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# Assessment of an experimental unit for greywater treatment; for water conservation purposes

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## Abstract:

Decreasing of freshwater is one of the biggest problems that faces Egyptian and international society as well, where increase in water consumption with population growth, rare rain with high evaporation, evolution of living, expansion of agricultural areas, and industrial projects, all push scientists to search about non-traditional resources of water. Since most daily activities don't required fresh water, it was necessary to find another source of water that can meet these proposes to save a high amount of freshwater consumed in such activities. One of the suggestions to find a new water resource is the reuse of greywater as non-potable water to face the continuous pressure on water consumption. In this study an experimental treatment unit has been tested and evaluated from the greywater treatment efficiency point of view. The filtration method using both up-down and down-up flow is selected to treat the greywater. Different filteration media such as: gravel, sand, MBB, and sponge were tested and evaluated from treatment efficiency point of view. Based on the analysis of the results of the experimental work; it was found that using sponge as filtration media is the most efficient strategy comparing with others for greywater treatment. The removal efficiency of evaluated parameters for sponge filter were; 98.8%, 86.91%, 67.90%, 71.15%, and 86.36% for TSS, Turbidity, COD, Nitrate, and Phosphate respectively. This treatment unit can be used for treatment of light greywater efficiently, and its effluent can be reused at least in toilet flushing and irrigation of green areas, saving huge amount of fresh water. Greywater reuse is highlighted because its participation in water resources conservation.

**Keywords:** *Water conservation, Greywater treatment, filter media, reuse, sponge, toilet flushing.*

## 1- Introduction

The water scarcity in all over the world is driven by both quantity of water and its quality issues (Michelle, et al, 2021). Global water scarcity is a leading challenge for continued human development and achievement of the Sustainable Development Goals (Flannery et al, 2021). Egypt as a part of the global is not far from the scarcity issue specially its population increased dramatically with limitation of traditional water resources.

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In Egypt, the main source of water is the Nile River, Egypt's share of Nile water is 55.5 billion $m^3$ / year, this share is constant, although water consumption increases with population growth, the evolution of living, expansion of agricultural areas, and industrial projects. These factors affect the per capita freshwater share (El-ashkar, 2015). Per capita share in 1897 about 5721$m^3$/ca/y as for in 2016 per capita share became below 603$m^3$/ca/y. Egypt's per capita share of water declined to 570 $m^3$ per year in 2018, said the Central Agency for Public Mobilization and Statistics (CAPMAS) in April 2019, which refers to the per capita is less than water scarcity limit, which is equivalent 1000 $m^3$/ca/y (Kevin et al., 2006). 82 % of Nile water is consumed in agriculture, 11% in industry and the rest consumption of homes (Rothenberger, 2010 and Osman et al., 2016), as shown in Figure (1).

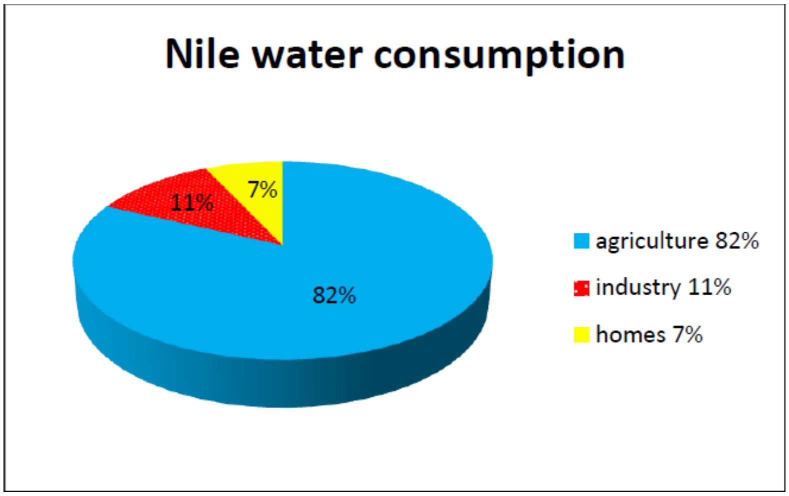


**Fig. (1)**: Nile Water Consumption

Since most daily activities don't required fresh water, it was necessary to find another source of water that can meet these proposes to save a high amount of freshwater consumed in such activities. One of the suggestions to find a new water resource is the reuse of greywater as non-potable water to face the continuous pressure on water consumption. This is a very important way to face water shortage and reaches to find water source can be used in some daily purposes without influence on potable water amount, providing a large amount of water to gardens irrigation, increasing green areas, and agriculture of some crops, and in other hand decrease the hydraulic load on wastewater sewerage system and in turn wastewater treatment plants (WWTPs).

### *1.1 Definitions of Greywater*

Greywater is the domestic wastewater from all sources except water from toilets (Eriksson et al., 2002). The rate of greywater daily production is around 190 liter per capita (Ashfaque and Abdul, 2015 ). (Jefferson et al., 2004) excluded wastewater comes from the kitchen, where it contains a high organic load, requiring biological treatment. If the greywater is treated, it can meet amount of water for daily purposes and save freshwater (Winward, 2008). This study clarifies how greywater treatment and reuse depending on its properties and reuse purposes. Figure (2) shows the sources of greywater from domestic wastewater; the greywater produces from the shower, washing machine and hand basin without mix with wastewater come from the kitchen basin and toilet.

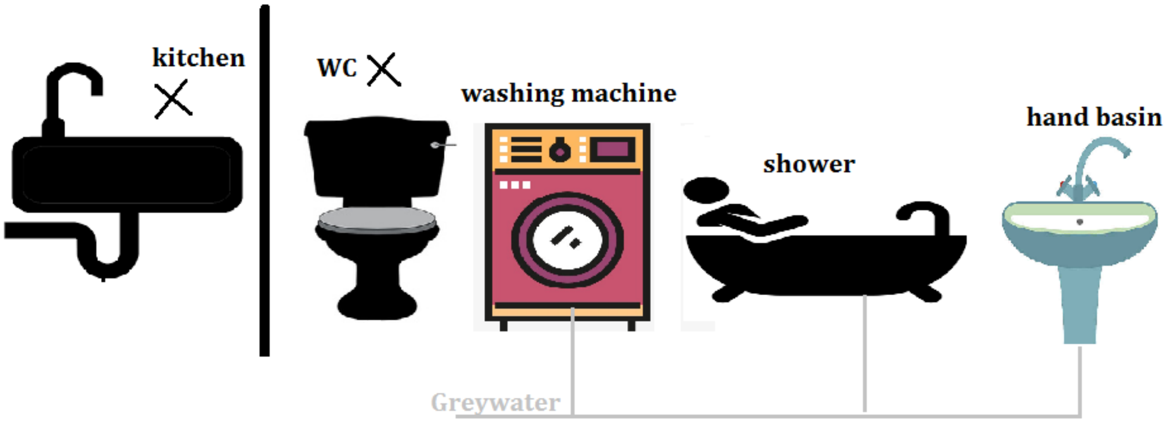


**Fig. (2):** Greywater sources. (Simon and Chris, 2013)

Water consumption rate per capita can be divided into different ratios, based on variant human activities done daily. Figure (3) refers to the ratios of domestic drainage.

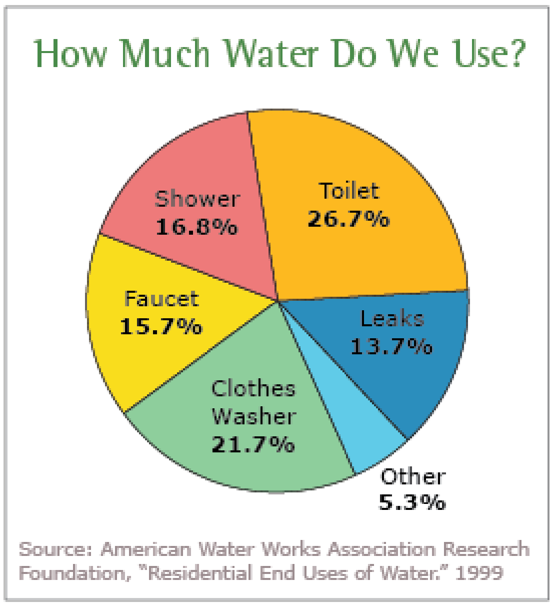


**Fig. (3):** Daily domestic drainage (Peter and William, 1998)

Greywater is divided into two types, low- loaded greywater (LGW), which includes wastewater comes from hand basin, showers and bath tubes (Butler et al., 1995), greywater comes from Mosques that used for Wodoa, and its amount represents more than 70% of the total greywater (Lambe, (2016), and high- loaded greywater (HGW), which is comes from kitchens and dishwashing. The following figure explain a different kind of greywater.

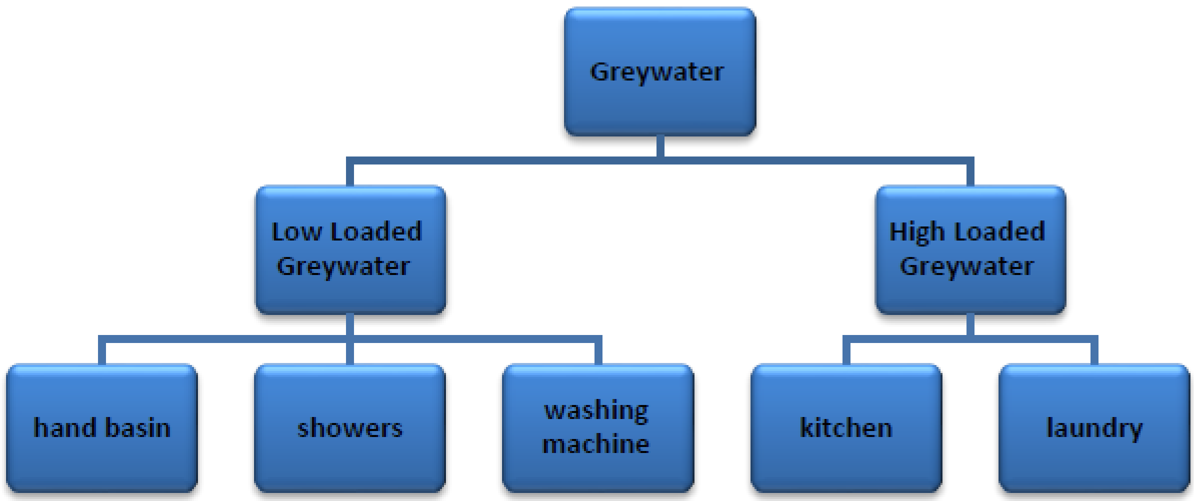


**Fig. (4):** Kind of Greywater.

The properties of low and high-loaded greywater can be summarized in the following table.

Table (1): Properties of low and high loaded Greywater, (Winward, 2008) and (FBR, 2008)

| Properties | Low-Loaded GW | | Mix (low and high loaded) GW | |
|---|---|---|---|---|
| | Range | Mean | Range | Mean |
| BOD (mg /L) | 85 – 200 | 111 | 250 – 550 | 360 |
| COD (mg /L) | 150 – 400 | 225 | 400 - 700 | 535 |
| TSS (mg /L) | 30 -70 | 40 | 45 - 330 | 93 |
| Turbidity (NTU) | NA | 19 | 22 - 200 | 67 |
| Total coliforms (MPN/ml) | 101 – 105 | 103 | 102 - 106 | 104 |

### *1.2 Treatment of Greywater and reuse*

There are many different methods applied for greywater treatment. The selected method depends on the degree of pollution of greywater. The main categories are divided into; Biological, Chemical, and Physical treatment methods. These methods can be summaries in figure (5).

Many researchers deals with most these method for greywater treatment, to evaluate them from different point of view. (Herna´ndez-Leal et al., 2011), studied the efficiency of treatment with activated carbon and ozone to evaluate the removal of selected micropollutants, based on adsorption and ozonation technique. (Thomaidi et al, 2022) used a green roof as a modified shallow vertical flow constructed wetland for greywater treatment in buildings, and they found that the operation of green roofs as modified vertical unsaturated constructed wetlands seems a sustainable nature-based solution for greywater treatment and reuse in urban areas. (Ken Ushijima et al., 2013), evaluated slanted soil system performance for light greywater reused in irrigation sector. According to their experiments, only fine soil (1–4 mm) more efficient than coarse soil in removing pathogens.

Greywater reuse is an appropriate method as a source of renewable water, to can meet daily water needs, it is sustainable. It is not seasonal like rainwater and is produced in large quantities daily through individual consumption of water. Greywater is easier to treat and reuse than black wastewater. Referring to the opinion of (Adi Maimon et al., 2014), there are three factors were found to have an effect on greywater quality: the type of treatment, the skills of the system designer and whether kitchen effluent was included/excluded from greywater. There are many different fields that can be used greywater instead of fresh water and in turn serve for water resources conservation. These fields include but are not limited to: Cultivate some crops, Green area irrigation, Improve wetlands, Toilet flushing, Cars washing, Industrial uses, and firefighting.

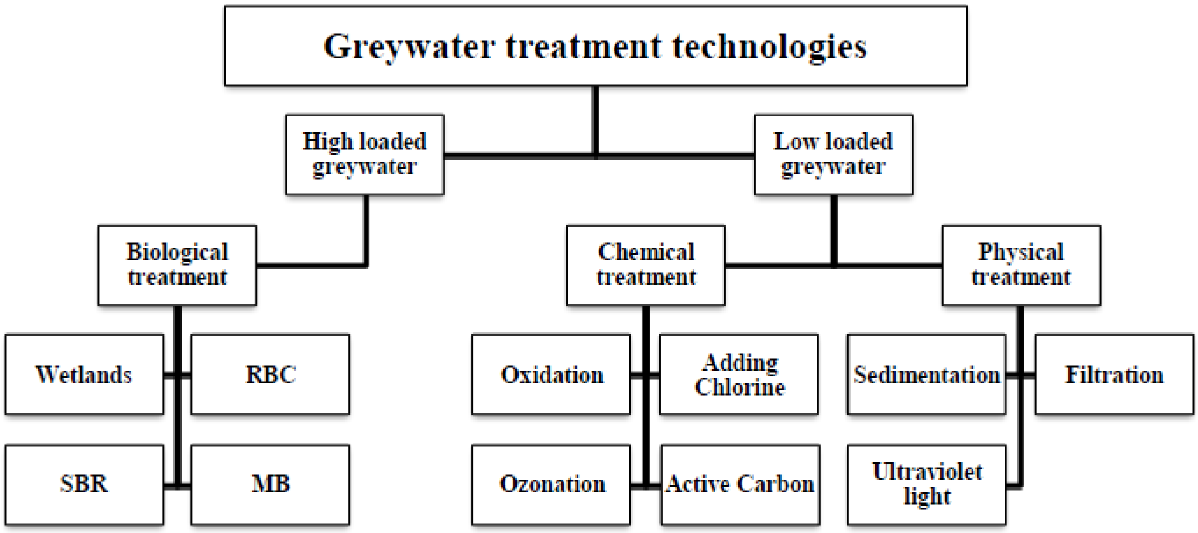


**Fig. (5):** Technologies of Greywater treatment.

### *1.3 Objectives of Study*

Attempt to construct and test a treatment unit used for treatment of greywater, then the treated greywater reused in different purposed that not required high quality characteristics like drinking water, in turn reduce the water demand. The capital and operation cost of this unit should be most economic and its efficiency should sufficient, acceptaple, and match with egyptian cod and standards for wastewater reuse purposes.

### *1.4 Expected Outcomes of the Study*

1- Save quantity of potable water and reduce water consumption.
2- Reduce cost of wastewater treatments by decreasing its quantity.
3- Increase the economic return from Tree forests where increase wood production and increase the production of fiber crops.
4- Combating desertification in Egypt by increasing water for irrigation, where the desert area in Egypt is nearly 95% from total area.

## 2. Materials and methods

### *2.1 Experimental unit*

Filtration is the Physical treatment process that has been chosen for study by the up - down flow method. The treatment unit is constructed from steel and coated by the polymer, and it is attributed to polymer resisting rust and abrasion. It contains four chambers described as follow:

### *I - First Chamber*

The first chamber works as an inlet room and settling chamber, where greywater can lose large amounts of settled solids by sedimentation. The first chamber is connected with the second chamber with 90/90 upward elbows; the elbow is about 5 cm above the floor of the system to avoid settled suspended solid being moved to the second chamber.

***II - Second Chamber***

The second chamber starts with a weir height of 20 cm for separation and reservation of settled solids. The weir is the third wall blocking the passage of suspended solids after the first chamber and elbows. The second chamber works as an extra settling chamber to ensure that settled solids are not passing to filtration media and clog its voids. The flow from the second chamber to the third chamber is up- down flow through the T junction to insure that floated material cannot pass to the following chamber. The second and Third chambers work as grease, oil, and grit trap unit.

***III - Filtration Media***

The third and fourth chambers contain filtration media, are changed for every strategy to find the best treatment results. The flow from the third to the fourth chamber is down-up flow through 3 cm hole at the base of the system. Figures (6) and (7) show the geometric details of the experimental unit.

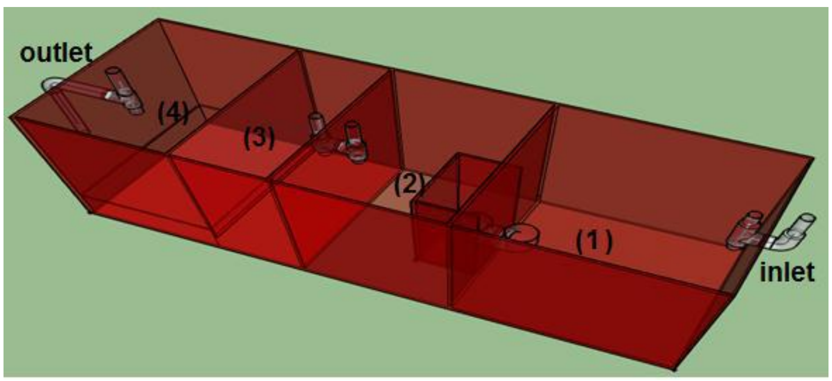


**Fig. (6)**: Isometric Shape of Experimental Unit**.**

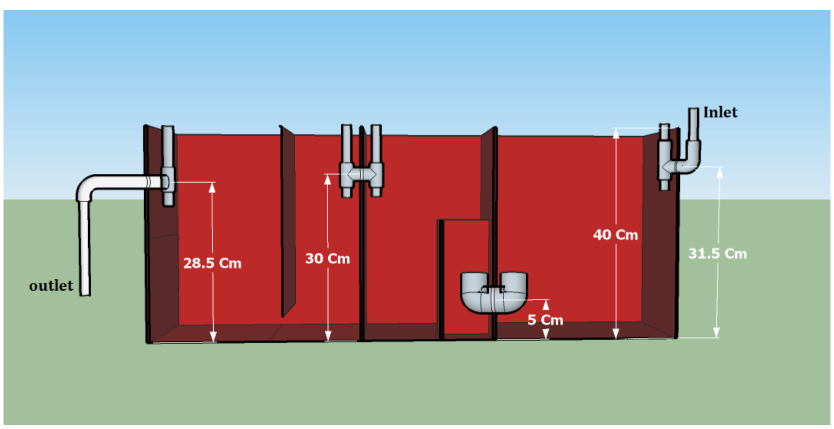


**Fig. (7)**: Elevation of the experimental unit

***2.2 Synthetic Greywater***

The synthetic greywater was created in the Sanitary and Environmental Engineering Lab. Engineering Faculty, Aswan University, Aswan, Egypt. Initial concentrations of the synthetic greywater are shown in table (2).

Table (2): Initial Concentrations of the Synthetic Greywater

| Parameters | pH | TSS mg/l | Turbidity NTU | $NO^3$-N mg/l | P mg/l | COD mg/l |
|---|---|---|---|---|---|---|
| Initial concentrations | 7.5 | 500 | 32 | 5.7 | 0.4 | 324 |

The concentration of nutrients (Nitrogen & Phosphorus) were so low, to match with the properties of natural greywater. The synthetic greywater is pumped to the experimental unit three times per day for 30 minutes each (8:30 – 9:00, 13:30 – 14:00, and 19:30 – 20:00). The feeding time of greywater was selected to simulate the variation of daily water consumption. The synthetic greywater samples were collected from the inlet and outlet of the unit. For physical analysis, total suspended solids (TSS) were measured by gravimetric method, and turbidity by WTW device. And concerned with chemical analysis, the measured parameters were; Nitrate, Phosphate, and COD by HANNA Device, and pH by WTW device.

Different filtration media have been tested. The tested filtration media were: gravel, sand, Apricot Kernels, movable bed reactors, and sponge, separated or combined of part of them.

The experiments were conducted under different boundary conditions, represented by the name of strategy. The main variables in different strategies were the configuration of filter media that have been used, and their thicknesses. Table (3) summarizes the different strategies that have been tested and evaluated.

Table (3): Description of filter media configuration refered by strategy number.

| **Strategies Number** | **3rd chamber** | | **4th chamber** | |
|---|---|---|---|---|
| | *Thickness (cm)* | *filtration media* | *Thickness (cm)* | *filtration media* |
| 1 | 20 | Gravel | 8 | Sand |
| 2 | 20 | Gravel | 10 + 10 | Gravel + Sand |
| 3 | 20 | Gravel | 20 | Sand |
| 4 | 20 | Gravel | 15 | Sand |
| 5 | 20 | MBB* tablets | 15 | Sand |
| 6** | 20 | Gravel | 15 | Sand |
| 7*** | 15 | Sand | 15 | Sand |
| 8 | 20 | Sponge | 20 | Sponge |

** Movable Bed Bio- filter with 2 cm gravel used as cover.*
***The third strategy contains fresh apricot kernels in the second chamber.*
**** Sand layer in 3rd chamber covered by 5 cm sponge.*

The main objective was to find out the best filtration media from removal pollutants efficiency point of view. Using a sponge as filter media was the best. The following figure shows the configuration of the sponge as filter media, and the direction of flow for the greywater.

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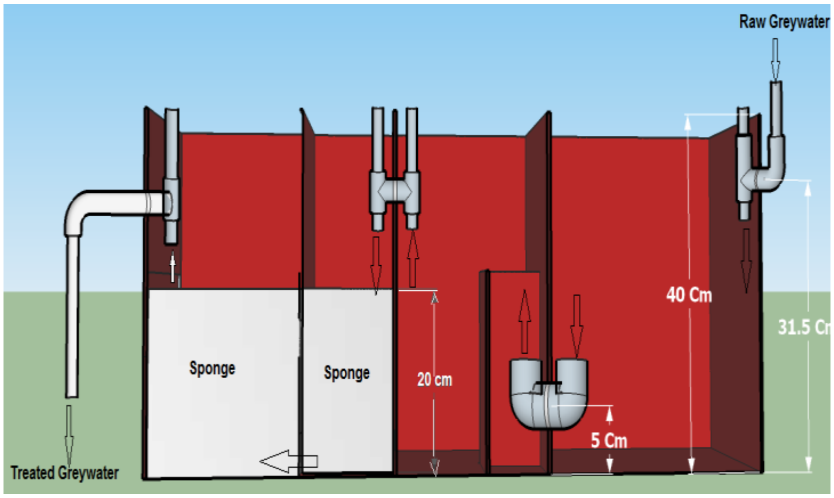


**Fig. (8)**: Configuration of sponge as filter media

## 3. Results and Discussions

From the analysis it was observed that increasing the sponge thickness improves the efficiency of contaminants removal. Similarly occurred when the thickness of sand was increased in another strategy. However, the preference was for a sponge based on its high ability to absorb the foam of soap and gets rid of phosphate; in addition, the cleaning and washing of the sponge is easier than cleaning other filters. By comparing the results of different tested filter media, and according to the fact that sand and sponge have a larger surface area than gravel or MBB tablets, that gives sand and sponge the ability to adsorb micro settling tanks. From the results of the experimental work, it was found the sponge had the best performance. It has exceeded the other strategies in all parameter's removal efficiency.

### *3.1 Removal efficiency*

Percentage of removal of different evaluation parameters has been calculated based on the following equation:

$$\textbf{Persentage of removal} = \left(\frac{Ci - Cf}{Ci}\right) \times 100 \quad (1)$$

Where:
Ci = Initial concentrations of the parameter.
Cf = Final concentrations of the parameter.

The removal efficiencies of evaluated parameters for all tested starategies are shown in the following figure.
Based on the analysis of the results, the sponge strategy so-called 8 th strategy, was the best and more efficient one.

### *3.2 Experimental unit wash time*

The experimental work for the sponge strategy extended to a longer period reach to 42 days. When the strategy performance declines, it is the time that the unit needs washing and cleaning the filtration media. Figure (10) shows TSS concentrations values and removal efficiency in sponge strategy during six weeks of experimental work.

Using the sponge as the filter is almost stable in TSS removal during six weeks. It works by highly efficient in TSS removal. Figure (11) shows Turbidity concentrations values and its removal efficiency in sponge strategy during six weeks of experimental work.

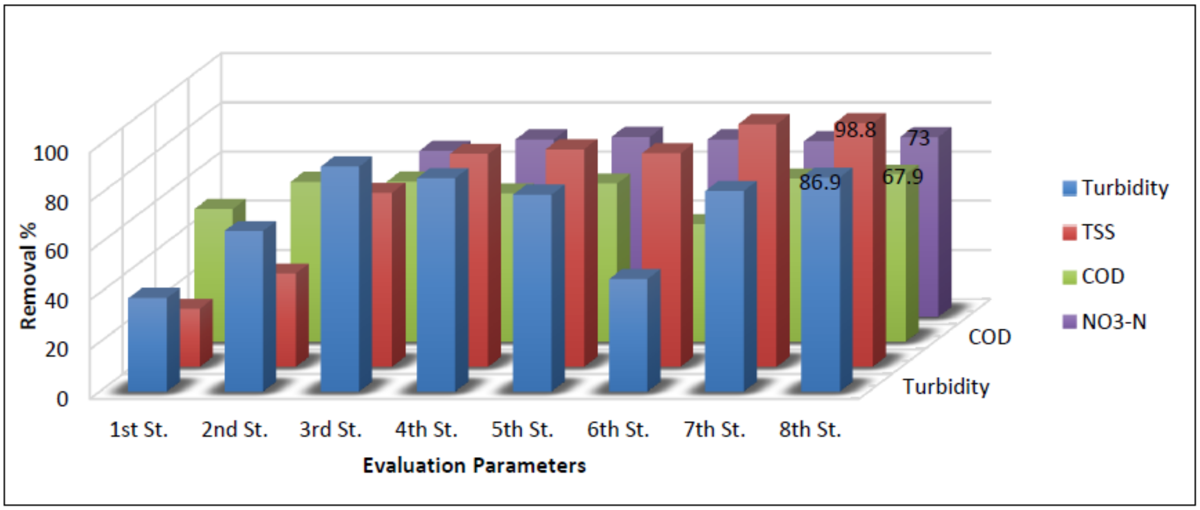


**Fig. (9)**: Removal efficiencies in different tested strategies

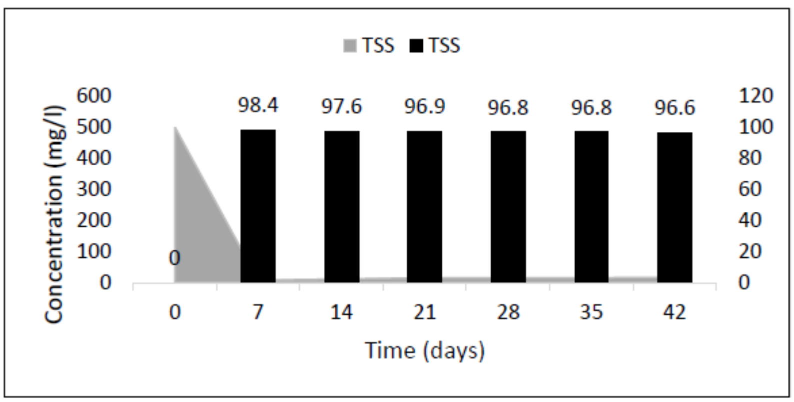


**Fig. (10)**: TSS concentrations and removal efficiency values

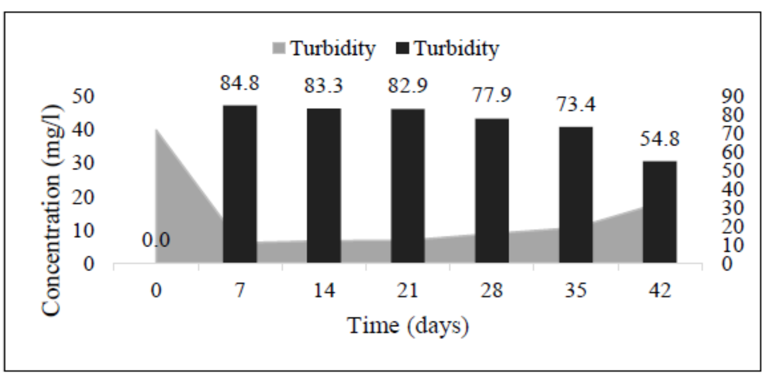


**Fig. (11)**: Turbidity concentrations and removal efficiency values

Turbidity removal efficiency decreased during experimental work. It reached 55% removal efficiency in the sixth week. Figure (12) shows COD concentrations values and removal efficiency in sponge strategy during six weeks of experimental work.

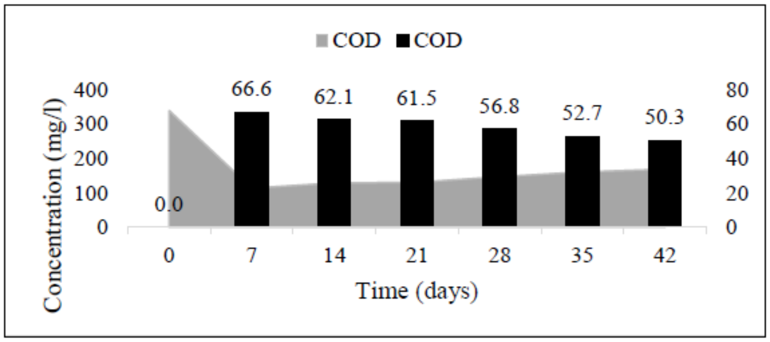


**Fig. (12)**: COD concentrations and removal efficiency values

COD removal efficiency decreased during experimental work. It reached 50% removal efficiency in the sixth week. Figure (13) shows the removal efficiency of main pollutants parameters during 42 days of experimental work.

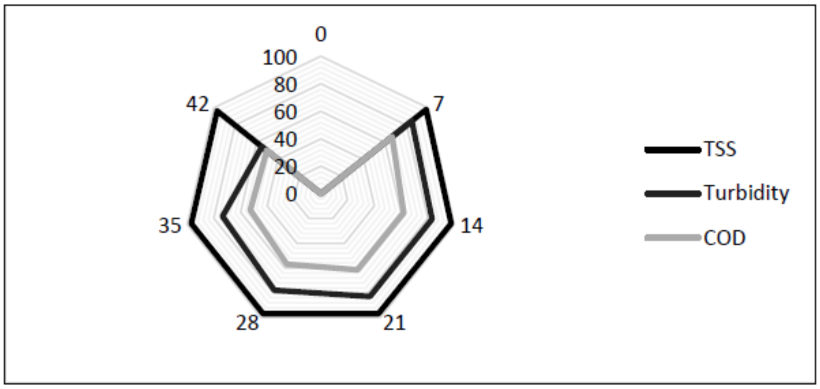


**Fig. (13)**: Removal efficiency for different parameters during 42 days

### *3.3 Egyptian and Different Codes*

Comparison effluent characterizations with Egyptian Code and Specifications and other different codes shown in table (4).

Table (4): Characteristics of effluent wastewater at Egyptian and different codes.

| **Parameter** | **Units** | **EPA** (guidelines) | **WHO (guidelines)** | **EU (guidelines)** | **Egyptian code – Levels [101]** | | | | **Strategy** |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | A | B | C | D | Sponge filter |
| **TSS** | mg/l | 30 | 65-180 | 2-60 | 15 | 30 | 50 | 300 | 8 |
| **Turbidity** | NTU | 10 | NA | 1-15 | 5 | NA | NA | NA | 6 |
| **COD** | mg/l | NA | NA | 60-100 | NA | NA | NA | NA | 113 |
| **BOD5** | mg/l | 25 | 120-240 | 10-70 | 15 | 50 | 80 | 350 | 43 |
| **Nitrate** | mg/l | <0.2 | NA | NA | NA | NA | NA | NA | 2 |
| **pH** | --- | 6-9 | NA | 6.5-9.5 | NA | NA | NA | NA | 7.5 |

A: Unrestricted reuse
B, C, and D: Restricted reuse
NA: Not Available

Comparing the characteristics of effluent applying sponge strategy and Egyptian standards code in field of wastewater reuse, the effluent matches with category B and can be reused in different fields. According to Egyptian standards code, treated wastewater at zone B can be reused in:

- ✓ Toilet flushing.
- ✓ Irrigating the green areas of educational facilities.
- ✓ Irrigating private or public parks.

COD concentration value in the fourth week is not acceptable to reuse in level B according to Egyptian Code. According to the results of experimental work, the sponge needs to clean or wash after four weeks of continuous work. Another solution effluent from the experimental unit after four weeks can be reused in level C according to Egyptian Code.

### *3.4 Case Studies*

3.4.1 Economics of Greywater Recycle & Reuse

Consider a building with 12 flats. Each flat has around 5 persons. The average consumption of freshwater is @ 180 l/ca/day. Hence total freshwater required shall be 12 x 5 x 180 = 10800 l/day. The cost of Municipal water is nearly 3 LE/$m^3$ (It is increasing day by day). Monthly water bill for only one building = 10800/1000 x 30 x 3 = 972 LE/month. Which is 11664 LE/year. The wastewater be produced from one person is around 150 l/day (80 – 90 % of water consumption). Light greywater represents nearly 70 % of wastewater, it is equal to 105 l/ca/day. This quantity of LGW when treated and reused completely, saving water quantity by = (105 x12 x5)/ 1000 x 30 = 189 m3/ month / building. Applying the same calculation for reuse of LGW only in toilet flushing that consumes around 20 % of fresh water, then (20 % x 180/1000) x (12 x 5) x 30 x 3 = 194 LE/month/building can be saved. The reduction in drainage quantity will save this on an ongoing basis, savings in wastewater treatment plant cost (Capital as well as operating cost). These benefits and others can only be gained if the greywater recycling system is installed. The treatment unit follows the physical process that means no need of chemicals, and/or electrical facilities except a submersible pump that is used for pumping the treated greywater to reuse. The total cost of the proposed treatment system contains only the cost of filter media, and the cost of submersible pump, in additional to the construction cost of the filtration tank. This cost for long time compared with gained benefits can be neglected.

3.4.2 Operation and Maintenance

For more durability the following instructions should be followed

- Periodical cleaning of sponge filters
- Sedimentation tanks require de-sludging every month.

## 4. Conclusions.

Based on the experimental work and analysis of its results, the followings have been concluded:

- The removal efficiency of evaluated parameters for sponge filter were; 98.8%, 86.91%, 67.90%, 71.15%, and 86.36% for TSS, Turbidity, COD, Nitrate, and Phosphate respectively.
- The tested treatment unit can be used for the treatment of light greywater.
- The effluent from this unit can be reused at least in toilet flushing, and irrigation of green areas.

- Reused LGW in toilet flushing only can save around 20 % of fresh water and minimize the water bill by the same ratio.

## 5. Recommendation.

A separate plumping system is required to separate greywater from black water in discharge, to achieve the desired benefit of the study. At the end of greywater effluent pipes, it is recommended to build separated an inspection room containing the suggested treatment unit. The treated greywater is re-pumped into the houses in separate lines from the drinking water supply pipes. It enables the residents to reuse it for several purposes such as domestic garden irrigation and firefighting or car washing, as well as pump it into the toilet flushing box.

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