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Analyzing the Impact of Different Filter Media for a Recharge Well in Harvesting Rain Water

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Abstract

This study investigates effects of various filter media designed to harvest rainwater for a recharge well installed at the College of Earth and Environmental Sciences (CEES), University of the Punjab, Lahore. The research assesses three different filter designs, namely F1, F2, and F3, and examines their efficacy. The aim is to evaluate the suitability of these filter media in ensuring that rainwater after passing through these filter media meet permissible limits of international as well as national water quality standards. The study focuses on several crucial water quality parameters, including pH, total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity (EC), cations, anions, and hardness. Results demonstrate that the parameters, except a few in all filter designs, successfully maintain water parameters within acceptable ranges. Notwithstanding, F2, in which a Bio-Char layer is used and which is the focus of the study, gave an EC value much higher than permissible limits. Overall, the research underscores the significance of appropriate filter media selection in harvesting rainwater to recharge groundwater. The findings from this study can serve as a valuable source for similar projects in future, offering insights into improving filter design, resulting in enhancing water quality and ultimately paving the way to sustainability of groundwater resources.

1 INTRODUCTION

1.1 Groundwater

Groundwater refers to the water that resides in pore spaces in a geologic stratum (Todd et al., 2005). This makes up a saturated zone and is commonly known as an aquifer. It is different from the unsaturated zone, which is commonly known as the aeration zone, where voids in the soil are permeated with water and air. In groundwater hydrology, hydrologists are mostly interested in the aquifer, which is important for engineering purposes, water supply developments and other geologic studies.

1.1.1 Types of Groundwater

Groundwater is water that is found below the surface of the Earth. It is simply the water under the surface where the soil is completely filled with water. This is present in the form of a layer and is also called an “aquifer.” There are four types of groundwater:

1. Connate water – Also referred to as fossil water. It is trapped in the pore spaces of rocks during their formation.
2. Meteorite water – Defined as the groundwater that originates from rainfall and other forms of precipitation such as drizzle, hailstorms and snowfall.
3. Juvenile water – Also referred to as magmatic water. It is brought closer to the surface of the Earth due to volcanism.
4. Oceanic water – Results from the seepage of already present groundwater laterally beneath the surface.

1.1.2 Sources of Groundwater

1. Rain Water – Excess rain water which percolates below the surface and is trapped after meeting an impermeable rock.
2. Melt Water – Water that infiltrates into the ground due to melting of snow during spring and summer seasons.
3. Surface Water – Forms out of excess rainfall, snowmelt, lakes, ponds and tributaries which confluence and start flowing on the surface in the form of rivers, streams, etc.
4. Magmatic/Plutonic Water – During volcanism, the steam coming out of molten rocks gets cooled and transformed into water.
5. Springs – Places where water flows out naturally onto the surface of the Earth.

1.2 Types of Aquifers

Aquifer means the groundwater that is formed out of precipitation infiltrating deep into the surface where it gets stored after reaching the impervious layer of rock or soil. The following four different types of geological formations of groundwater are discussed:

1. Aquifer – Defined as a saturated layer of rock that stores water and yields water in an enormous quantity. Divided into:

- • Unconfined aquifer: has an open water surface; the water table exists near the surface.
- • Confined aquifer: a confined layer of groundwater between two impervious layers.

1. Aquitard – An aquifer that allows water to flow through but does not yield water in enough quantity due to its partially permeable nature.
2. Aquiclude – A rocky layer which is impermeable and does not permit flow of water, although it contains a large amount of water.
3. Aquifuge – A type of geological formation which is neither porous nor permeable.

1.3 Human Dependency on Groundwater Globally

The global population is expected to reach 8.5 billion by 2030 and could cross 10.4 billion by the end of this century (United Nations Department of Economic and Social Affairs, 2022). Since groundwater is a primary source of fresh water (Rodell et al., 2009), around 68 percent of the total global population shall be residing in urban centers by 2050 (Economic et al., 2019). Urban areas are more prone to water crisis, and one of the most acknowledged techniques across the world to replenish the water table is artificial recharging of groundwater.

1.4 Groundwater Situation in South Asia

South Asia is the world’s most populated region, where India and Pakistan are the most densely populated countries. These countries are heavily dependent upon groundwater for domestic, agriculture

and industrial purposes. South Asia accounts for nearly 34 percent of total groundwater usage (Hirji et al., 2017). With a fast-growing population and excessive exploitation of groundwater, it has become one of the most water-stressed regions globally.

1.5 Growing Water Needs in Pakistan

Pakistan is home to one of the largest glaciers in the world (Jilani et al., 2007). With growing population, the demand for water is continuously rising. Demand for water is estimated to reach 274 million acre-feet (MAF) by 2025, while supply seems to remain stagnant at 191 MAF, resulting in a demand-supply gap of approximately 83 MAF (IMF, 2015). More than 70 percent of the population depends upon groundwater for drinking and domestic purposes (Lashari et al., 2007).

1.6 Pakistan's Heading Towards Water Scarcity

According to PCRWR (2015), the total surface water availability in Pakistan is about 190 BCM whereas availability of groundwater is about 73 BCM. The Water Resource Vulnerability Index (WRVI) for Pakistan comes to be 77 percent, which makes it a severely water-scarce country (Ashraf, 2018). In Lahore, the water level has gone down to more than 40 meters, which used to exist about 4.5 meters below the surface (Mahmood et al., 2011).

1.7 Artificial Recharging of Groundwater

Artificial recharging of groundwater is an anthropogenic activity by which the amount of water that enters an aquifer can be increased through artificial means. It is an important method by which not only is the aquifer replenished but also the needs of the growing population can be addressed, and it also helps in preventing urban flooding (Hassan et al., 2016).

1.8 Artificial Groundwater Recharging – A Viable Solution

Global growth of population at an exorbitant rate, coupled with growing needs, demands a sustainable groundwater supply. Groundwater recharging seems a viable solution in coming years (Hassan et al., 2016). Direct well recharging is a promising option of groundwater recharging in water-scarce areas including semi-arid and arid regions (G. Kumar et al., 2021).

1.9 Limitations of Artificial Groundwater Recharging

Maintaining groundwater quality in artificial recharging is a main task to avoid pollution of the aquifer. Researchers have adopted various filter media based on the composition and type of materials to filter rain or storm water. Dry wells are being used to recharge aquifers; however, the problem of contamination of the aquifer is still unresolved (Sasidharan et al., 2018).

1.10 Objectives of Study

The key goal of this study is to find an appropriate filter media, depending upon the physicochemical analysis of harvested rainwater, that can be used to recharge an aquifer/well so that the harvested water does not harm the groundwater. Additional objectives include:

- • To qualitatively analyze the physicochemical parameters of harvested rainwater and water samples for existing and proposed filter media for aquifer recharging.
- • To compare the results of all parameters with WHO standards, and to identify those parameters which degrade the quality.
- • To propose/design a prototype model of suitable filter media that not only filters rainwater but also prevents the water-quality deterioration of the aquifer.
- • To modify the already installed filter media on the basis of findings, in order to resolve the problem.

2 MATERIALS AND METHODS

2.1 Study Area

The study area lies in Lahore, one of Pakistan's largest cities and the capital of Punjab Province. It is situated between 31°20' and 31°50' northward and 74°05' and 74°37' eastward. Lahore has an area of 1,772 square kilometers and is located at a height of 217 meters. According to latest estimates, the population of Lahore is hovering around 11.12 million and the city is currently growing at 3 percent annually (Pakistan Bureau of Statistics, 2017). The study area is a recharge well located at the College of Earth and Environmental Sciences (CEES), University of the Punjab (PU) – the largest and most renowned educational institution, which lies at the heart of Lahore on Canal Bank Road. The recharge well has location coordinates 31°29'50.1108" N and 74°17'44.2752" E. Figure 1 shows the University of the Punjab guide map indicating the location of the recharge well and an actual picture of the recharge well at the campus.

2.1.1 Climate of Lahore

The climate of Lahore is accompanied by seasonal variation in terms of temperature and rainfall. As far as temperature is concerned, the mean annual temperature of the city hovers at 24°C. January sees the lowest temperature, dropping to as low as 12°C, while June gets the highest temperature, with mercury levels hitting more than 36°C. In terms of rainfall, the average annual rainfall is recorded as 675 mm, which varies between 300 and 1200 mm. The city receives the major portion of this rainfall between May and September, which is also known locally as the monsoon period. This monsoon rainfall, according to studies, is estimated to recharge groundwater levels by nearly 40 mm on an annual basis (Gabriel et al., 2010).

2.1.2 Hydrogeology of Lahore

Geological studies of Lahore suggest that the strata are comprised of a loose or unconsolidated alluvial amalgam. The rocks are chiefly composed of sodium and bicarbonates. The sediments are supposed to have been deposited by tributaries of the Indus River during the Pleistocene era. The above strata of alluvial rocks, having sodium and bicarbonates, usually yield higher amounts of water, which makes the

aquifer system of Lahore a high-yielding aquifer system. This also implies that such aquifers are susceptible to recharging (Greenman et al., 1967).

2.2 Study Design

Prototype models of filter chambers for a recharge well were created and placed in the laboratory to assess the overall process of artificial recharging. The actual recharge well consists of a filter chamber having a depth of 4 feet below the natural surface level. The chamber consists of a filter media having a total of 4 layers of Boulders, Crushed Stone 1, Crushed Stone 2 and Silica Sand from bottom to top. Each layer is 1 foot deep. For the sake of convenience, the filter chamber was scaled down at a ratio of 1:6 into an acrylic box having a volume of 1' x 1' x 1', kept transparent to analyze the internal condition of the water and the overall behavior of the filter media. Two such boxes were made. In one box, the actual existing filter media of the recharge well was placed in the same sequence as in the actual well, while different filter media were tested in the other box.

2.2.1 Schematic Diagram of Study and Layout of Recharge Well

The schematic diagram of the study and the layout of the existing recharge well with its filter media are illustrated in Fig. 2, together with the two acrylic boxes used for the prototype models.

2.2.2 Layouts of Existing and Proposed Filter Media Designs

The layouts showing the existing and proposed filter media designs for the study are illustrated below. All filter media designs are scaled down at 1:6 in comparison to the actual filter chamber of the recharge well for the sake of convenience. The compositions of all filter media are shown in the pictures.

2.2.3 Prototype Models

In the current study, 3 prototype models of the above-mentioned filter designs were developed in two acrylic boxes. One box held the existing filter media, while in the second box, 2 proposed filter media designs were developed and tested so that a good comparison could be made. The water used in all trials was rainwater stored in a tank, collected via the rainwater harvesting (RWH) system installed at CEES, PU.

2.2.4 Rainwater Harvesting (RWH) System at CEES, PU

In 2017, a rainwater harvesting (RWH) system was installed at CEES, PU to capture excess rainfall from the rooftop of the college buildings. The rainwater is stored in a polymer water tank and is then utilized for gardening in order to conserve precious groundwater. In this research, the same water was used in all trials to ensure natural prevailing conditions as much as possible.

The rainwater harvesting system used in this study is shown in Fig. 3

2.3 Analysis of Sample

2.3.1 Physical Analysis

The physical analysis includes physical tests which indicate properties pertaining to the senses. These parameters include total dissolved solids, electrical conductivity and total suspended solids. The first two parameters were measured in the laboratory using a Hanna HI9811-5. This instrument is user-friendly and gives instant and accurate readings.

2.3.2 Chemical Analysis

Chemical tests indicate how much water carries minerals and organic substances that influence water quality. These include pH, carbonates, bicarbonates, chlorides, hardness, and some heavy metals which were subjected to chemical analysis. The titration method was used to determine chloride, hardness, carbonates, and bicarbonates. An Atomic Absorption Spectrophotometer was also used to determine the levels of lead and chromium.

2.4 Methodology for Physical Analysis

2.4.1 Determination of EC and TDS in Sample

Procedure:

- • Hanna HI9811-5 was used to measure the EC and TDS in the test.
- • The electrode was placed in 50 ml of sample in a beaker.
- • The instrument was switched on.
- • The respective button was pressed and the reading noted down when it became stable.

2.4.2 Determination of Total Suspended Solids

Procedure:

1. 1. A filter paper was taken and weighed (noted as W1).
2. 2. 50 ml of sample was taken and passed through the filter paper.
3. 3. The filter paper was dried by placing it in the oven at 121°C for half an hour.
4. 4. The filter paper was placed in a desiccator, if necessary, to reach normal temperature and obtain a constant weight (noted as W2).

Calculations:

TSS (mg/L) = (W2 − W1) / 50 ml × 1000 = ___ ppm

2.5 Methodology for Chemical Analysis

2.5.1 Determination of pH in Sample

Procedure:

A pH meter (Hanna HI9811-5) was used to determine the pH of the sample. 50 ml of sample was taken in a beaker and the electrode placed in it. The multi-meter was turned on, the pH button pressed, and the value noted when it became stable.

2.5.2 Determination of Carbonates and Bicarbonates

Reagent:

Standard solution of H_2SO_4: 3 ml of concentrated sulphuric acid (H_2SO_4) was taken into a 1000 ml volumetric flask, filled up to the mark with distilled water, stirred well, and stored in a tightly closed glass container.

Indicators:

1. 1. Phenolphthalein indicator: prepared by dissolving 0.5 g of phenolphthalein (in powder form) in 50% ethanol.
2. 2. Methyl orange indicator: prepared by dissolving 0.1 g of methyl orange powder in 20% ethanol.

Procedure:

50 ml of water was taken in a flask with the help of a pipette. 2–3 drops of phenolphthalein were added; if no color appears, carbonates are absent, but if a pink color appears, this reflects the presence of carbonates. The solution was then titrated against N/10 sulfuric acid to a colorless end point. Three readings were taken. The flask, along with its solution, was saved for bicarbonate and chloride determination.

Calculations:

Phenolphthalein alkalinity = ml of H_2SO_4 used with phenolphthalein × 1000 / ml of sample used

Total alkalinity = (ml of H_2SO_4 used with phenolphthalein + methyl orange) × 1000 / ml of sample used

2.5.3 Determination of Chlorides

Reagent:

Standard solution of $AgNO_3$: set up by dissolving 8.5 g of reagent-grade silver nitrate ($AgNO_3$) in distilled water, diluted to 1 liter and mixed thoroughly.

Indicator:

Prepared by dissolving 5 g of K_2CrO_4 in 100 ml of distilled water.

Procedure:

- • 50 ml of sample was taken in a conical flask.
- • 2–3 drops of potassium chromate indicator were added.
- • The sample was titrated against $AgNO_3$ until the reddish-brown end point was reached.
- • Three similar readings were taken.

Calculations:

Cl (mg/L) = volume of $AgNO_3$ used × 1000 / ml of sample

2.5.4 Determination of Hardness

Reagent:

1. 1. Standard EDTA (0.01 M).
2. 2. Eriochrome Black T as an indicator.
3. 3. Ammonia buffer solution.

Reagent preparation:

1. 1. EDTA solution: 4 g of EDTA and 0.1 g of magnesium bicarbonate were dissolved in 800 ml distilled water.
2. 2. Eriochrome Black T: 0.4 g of Eriochrome Black T and 4.5 g of hydroxylamine hydrochloride were added to 100 ml of 95% ethyl alcohol.
3. 3. Ammonia buffer: Stock A – 16.9 g of NH4Cl in 143 ml of concentrated NH4OH; Stock B – 1.25 g of the magnesium salt of EDTA dissolved in 50 ml distilled water. Both stock solutions were mixed and diluted to 250 ml with distilled water.

Procedure:

1. 1. Standard EDTA was used to fill the burette up to the mark.
2. 2. 50 ml of water sample was added to a conical flask.
3. 3. 1 ml of ammonia buffer was added.
4. 4. 5–6 drops of Eriochrome Black T indicator were added; the solution turned wine red.
5. 5. The mixture was titrated against the EDTA solution to an end point where the color changed from wine red to blue.
6. 6. The final reading was noted and the process repeated to obtain a concordant value.

Calculations:

Total hardness in water, mg/L (CaCO3 scale) = ml of EDTA used (non-boiled) × 1000 / 50 ml of sample

2.5.5 Determination of Sodium and Potassium

Reagents:

Stock KCl solution (1000 ppm K): prepared by precisely weighing 1.908 g of KCl (potassium chloride) and dissolving it in about 200 ml of distilled water in a 1-liter volumetric flask, then adding sufficient distilled water up to the mark.

Stock NaCl solution (1000 ppm Na): 2.542 g of NaCl (sodium chloride) was dissolved in a 1-liter volumetric flask to make a 1000 ppm Na standard by adding distilled water up to the mark.

0.5 ml, 1 ml, 2 ml, 5 ml, and 10 ml of both stock solutions were taken separately in beakers and diluted with 100 ml of distilled water to make 5 ppm, 10 ppm, 20 ppm, 50 ppm, and 100 ppm solutions of sodium and potassium, respectively.

Procedure:

- • The apparatus was switched on, followed by the air compressor.
- • The air pressure was set and the LPG supply turned on.
- • The flame was ignited and allowed to warm up for 5 minutes.
- • A beaker of distilled water was aspirated into the instrument to remove any contamination.
- • The solutions (10 ppm, 20 ppm, 50 ppm, and 100 ppm) of sodium and potassium were then used in separate trials to calibrate the instrument.
- • The sample was then aspirated and the readings noted.
- • It was also observed that the flame changed in color and intensity each time a different solution or the sample was aspirated into the instrument.
- • The instrument directly gives the values of sodium or potassium in the sample, in ppm.

2.5.6 Heavy Metals Detection by Atomic Absorption

Flame photometry, also known as flame atomic absorption spectrometry, was first developed in the 1950s. Owing to its simplicity, this technique has since been used to determine the quantity of heavy metals in a water sample. It uses the principle of atomic absorption, which states that every atom or ion absorbs light of a unique wavelength. When an atom or ion is exposed to its unique wavelength of light, electrons in it absorb the energy and jump from the ground state to an excited state. The instrument then measures and records the amount of energy absorbed by the electrons and reports the concentration of elements in the sample. In atomic absorption spectrometry (AAS), a solution containing the analyte is introduced into the flame, which excites the atoms from the ground to the excited state; the atoms absorb light of specific wavelengths, resulting in excitation of electrons.

The methods followed for each physical and chemical test are summarized in Table 1

Table 1
Tests and methods followed.

Test	Method Followed
pH	pH meter, Model HI9811-5
EC	EC meter, Model HI9811-5
TDS	TDS meter, Model HI9811-5
TSS	Filtration and oven drying
Chloride	Titration
Alkalinity (carbonates and bicarbonates)	Titration
Hardness	Titration

The methodology for heavy metal detection using AAS is shown in Table 2

Table 2
Heavy metal detection methodology.

Metal	Methodology
Lead (Pb)	AAS
Chromium (Cr)	AAS

3 RESULTS AND DISCUSSION

3.1 Results

All the results of the respective parameter analyses are listed in Table 3.

Table 3
Results of parameter analyses.

Parameter	Rain Water Sample	Filter No. 1 (Existing)	Filter No. 2 (Proposed)	Filter No. 3 (Proposed)	WHO Limits
pH	6.2	6.9	8.2	7.5	6.5–8.5
TDS (ppm)	90	270	580	100	< 1000
EC (µS/cm)	190	550	1170	220	400
Temperature (°C)	17	17	22	22	12–25
Carbonates (mg/L)	Absent	Absent	Absent	Absent	–
Bicarbonates (mg/L)	100	305	50	32	125–350
Chlorides (mg/L)	30	38	88	180	250
Sodium (mg/L)	8	10	30	20	50
Potassium (mg/L)	13	15	40	22	30
TSS (mg/L)	43	326	640	0	166
Hardness, CaCO3 (mg/L)	84	190	102	80	500
Cr (mg/L)	0.028	0.071	0.076	0.074	0.05
Pb (mg/L)	−3.885	−3.973	−2.994	−1.245	0.01

3.1.1 pH

pH of water represents the amount of hydrogen ions dissolved in the water sample. It is not a physical parameter that can be measured as a concentration or in quantity; rather, it is used to determine whether water is alkaline (basic) or acidic in nature. According to the World Health Organization (WHO), the value of pH for water should be between 6.5 and 8.5. The pH scale is used to determine how acidic or basic a solution is. Pure water has a pH of 7; pH values less than 7 are acidic, while pH values around 7 are neutral. pH is often tested electronically, and pH in surface water structures should be between 6.5 and 8.5 according to WHO and EPA guidelines. Acidic water with a pH of less than 6.5 is harmful to human beings; metal particles such as manganese, copper, lead, and zinc may be present in acidic water, giving it higher quantities of harmful metals and causing discomfort and unpleasant taste. In this study, all the filter designs F1, F2 and F3 have pH values lying within the permissible limits of WHO and national water quality standards. Thus, as far as pH is concerned, the filtered water is fit for recharging the aquifer.

3.1.2 Total Dissolved Solids

Total dissolved solids (TDS) represents the amount of total dissolved solids in water and has an impact on water's electrical characteristics; it refers to the quantity of impurities in water. TDS should not exceed 500 mg/L according to the EPA. According to WHO, TDS levels exceeding 1000 mg/L are generally considered unsuitable for human consumption.

3.1.3 Electrical Conductivity

Electrical conductivity is measured in mhos (reciprocal of ohms) or siemens. It is defined as the ability of water to conduct a flow of charges. Since its value in water is very low, it is expressed in milli-siemens or micro-siemens, in terms of the concentration of ions in water that act as electrolytes. Electrical conductivity depends on the value of pH and the amount of CO2, which causes ionization in water; therefore EC is an important parameter for checking water quality. The EC value should not exceed 400 µS/cm according to WHO. Water with an EC of 150 mS/m tastes salty, while water with an EC of more than 300 mS/m is unable to quench thirst. In this study, EC values of F1 and F2 were found to be higher than WHO limits, with the EC of F2 much higher than the permissible limit.

3.1.4 Carbonates and Bicarbonates (Alkalinity)

Alkalinity is defined as the presence of at least one particle in water, such as hydroxides, carbonates, and bicarbonates. Alkalinity, which is linked to pH, is a measure of water's capacity to neutralize acids. The lower the alkalinity, the more likely that the water will be caustic. The most commonly acknowledged source of alkalinity is bicarbonates. Alkalinity in water helps maintain the pH balance of the water. High alkalinity values in drinking water are beneficial since they keep the water safe to drink. On average, the alkalinity in drinking water should be between 20 and 200 mg/L, according to WHO.

Carbonates:

Carbon dioxide is broken down naturally in water and appears in the mixture primarily as bicarbonate and carbonate particles. Carbonate formed in this manner suggests a connection between the carbon cycle and the hydrological cycle. During photosynthesis, plants partially draw upon the significant supply of atmospheric carbon dioxide, leading to production of cellulose, starch and similar carbohydrates; these components are then reduced to carbon dioxide and water through respiration, releasing energy that can be stored. Dissolved carbon dioxide, along with temperature, pH, cations, and other dissolved salts, all contribute to the grouping of carbonates in different fluids.

Bicarbonates:

Across all hydrological systems, bicarbonate (HCO3) particles are the main alkaline components. CO2 dissolution leads to carbonate-containing minerals, bringing bicarbonate alkalinity into the water. The bicarbonate concentration in mineral water coming from limestone-rich locations is often high, and the bicarbonate amount in water is influenced by the weathering of rocks. Bicarbonates, such as bicarbonate of magnesium and calcium, are dissolvable in water and result in water hardness.

Bicarbonate may be found in all physiological fluids and organs, and plays an important role in the body's acid–base balance.

In this study, carbonates are absent in the water samples of all three filter media, while only F2 has bicarbonate values lying within range.

3.1.5 Chlorides

Chlorine (Cl, atomic number 17) is an active element, abundant in nature in its chloride form, which may be found in a variety of salts. Chloride occurs in surface and groundwater naturally as well as artificially, such as through storm water runoff including saltwater, inorganic waste, landfill leachates, septic tank effluents, industrial effluents, water-structure spillage, and coastal seashore intrusion. Higher amounts of chloride increase the electrical conductivity of water, hence increasing its corrosive potential, and chloride reacts with metal particles in metallic channels, resulting in the presence of metal in drinking water. WHO has established an acceptable limit of 250 mg/L for chloride in water.

In the current study, chloride values of all filter media are within WHO limits and much lower, except in F3, where the value does not exceed the limit but is quite close to the threshold.

3.1.6 Hardness

Hardness in water refers to the presence of dissolved salts of calcium and magnesium. If it exceeds limits, water would be unsuitable for drinking, bathing and washing; thus it is important to estimate the amount of substances that produce hardness in water, which can be done by complexometric titration. This procedure involves titrating a water sample against a standard solution of ethylenediaminetetraacetic acid (EDTA), available commercially as its disodium salt. Hardness is of two types: temporary and permanent. The former occurs due to the presence of bicarbonates of calcium and magnesium and can be easily removed by boiling the water. The latter is due to the presence of chlorides and sulphates of calcium and magnesium, which cannot be removed by boiling. Since this study deals with rainwater intended for aquifer recharging, only temporary hardness is of interest here.

The values of hardness in all filter media lie within WHO limits.

3.1.7 Sodium and Potassium

Sodium is one of the important alkaline elements that the human body needs for proper functioning, as it is required by various body organs. In water, a salt disassociates into Na + and Cl−, contributing to the amount of sodium in a sample. Potassium is also essential for body functioning, as it helps maintain proper blood pressure and promotes growth and functioning of the muscular and nervous systems. According to WHO, it is naturally present in water; however, its amount can increase through the use of potassium permanganate as a disinfecting agent. Higher amounts of K + can lead to kidney failure, heart disease, hypertension and other serious conditions.

Both sodium and potassium concentrations in a water sample are estimated through flame photometry, also known as atomic emission spectrometry. A solution containing sodium and potassium is sprayed into the flame; the heat of the flame, at about 1800°C, excites a small amount of atoms. As the excited atoms fall to a lower energy level, they emit light (photons) at a characteristic wavelength (Na: 589 nm, or K: 766 nm).

In this study, the concentrations of both sodium and potassium in all filter designs were found to be within permissible limits.

3.1.8 Total Suspended Solids (TSS)

Almost everywhere in the world, surface water contains impurities in the form of dissolved or suspended solids. Total suspended solids (TSS) represents the amount of these impurities suspended in water. Theoretically, TSS is defined as the amount of large particles that do not pass through filter paper and are visible to the naked eye. For water intended for drinking and similar uses, it is important to estimate the concentrations of both suspended and dissolved solids, as water appears turbid due to these particles. One of the most common pollutants in the world is “dirt,” which resides in water in the form of TSS and makes water turbid.

Higher concentrations of suspended solids in water may settle, forming a layer that can prevent sufficient transfer of oxygen, leading to the death of organisms and eutrophication of the water body. Moreover, excess TSS decreases the effectiveness of water disinfecting agents; therefore TSS, or turbidity, has to be removed from drinking water at treatment facilities on a priority basis.

In the current study, values of TSS in all filter media are more than 150 mg/L, meaning the water is quite dirty; however, since the water here is not intended for drinking, the TSS values can be overlooked.

3.1.9 Lead

Lead is one of the most frequently found heavy metals on Earth’s surface. It is present in tube-well water to some extent as a result of disintegration from general sources but, more importantly, is found in plumbing frameworks including metallic pipes, couplings, fittings, or connections with residences. Lead can be leached from polyvinyl chloride (PVC) pipes, resulting in measurable lead concentrations in drinking water. The amount of lead released from a structure can be determined by factors including pH, temperature, water quality, chloride and oxygen concentrations, and the duration for which the water has been standing. The body does not contain any inorganic lead naturally; lead intake through diet is not absorbed and is disposed of in feces, while lead that is utilized but not stored is expelled through the kidneys. Adults with blood Pb levels between 50 and 80 µg/dL may show signs of chronic lead poisoning.

In this study, lead values in all filter media F1, F2 and F3 were found to be within WHO limits.

3.1.10 Chromium

On the surface of the earth, chromium is found in dispersed form and can exist in oxidation states with valency ranging from + 3 to + 6. The positive ion of chromium-III (Cr3+) forms hydroxides in water and is absorbed typically at high pH levels. The ratio of chromium-III (Cr3+) to chromium-VI (Cr6+) varies greatly in surface waters, and significant concentrations of the latter can be found locally. Salts of chromium-VI (Cr6+) are easier to dissolve than those of chromium-III (Cr3+). Humans require the trace element chromium-III (Cr3+); however, extended exposure may be detrimental. Due to its severe toxicity and carcinogenic nature, chromium-VI (Cr6+) is the oxidation state of most concern in occupational safety and health as well as environmental hydrology, and has been associated with stomach and gastrointestinal cancer in humans and animals. It enters drinking water through industrial pollution, as it is utilized in the production of stainless steel, textiles, corrosion-protection coatings, and leather tanning. WHO has recommended an acceptable limit for chromium of 0.05 mg/L.

In this study, the values of chromium in all three filter media samples are slightly higher than WHO permissible limits, which needs proper modification and further analysis to remove such contamination.

The results of this research are useful for understanding the efficiency of different filter media designs for rainwater harvesting and groundwater recharge systems. Three different filter configurations (F1, F2, and F3) and their ability to treat collected rainwater prior to injection into the aquifer were compared.

The comparative results of all physicochemical parameters across the three filter designs are presented in Fig. 4.

3.2 Discussion

3.2.1 Water Quality Parameters

The results indicate that the majority of the physicochemical parameters for all the filter designs were within the permissible/desired range determined by WHO and national water quality standards. The pH values (6.9–8.2) and TDS values (270–580 mg/L) remained within the specified limits, showing that the filter media proved very effective in maintaining fundamental water quality parameters. The electrical conductivity (EC) values, however, showed some significant differences, especially in F2 (1170 µS/cm), which far surpassed the WHO recommended value of 400 µS/cm. This higher EC is likely due to the biochar included in F2, since biochar can sometimes contain inorganic ash residues that lead to higher ionic concentrations (Lehmann et al., 2011). The issues faced with EC in recharge well systems have been confirmed in other previous research carried out by Hameed et al. (2022) in Lahore, where similar problems with the treatment of biochar were reported.

3.2.2 Heavy Metal Removal

The analysis of heavy metals showed that all designs had lead levels within the allowable limits, indicating the effectiveness of the filtration system in removing lead from water. The concentration of chromium, however, was slightly above the WHO standard (0.05 mg/L) in all samples, ranging from 0.071 to 0.076 mg/L. The concentration of chromium in this study is similar to results obtained in other

urban studies where industrial activities and urban runoff have been found to be major sources of chromium contamination (Kumar et al., 2021). The occurrence of chromium indicates that additional treatment processes might be needed, especially in urban rainwater harvesting systems where atmospheric deposition is a source of heavy metal contamination (Islam et al., 2007).

3.2.3 Filter Media Performance Comparison

Of the three designs, F3 had the lowest TSS (166 mg/L) and the best overall water quality indicators compared to F1 and F2. This result is in accord with the study of Kumar et al. (2012), who found that fine sand layers can considerably improve the filtration efficiency of recharge systems. The elevated EC levels in F2 showed that biochar materials need pre-treatment or washing before use, although they showed promise in their ability to remove pollutants. It is recommended to test biochar produced from seasonal fruits, in line with emerging research on sustainable filtration media (Stiefel et al., 2009).

3.2.4 Practical Implications for Groundwater Management

Maintenance of most water quality parameters within acceptable limits indicates the ability of properly designed filter media to treat harvested rainwater for use in aquifer recharge. This is especially important for Lahore, where groundwater levels have dropped from 4.5 meters below the surface to more than 40 meters (Mahmood et al., 2011). The study's recommendation for vegetated stormwater drains and bio-retention chambers prior to entering the filter media is consistent with other recommendations for stormwater management that have proven effective in other urban settings (Tubau et al., 2017). The use of optimized filter media design can play a major role in ensuring groundwater sustainability in the country under the very critical condition of water scarcity (WRVI of 77%), and can also help in reducing urban flooding risks.

4 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

The following conclusions have been drawn from the current study:

1. 1. Both pH and TDS of water samples from all three-filter media are within the limits of international and national water standards.
2. 2. The EC values of F1 and F2 are much higher than permissible limits. The higher EC value in F2 might be due to inorganic content, in the form of ash, in the biochar placed as the uppermost layer in the filter design.
3. 3. Carbonates in all water samples were absent, as per WHO guidelines.
4. 4. Bicarbonate values of all water samples lie within the limits of water standards.
5. 5. Both sodium and potassium content are higher in F2 as compared to F1 and F3; notwithstanding, all values come within the purview of permissible limits.

6. 6. Hardness in all filter media F1, F2, and F3 is within the range of WHO limits.
7. 7. The values of the heavy metal lead (Pb) are within limits, while those of chromium (Cr) are slightly higher than the specified WHO limits.
8. 8. The turbidity of F2 is highest in comparison to F1 and F3.
9. 9. Overall, the quality of water after analyzing the above-mentioned parameters is satisfactory, given that this rain-harvested water is to be used for aquifer recharging.
10. 10. The study may be helpful in future designing of filter media for recharge wells for rainwater harvesting and aquifer recharging.
11. 11. Both fine sand in F3 and Bio-Char in F2, placed above the silica sand, proved to be good additions to the layers of filter media, compared to conventional filter media used for aquifer recharging.
12. **4.2 Recommendations**
13. 1. A proper concrete structure must be used on the rooftop to harvest rainwater.
14. 2. A raised platform must be built before the water reaches the filter media, so that the water resides for a few minutes, allowing dirt to settle. Provision of a bio-retention tank before the entrance of rainwater into the filter media is also highly recommended.
15. 3. Bio-Char from different materials, such as seasonal fruits, must be tested to improve the efficacy of filter media, as biochar is cheap and efficient in filtering impurities in rainwater.

Declarations

Author Contribution

sonia anwar :write up paper and manuscript,methodology resultsrana muhammad shoaib:methodologyshumaila :write up data gathering

Data Availability

Based on the file, here is the data availability statement:Data Availability Statement: The data supporting the findings of this study are presented within the paper. Raw data generated and analyzed during this research, including the results of physicochemical parameter analyses for rainwater and filtered water samples from the three filter media designs (F1, F2, and F3), are available from the corresponding author upon reasonable request.

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Figures

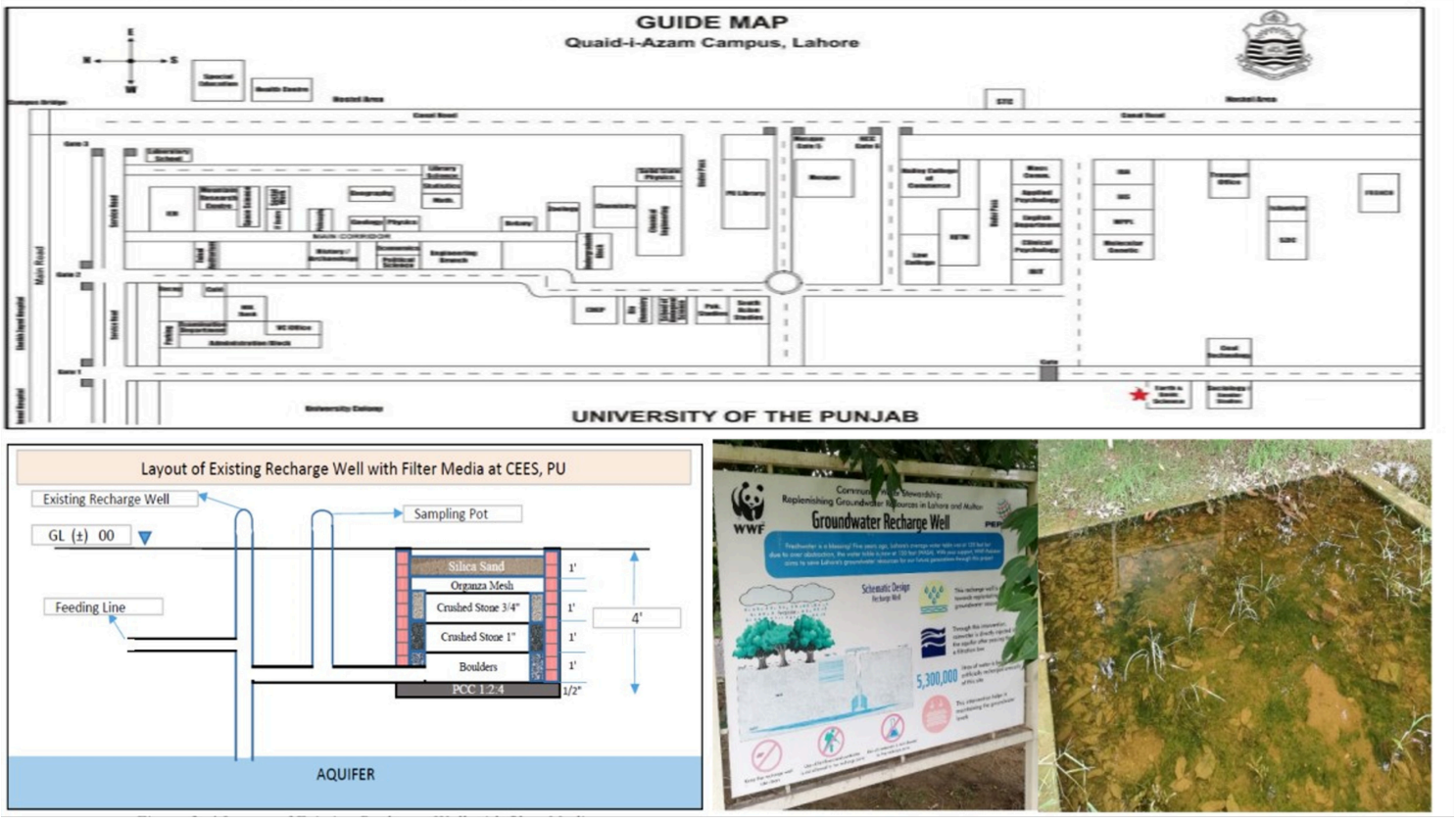


Figure 1

PU guide map showing the location of the recharge well, layouts of existing and proposed filter media, and the actual recharge well at CEES.

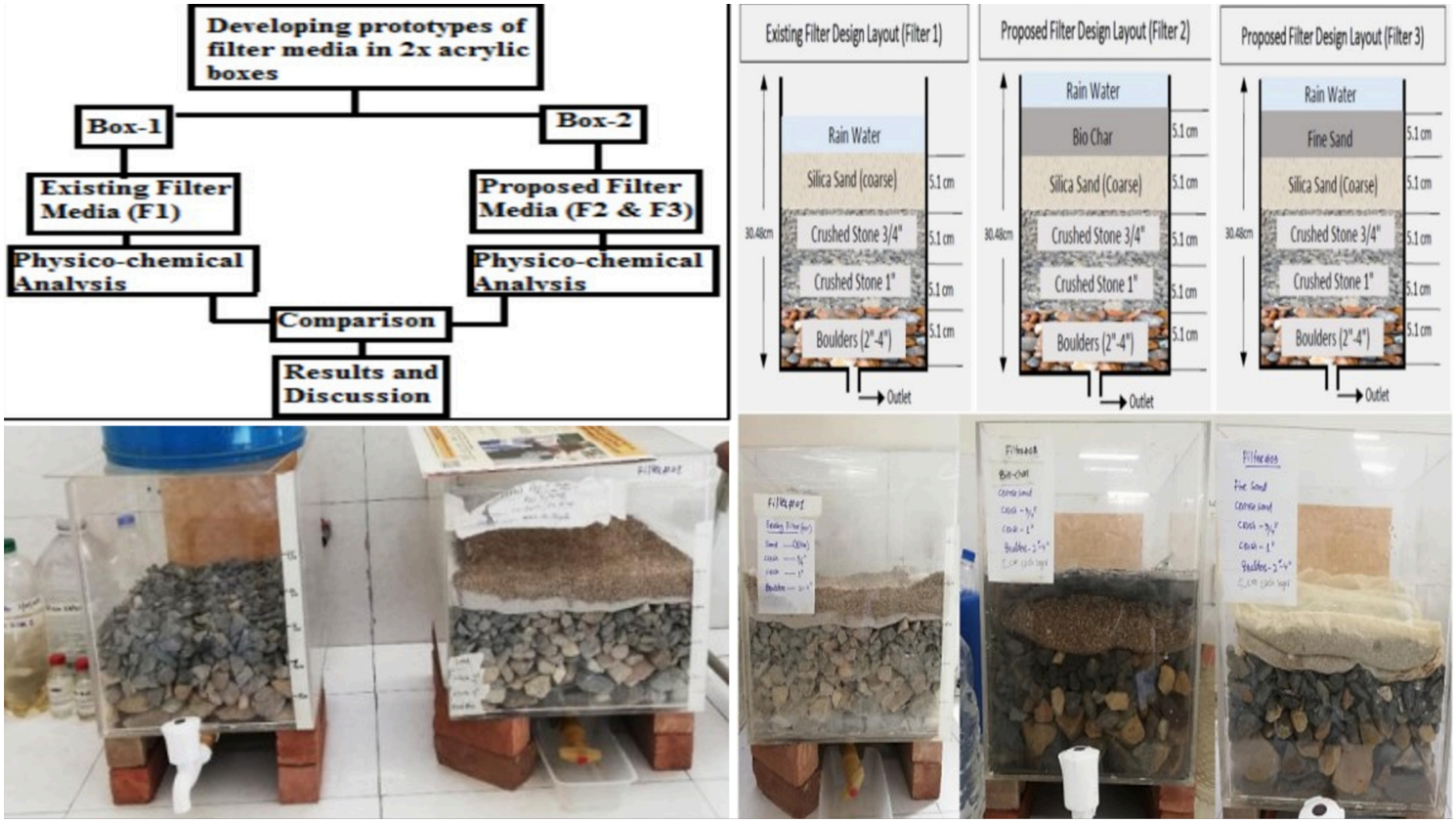


Figure 2

(a) Schematic diagram of the study and layout of the existing recharge well with filter media; (b) two acrylic boxes for the prototype models, showing prototypes of the existing and proposed filter media designs.



Figure 3

Rainwater harvesting system installed at CEES, PU.

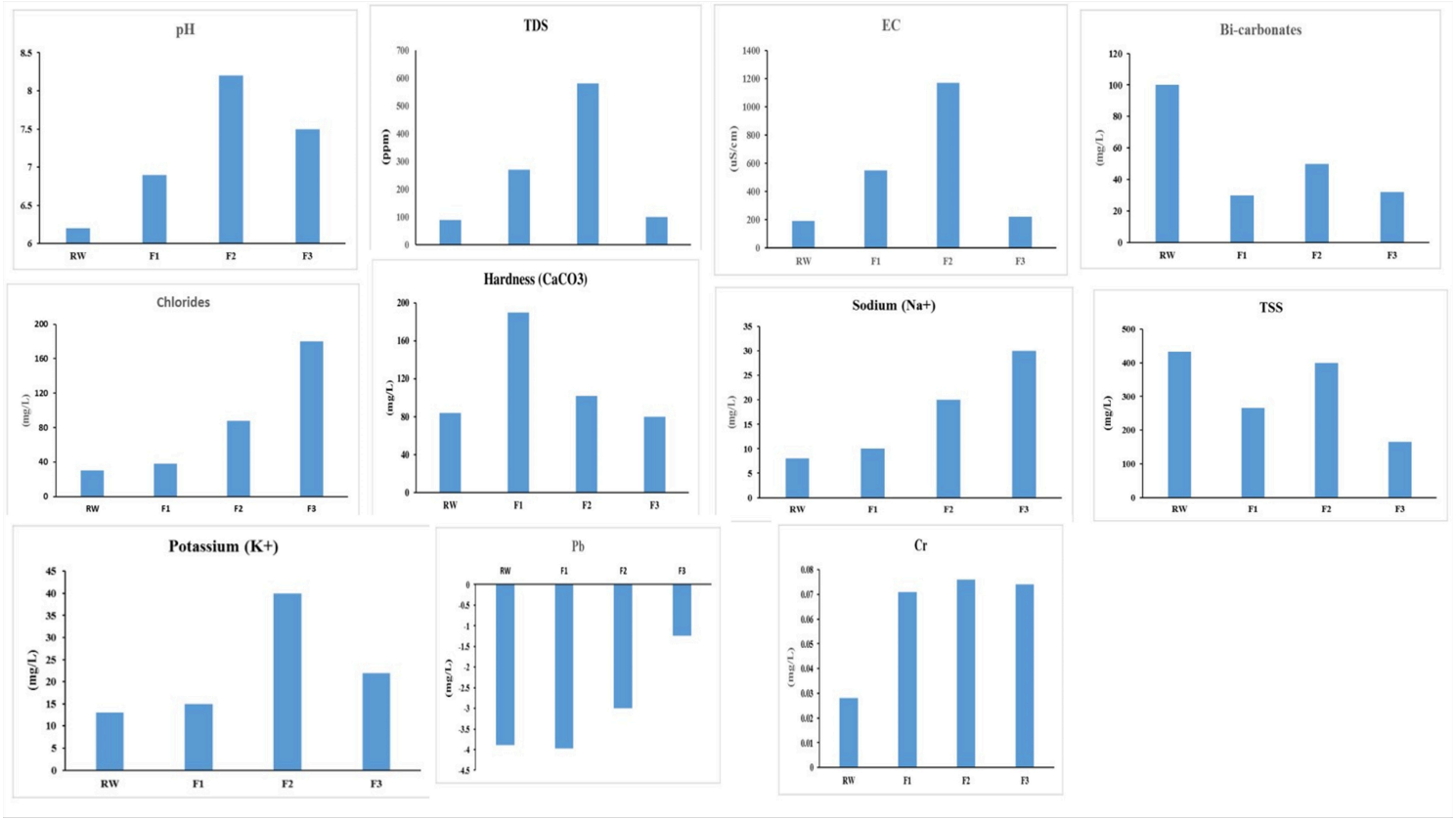


Figure 4

Bar charts of pH, TDS, EC, hardness, bicarbonates, chloride, sodium, TSS, potassium, Pb, and Cr concentrations.

Supplementary Files

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