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A Comprehensive Study of Variation in Water Quality Parameters to Design a Sustainable Treatment Plant

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ABSTRACT

In this paper, greywater samples are collected from the kitchens of different types of buildings (residential and commercial) located in different districts within the city of Jeddah, Saudi Arabia. The collected samples are analyzed and compared with the potable water from the same region. The parameters investigated are pH, conductivity, total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), total hardness, temporary hardness, permanent hardness, alkalinity, chloride, and biochemical oxygen demand (BOD). It was found that the amount of total suspended solids is very high in the greywater samples. It shows the presence of both temporary and permanent hardness. Their alkalinity values are greater than hardness. It may be due to the number, lifestyle, age of the occupants, presence of children, and social and cultural behavior of residents. The concentration of BOD level is very low, which shows that the greywater samples have lower concentrations of organic compounds. Design details of the greywater treatment plant are suggested based on the results of the analysis. This includes a screening chamber, grit chamber, settling tank, and filtration unit. The treated greywater is recommended for reuse for gardening, landscaping, and toilet flushing purposes.

INTRODUCTION

Saudi Arabia is an arid region and depends for its water supply mainly on desalination. Water processed from the Red Sea is used for domestic and commercial purposes. Baig (2014) mentioned that the per capita water consumption rate is higher in Jeddah, and the water demand is increasing drastically. Al-Juaidia & Attiahb (2020) and Anjum et al. (2019) mentioned that Saudi Arabia might face a significant water shortage without water conservation. Hence, it is the right time to recycle greywater and conserve water. The treated water replaces potable water for toilet flushing, fighting fires, gardening, washing cars, and other possible purposes.

The percentage of greywater generated varies regionally between households and depends on how efficiently and effectively the water is used. In addition, it contains fewer impurities compared to black water (Oteng-Peprah et al. 2018, Gross et al. 2015). In Saudi Arabia, greywater and black water are collected through a single pipe system in most buildings, requiring intense and vigorous treatment.

This paper aims to suggest a cost-effective treatment plant for greywater. To achieve this objective, the characteristics of greywater collected from kitchen lines of different buildings in three districts, namely Al-Fayha, Al-Bawadi, and Al-Aziziyah in Jeddah, Saudi Arabia, are analyzed.

MATERIALS AND METHODS

The samples are stored, preserved, and tested per the specifications of the Central Pollution Control Board (CPCB) (2011).

Collection of Samples

The greywater and tap water samples are collected from different buildings at different locations with minimum volumes varying from 500 mL to 1000 mL. The samples are collected at different times and days. It is assumed that they are of the same nature and are collected manually and randomly. The point of collection, date, hour, and time are recorded for the samples. The results of all samples obtained from the Al Fayha district are collectively mentioned under Area 1, from Al Bawadi as Area 2, and Al-Aziziyah as Area 3. The results of greywater are compared with the potable water of the same locations and with established data to study the variation in the pollutant level.

Preservation of Samples

Samples are collected in glass bottles of a minimum of 500 mL and are analyzed immediately at the site for pH and within 2-3 hours at the lab for total solids, total dissolved solids, and alkalinity. Chloride is measured within 2-3 days for refrigerated samples. Hardness is measured by adjusting the pH of the collected samples to two or less by adding sulfuric acid (H_2SO_4), and then it is refrigerated and measured within 2-3 days. The samples are collected by overflowing the BOD bottles for BOD and dissolved oxygen and are analyzed immediately.

Analysis of Samples

The various characteristics of the samples analyzed in this paper are pH, conductivity, total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), total hardness, temporary hardness, permanent hardness, alkalinity, chloride, dissolved oxygen and Biochemical oxygen demand (BOD). The methods and the details of the equipment used for the analysis of the different characteristics are as per Khan and Kaafil (2020).

pH and alkalinity: pH is measured using a pH meter (Denver Instrument model # 215) and it is calibrated using laboratory-supplied buffers of pH = 4 (HACH), pH =7 (Panreac), and pH=10 (Panreac). usual precautions calibrate pH meters. The alkalinity of the samples is measured by the potentiometric method. Total alkalinities are calculated in milligrams (mg) of calcium carbonates ($CaCO_3$) and calcium hydrogen carbonate per L.

Total solids, total dissolved solids, and total suspended solids: To measure total solids (TS), 50 cm^3 of greywater sample was evaporated and dried in temperature temperature-controlled electric oven at 103-104°C for 24 h. Total dissolved solids (TDS) were measured using a TDS/EC meter at 25.6°C (Hanna instrument model # hi 98312). Total suspended solids (TSS) were the difference between total solids and total dissolved solids.

Total hardness: A mixture of cations and anions causes the hardness of the water. Total hardness is expressed as the concentration of calcium and magnesium ions (Ca^{2+} and Mg^{2+}), and it is measured in terms of calcium carbonate ($CaCO_3$)as mg per L (US EPA 2000). In this paper, the hardness of samples is determined by EDTA titration using Eriochrome Black T after buffering 25 mL of the acidified sample with 2 mL of buffer solution (NH_3 + NH_4Cl).

Chloride: The collected samples are neutral and are made slightly alkaline before titrating against standardized silver nitrate ($AgNO_3$) to find the amount of chloride (Cl^-). At the end of the titration, it changes the orange color of potassium dichromate to a red precipitate of silver chromate (VI).

Dissolved oxygen (DO) and Biochemical Oxygen Demand (BOD): The Biochemical Oxygen Demand (BOD) of the sample is the difference between the dissolved oxygen (DO) at zero days with DO after incubation of the sample for 3 days at 27.5°C, which is equivalent to BOD_5 (CPCB 2011).

Dilution water was prepared from aerated distilled water that added 1 mL of phosphate buffer of pH 7.2 (AppliChem Panreac), 1 mL of magnesium sulfate ($MgSO_4$ 0.091M),1 mL of calcium chloride ($CaCl_2$ 0.247 M) and 1 mL of Iron(III) chloride ($FeCl_3$ 0.09M) and then diluted to 1 L (US EPA 2000). The prepared dilution water is tested immediately to ensure that the DO concentration is around 7.5 $mg.L^{-1}$, and it is used for diluting the greywater samples. Greywater samples are tested for residual chlorine by the iodometric titration method (US EPA 2000), which is found to be absent. Different dilutions tried for samples are 20%, 50%, 70%, 90%, 95%, 98%, and 99%. BOD results are obtained with 98 % dilution for most samples and a few with 99% dilution. Quality check for dilution water is also carried out as it may cause significant alteration in results.

RESULTS AND DISCUSSION

The analysis results of the greywater samples collected from the kitchen line of the buildings located in the Al-Fayha district are mentioned under Area 1, and those samples are from the Al-Bawadi district as Area 2 and from Al-Aziziyah district as Area 3. The pH of potable water (tap) and greywater samples of area 1 is neutral and very weakly acidic for areas 2 and 3 (Fig. 1). The average pH value of the collected greywater samples is 6.53. The electrical conductivity of the greywater generated from different areas is compared with the potable (tap) water of the corresponding area (Fig. 2). The percentage increase in the electrical conductivity of the greywater samples compared to potable water is 58%, 35% and 36% for area 1, 2 and 3 respectively. The temporary and permanent hardness is found from the samples' alkalinity (Fig.3a) and total hardness (Fig. 3b). Area 1 includes the samples collected from a commercial kitchen, which shows very high percentage increase in hardness of grey water with respect to potable water samples of that area(Fig.3b). The hardness of the potable water in area 1 is less than the total alkalinity in-terms of carbonate (CO_3^{-2}) and hydrogen carbonate (HCO_3^{-}) which shows the absence of permanent hardness. However, the other areas' greywater samples and potable water (tap) samples show both temporary and permanent hardness as their alkalinity values are greater than hardness. The percentage increase in hardness compared to their potable water is 70% for Area 1, 15% for Area 2, and 20% for Area 3. Area 2 and Area 3 include the samples collected from residential buildings alone

The total solids (Fig. 4a) of the greywater samples of different areas are very high compared to potable water and are mostly in the form of suspended solids (Fig. 4b). Also, it is noticed that the total dissolved solids (Fig. 4c) are very less in all the three areas. It may be due to greywater generated from the kitchen, which normally contains food particles that remain suspended solids. The chloride content of greywater samples is higher than the potable water of all three areas (Fig. 5), and it is found that the samples with more hardness have more chloride content (areas 2 and 3). The greywater samples of areas 2 and 3 show permanent hardness in the form of chlorides of calcium and magnesium ions. BOD is an indicator of bio-degradable organic matter and is given in Fig. 6.

The concentration of BOD in greywater samples is very low, indicating that greywater samples have lower concentrations of organic compounds. The characteristics of the potable and greywater of the different areas are summarized in Table 1. It is found that the amount of total suspended solids is very high in the samples, and the number,

Table 1: Characteristics of potable and greywater of different areas.

Parameters	Area 1		Area 2		Area 3	
	Potable water	Grey water	Potable water	Grey water	Potable water	Grey water
pH	7.45	7.10	6.10	5.81	6.14	6.68
EC µSiemens/cm	82.29	206	361	550	76	120
Alkalinity mg of $HCO_3^-.L^{-1}$	51.24	46.66	29.28	42	58.56	70.76
Alkalinity mg of $CaCO_3^{-2}.L^{-1}$	42.00	38.25	24.00	34.43	48.00	58.00
Total Hardness mg as $CaCO_3^{-2}.L^{-1}$	36.00	123.20	134.40	159.26	88.52	114.90
Temporary Hardness	36.00	38.25	24.00	34.43	48.00	58.00
Permanent Hardness	0	84.95	110.40	124.83	40.52	56.90
TS $mg.L^{-1}$	200	2900	350	6000	200	500
TSS $mg.L^{-1}$	140	2740	140	5710	140	400
TDS $mg.L^{-1}$	60.00	170	210	280	60	100
Cl^- $mg.L^{-1}$	29.41	49.20	203.91	406	29.20	230
DO_0 $mg.L^{-1}$	8.12	13.00	10.15	11.87	9.12	11.25
DO_3 $mg.L^{-1}$	6.00	2.75	9	1.37	6.62	3.20
BOD $mg.L^{-1}$	2.12	10.25	1.15	10.50	2.50	8.05

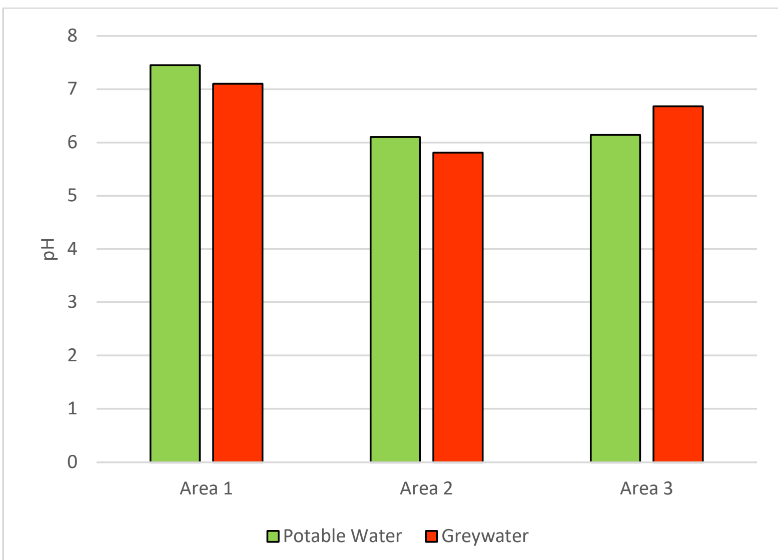


Fig. 1: pH of the different water samples.

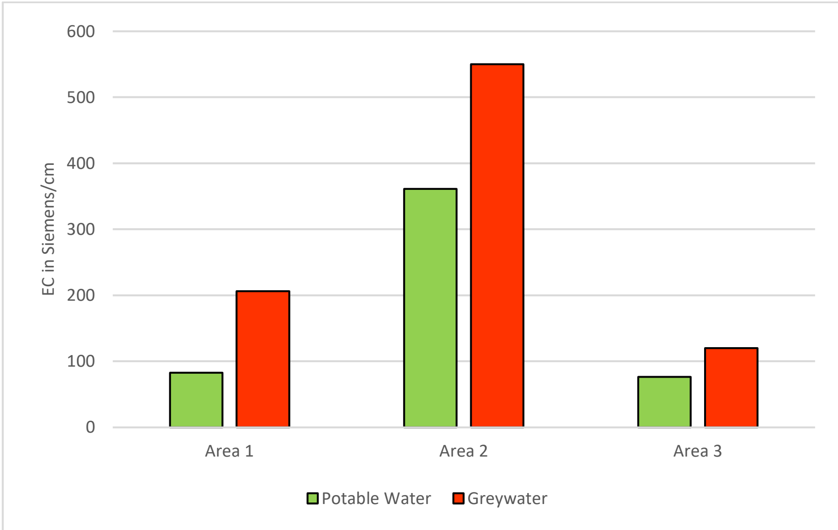


Fig. 2: Electrical conductivity of different water samples.

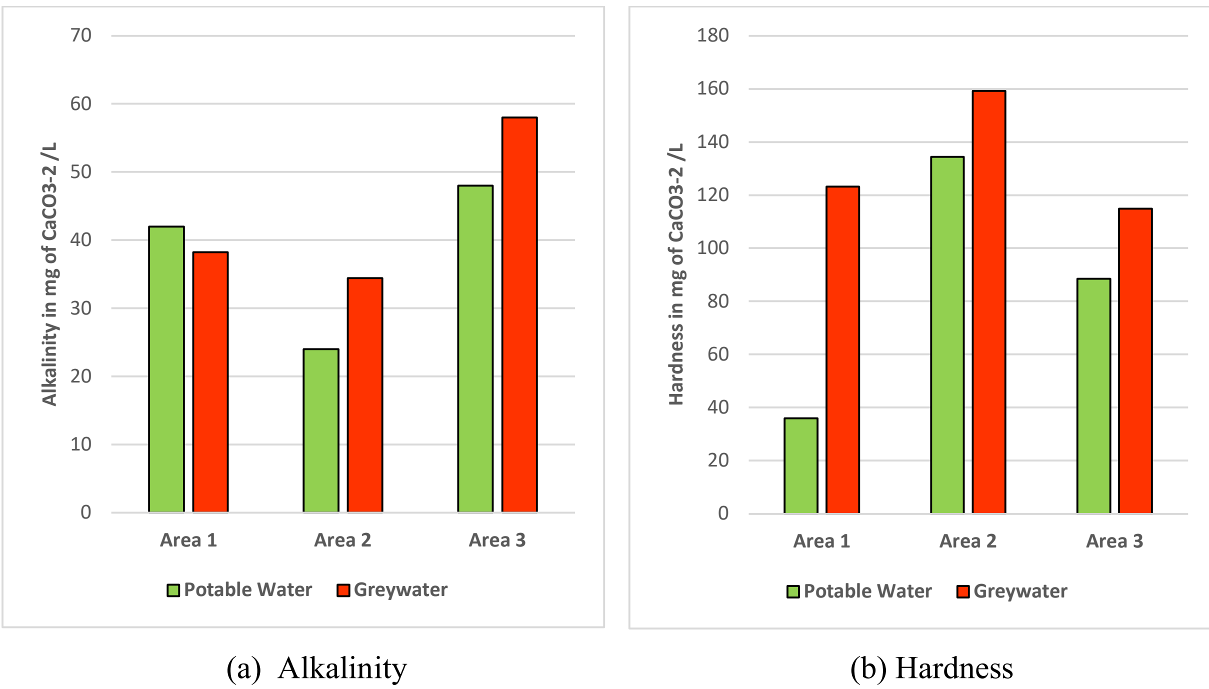


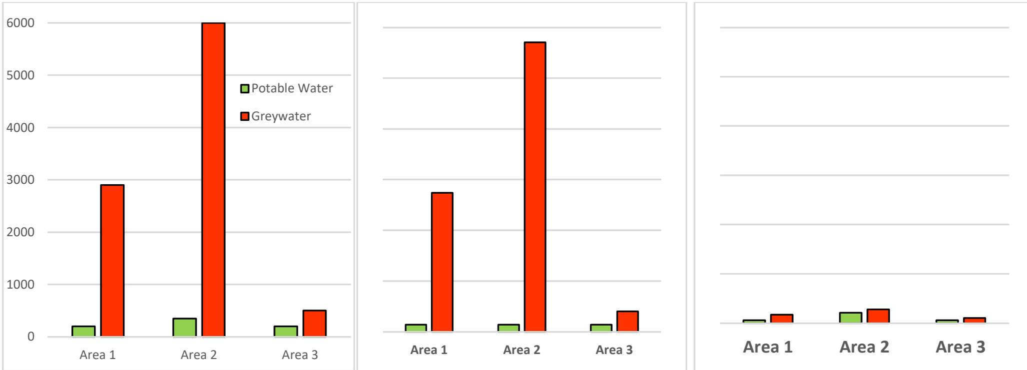
Fig. 3: Alkalinity and hardness of different water samples.

lifestyle, age of the occupants, presence of children, social and cultural behavior of residents, and water usage patterns of the occupants influence the variations in the results. It is found that the samples with more hardness than potable water(tap) show higher concentrations of hard ions, and higher values of chlorides and electrical conductivity support it.

Comparison with Established Data

The average values of the characteristics of the greywater samples collected from different areas are compared with the established data (Pescod 1992) and are listed in Table 2.

It is found that alkalinity and total dissolved solids are weak, and it depends on the usage pattern of the water, and correspondingly, the treatment process will change. The



(a) Total solids (b) Total suspended solids (c) Total dissolved solids

Fig. 4: Total solids, total suspended solids, and total dissolved solids of different water samples.

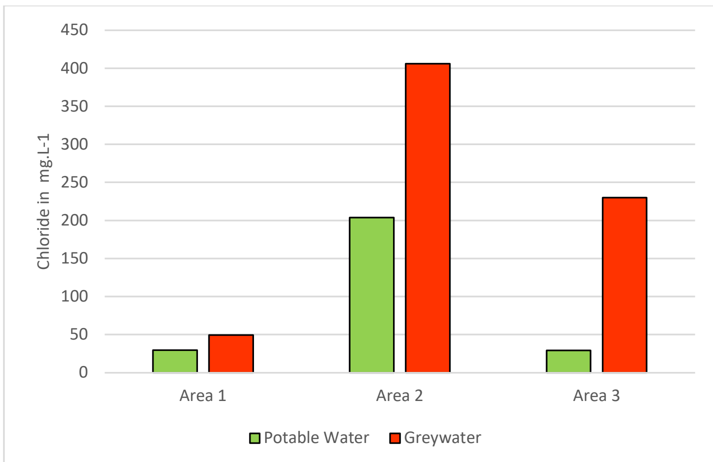


Fig. 5: Chloride values of the different water samples.

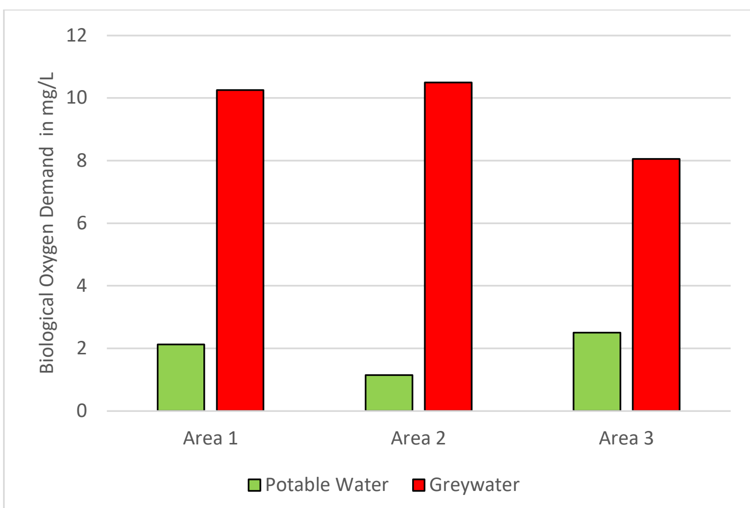


Fig. 6: BOD of different water samples.

Table 2: Comparison of results with established data (Pescod, 1992).

Constituents	strength			Test results
	Strong	Medium	Weak	
Alkalinity as $CaCO_3$in mg.L^{-1}	200	100	50	43.56
Total solids g.L^{-1}	1.2	0.7	0.35	3.1
Total dissolved solids g.L^{-1}	0.85	0.5	0.25	0.18
Total suspended solids g.L^{-1}	0.35	0.2	0.1	2.95
Total hardness as mg $CaCO_3$/L	180	120	60	132.45
BOD mg.L^{-1}	300	200	100	12
Chloride mg.L^{-1}	100	50	30	228

suspended solids are very high, whereas total hardness is found to be medium. Chloride is one of the anions causing permanent hardness, and it is found to be medium, 228 mg.L^{-1} when compared with established data. The level of BOD was found to be very weak, 12 mg.L^{-1}, which shows a low pollution level. This comparative study gives an idea to the author to choose the greywater treatment process.

Quality of Water for Reuse

Water quality parameter for urban reuse is assessed by comparing the results with normative references and guidelines followed in different countries (US EPA 2004 & ANQIP 2011) and is reported in Table 3. The possible urban reuse is landscape irrigation, toilet flushing, fire protection, commercial air conditioners, and gardening. It is found that the pH, TDS, and BOD of the greywater samples are within the acceptable range for urban reuse without any treatment. It is recommended to do physical-chemical treatment to remove TSS before its reuse.

Design of Greywater Treatment Plant

The different technologies used to treat greywater depend on guidelines and standards (Gross et al. 2015, CPCB 2011) and include physical, chemical, and biological processes. One of the biggest prospects of reusing treated grey water is reducing desalinated water usage.The factors that influence the selection of different types of treatment include the volume of greywater to be treated, characteristics of the greywater, and reuse applications. Also, reducing the volume of greywater generation through various water conservation technologies and decreasing the pollutant load is recommended. It is well established by Wurochekke et al. (2016) that the greywater intended for treatment and reuse should not be stored for longer periods as this encourages the growth of the microbial population present in it.

Table 3: Water quality parameters for urban reuse.

Parameters	Range	Results obtained
PH	6-9 (US EPA 2004)	6.53
TSS [mg.L^{-1}]	≤ 30 (ANQIP 2011) ≤ 30 (Ministry of Health Canada 2010)	2950
TDS [mg.L^{-1}]	500-2000 (US EPA 2004)	180
BOD	≤ 10 (US EPA 2004) ≤ 20 (Ministry of Health Canada 2010)	12

An extensive literature survey is conducted to study different physicochemical and biological methods to treat greywater. Physicochemical methods include screening, grit removal, sedimentation, sludge thickener, ion exchange, multimedia filtration, adsorption, reverse osmosis, and ultra-filtration. Biological methods are broadly classified as aerobic and anaerobic. Aerobic methods are divided into suspended growth (viz. Activated sludge process, Aerated lagoon, Waste stabilization pond, etc.) and attached growth (viz. Tricking filter, Rotating bio discs, Constructed wetlands, etc.). Anaerobic treatments comprise contact beds, up-flow anaerobic sludge blanket reactors, sludge digesters, and anaerobic ponds (Droste & Gehr 2018).

Filtration removes the particulate matter. During filtration, turbidity, colloidal matter of non-settleable type protozoan cysts, and helminth eggs are removed. The protozoa are stopped in the gravel, the bacteria by the medium gravel, and the viruses by the sand (Couto et al. 2014). However, this considers only the physical process of solids removal. In these systems, both physical and biological processes remove solids (Vuppaladadiyam et al. 2019).

It is suggested to set up a sustainable treatment plant based on the results obtained from the analysis. It includes a screening chamber, grit chamber, sedimentation tank, and filtration tank. It is recommended to use the two-pipe system to separate greywater from blackwater. The outlet of greywater is passed through a screening chamber to remove floating solids and then to the grit chamber to remove the grease and oil. The greywater samples contain high

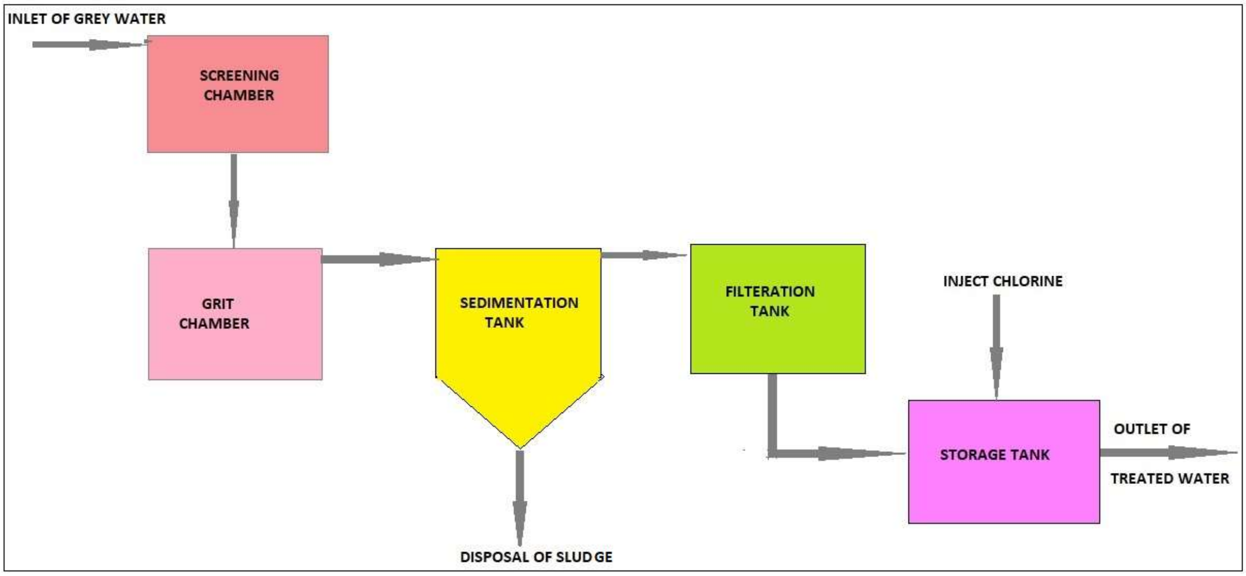


Fig. 7: Schematic view of sustainable treatment plant.

levels of suspended solids, so it is recommended to use a sedimentation tank with a coagulant to settle the suspended solids under gravity. The detention time is approximately 2 to 4 hours for the sediments to settle. The clear water collected from the top of the sedimentation tank is passed to the filtration tank to remove the microbes. The hardness of greywater samples is due to soluble calcium and magnesium chloride so it won't cause a scaling problem.

The capacity of the filtration tank designed in this paper is 20-L filled with locally available materials, marble, and gravel, acting as a drain with a size range of 2-16 mm to a height of 100 mm from the bottom of the unit. Sand is placed on top of the gravel to a height of 500 mm. The sand screens off particles larger than their pore size, while the marbles and gravel act as a drainage system to let off filtered greywater. The filtered greywater is collected from the bottom of the tank and sent to the storage tank. Chlorine is added to the storage tank as disinfection depends on the urban reuse option. The schematic view of the recommended treatment plant is shown in Fig. 7.

CONCLUSIONS

The research is conducted on the greywater samples collected from households in three different districts within the city of Jeddah, Saudi Arabia. The results show that the quality of greywater with respect to PH, TDS, and BOD is within the acceptable range for reuse as toilet flush, gardening, landscape, and irrigation without any further treatment. Also, it is recommended to pass the greywater to a sedimentation tank with coagulants before reuse to remove the suspended solids. The greywater samples generated from the kitchen have low pollution levels, so it is recommended to set up primary stages of treatment with sustainable material, a cost-effective treatment method.

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