percentage passing through sieves tend to have larger particle sizes, which can include materials like sand and gravel. This property of soil allows water to pass more easily.

Similarly, the %passing at 90ft is maximum which shows that the soil is siltier and is more fine-grained. Fine-grained soils include materials like silt and clay, which have smaller particle sizes and tend to retain more of the soil on the finer sieves. This behavior of soil shows that soil is incompressible and is enough good for performing heavy engineering works on it.

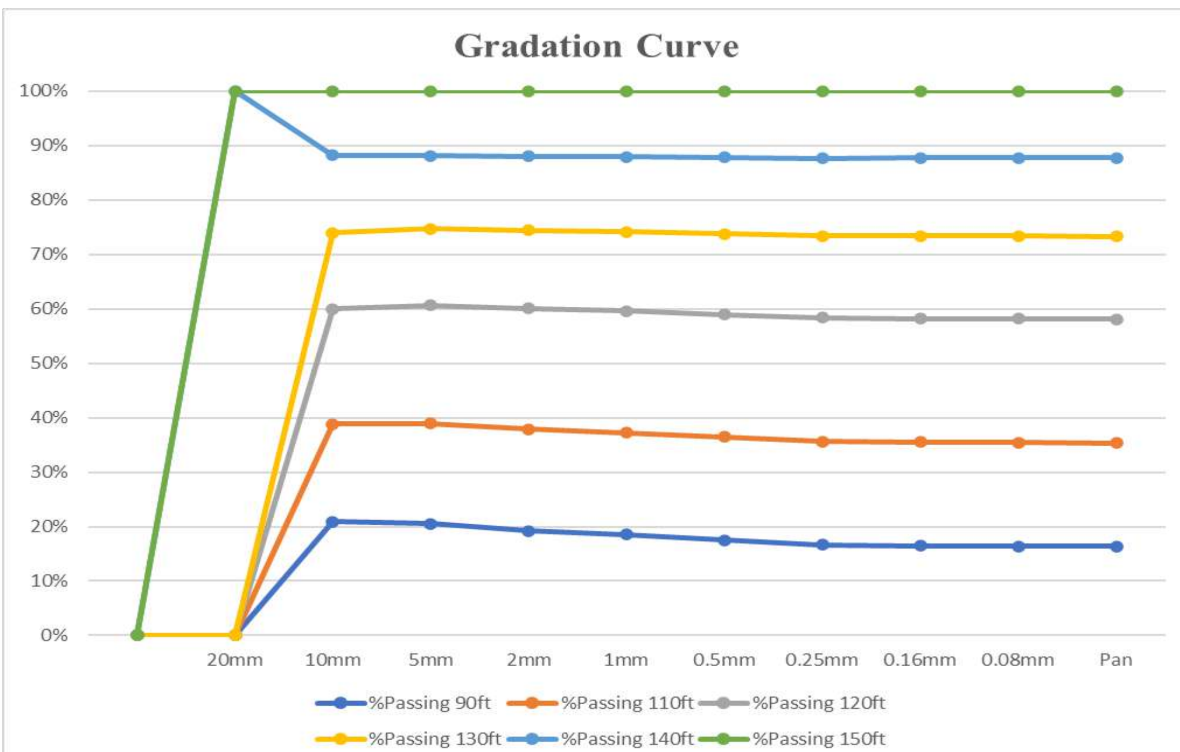

Table 10: Soil gradation curve of library site

7.5.3. Soil Gradation Analysis (MP Hall Site)

The same soil gradation test was conducted for the MP Hall site catchment area, as did for the library catchment area.

Table 11: Soil analysis of MP hall site recharge well

Sieve No	Sample Type (Weight 200mg)											
	80ft	70ft	100ft	120ft	Weight retained(gm)				%Passing			
	Weight from sieve				80ft	70ft	100ft	120ft	80ft	70ft	100ft	120ft
20mm	99.4				100.6				50.3			
10mm	0.0	7.5	46.1	0.0	100.6	192.5	153.9	200.0	50.3	96.2	76.9	100.0
5mm	12.3	9.4	22.4	2.9	88.3	183.1	131.5	198.0	44.1	91.5	65.5	99.0
2mm	11.4	6.8	17.4	0.8	76.9	176.3	114.5	197.2	38.4	88.1	57.2	98.6
1mm	4.8	3.4	5.2	0.4	72.1	172.9	109.3	196.8	36.0	86.4	54.6	98.4
0.5mm	4.4	3.1	3.3	0.5	67.7	169.8	106.0	196.3	33.8	84.9	53.0	98.1
0.25mm	5.8	3.9	4.9	1.3	61.9	165.9	101.1	195.0	30.9	82.9	50.5	97.5
0.16mm	1.3	1.7	1.6	0.8	60.6	164.2	99.5	194.2	30.3	82.1	49.7	97.1
0.08mm	1.0	1.4	1.0	0.4	59.6	162.8	98.5	193.8	29.8	81.4	49.2	96.9
Pan	0.9	1.1	1.1	0.5	58.7	161.7	97.4	193.3	29.3	80.8	48.7	96.6

The graph of soil gradation is given below, the yellow line shows that %passing at 150ft depth was maximum and minimum at 70ft depth. From the below curves the %passing at 120ft depth is maximum which shows that the soil is more granular and coarse-grained in nature. Soils with a higher percentage passing through sieves tend to have larger particle sizes, which can include materials like sand and gravel. This property of soil allows water to pass more easily.

Similarly, the %passing at 70ft is minimum which shows that the soil is siltier and is more fine-grained. Fine-grained soils include materials like silt and clay, which have smaller particle sizes and tend to retain more of the soil on the finer sieves. This behavior of soil shows that soil is incompressible and is enough good for performing heavy engineering works on it.

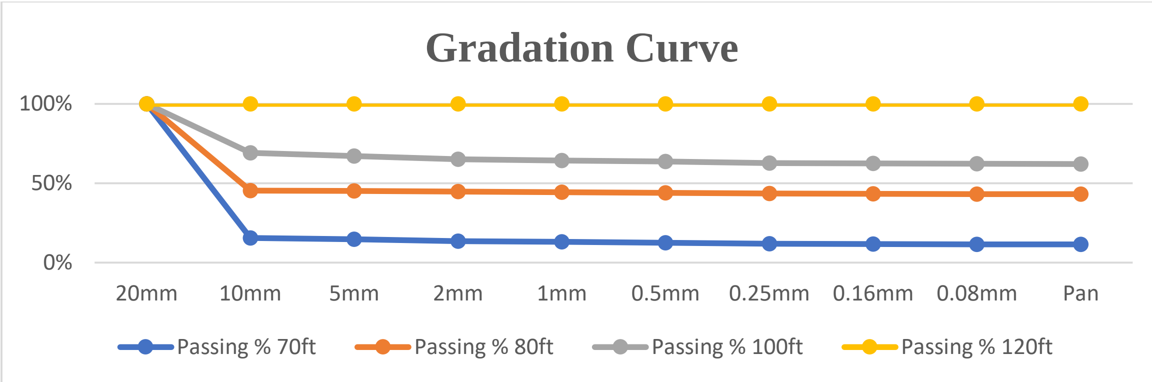

Figure 42: gradation curve of MP hall site catchment area

COMMENTS ON SOIL ANALYSIS

- The above results shows that our soil is well graded soil.

7.5.4. Operational Condition of Recharge Well

After the design and installation of both recharging well, monitoring of both recharges Well were did to check the operational condition after every rainfall. The maintenance was also carried out, to remove the clogging materials from the filter.

Figure 43: Library site

Figure 44: MP hall site

9. Calculation for Total Recharge Up till Now

(Library Site)

1	Annual rainfall intensity	1336mm
2	No. of days of project up to till now	72 days
3	Total area	1000 m^2
4	Runoff coefficient for rooftop	0.9
5	Runoff coefficient for open area	0.6

Table 12: rainfall data calculation of library site

$$Annual\ rainfall\ intensity = \frac{1336mm}{Annum}$$

$$\frac{1336}{1000} = 1.34m^3$$

$$No. of\ days\ of\ project\ upto\ till\ now = 72\ days$$

$$Rainfall\ upto\ till\ now = \frac{rainfall\ intensity}{days\ in\ year}$$

$$=> \frac{1.34}{365} = \frac{0.0037}{day}$$

$$= 0.0037 \times 72\ days$$

$$= 0.264$$

Now,

$$rooftop\ flow = area \times runoff\ coefficient \times rainfall\ intensity$$

$$= 1100 \times 0.9 \times 0.264$$

$$= 261m^3$$

To calculate open-area flow, we used the following formula:

$$open\ area\ flow = square\ meter \times runoff\ coefficient\ \times total\ rainfall$$

$$= 1000 \times 0.6 \times 0.264$$

$$158.4m^3$$

$$total\ availible\ supply = 261 + 158.4$$

$$= 419.4m^3$$

$$total\ recharge\ capicity = vol\ capture \times evaporation \times withdrawl$$

$$=> 419.4 \times 10\% = 41.94$$

$$= 419.4 - 41.94 = 377.46$$

$$total\ recharge = \frac{377.46m^3}{72days}$$

(MP Hall Site)

1	Annual rainfall intensity	1336mm
2	No. of days of project up to till now	72 days
3	Total area	799 m^2
4	Runoff coefficient for rooftop	0.9
5	Runoff coefficient for open area	0.6

Table 13: Rainfall data calculation of MP hall site

$$Annual\ rainfall\ intensity = \frac{1336mm}{annum}$$

$$\frac{1336}{1000} = 1.34m^3$$

$$total\ precipetation = \frac{annual\ rainfall\ intensity}{no.of\ rainy\ days}$$

$$=> \frac{1.34}{365} = \frac{0.0037}{day}$$

$$=> 0.0037 \times 72\ days = 0.264$$

Rooftop runoff is calculated as

$$rooftop\ runoff\ = area \times runoff\ coefficient\ \times rainfall\ intensity$$

$$=> 1765 \times 0.9 \times 0.264 = 419.3m^3$$

The formula for determining the flow in an open region is,

$$flow\ in\ open\ area = total\ area \times runoff\ coefficient \times rainfall\ intensity$$

$$\equiv> 799 \times 0.6 \times 0.264 = 126.6m^3$$

$$Total\ available\ supply = 419 + 126.56$$

$$= 545m^3$$

$$Total\ recharge\ capacity = Vol\ capture \times evaporation \times withdrawl$$

$$=> 545 \times 10\% = 54.59$$

$$=> 545 - 54.59 = 491.33$$

$$Total\ recharge = \frac{491.33m^3}{72\ days}$$

Total Recharge = 491.33m^3/72days

10. Conclusion and Recommendations

Among the many water saving measures taken at UET Taxila is the installation of the replenishment of ground system. The global water crisis can at last be addressed by installing groundwater recharge wells. Adopting it alongside eco-friendly water-management practices and citizen engagement will considerably improve water security for present and future generations. This method of water management is useful for policymakers, water resource managers, and communities.

The future of freshwater recharge wells as a viable way of regulating water supplies has been the subject of extensive scientific study. After years of study and evaluation of a wide variety of studies, the advantages of groundwater recharge wells for recovering ecological balance, replenishing depleted aquifers, and mitigating the impacts of groundwater depletion became obvious.

The findings highlight the significance of giving due attention to groundwater recharge well design, placement, and management. Hydrogeological circumstances and their outcomes can be used to pinpoint future well construction sites. The quality of the water is measured again once it has been recharged. The filter medium appears to be functioning properly, as evidenced by the monitoring results.

Furthermore, this research emphasizes the importance of integrated water resource management strategies, combining groundwater recharging wells with rainwater harvesting, watershed management, and water conservation initiatives. Such integrated approaches can significantly improve water availability, especially in regions facing water scarcity and stressed groundwater reserves.

This research also underlines the necessity for continuous monitoring, data collection, and adaptive management of groundwater recharging wells. Long-term assessments of their performance and periodic revisions of strategies are crucial to adapt to changing environmental conditions and emerging challenges.

It is recommended for further studies that focus on the waste handling of filter media in recharging well

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