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Rice Straw as a Sustainable Treatment Medium for Grey Wastewater: A Case Study in Damietta, Egypt

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ABSTRACT

The current study aimed to assess the feasibility of using agricultural waste (rice straw), along-with sand and gravel (treatment system A), to treat grey wastewater in comparison to other treatment systems (B, C, and D), which contain diverse treatment media, like sand and gravel only, activated carbon beside sand and gravel, and fired clay along-with sand and gravel, respectively, as wastewater filters. Grey wastewater samples were collected from three selected homes in Damietta Governorate, Egypt, and treated using the four different treatment systems. According to the standard methods of analyses, some physico-chemical characteristics of the grey wastewater, including: temperature, pH, turbidity, TDS, EC, NH_3, O.P, BOD, and COD, were examined before and after the treatment. Moreover, microbiological characteristics such as TBC, TC, and E. coli were also inspected. The results showed that the physico-chemical characteristics of the treated grey wastewater via the applied treatment systems complied with the ESL for effluents discharged to the sewer systems. The outcomes revealed that the cost-effective treatment system (A) was the best in removing some physico-chemical characteristics compared to the other applied systems, especially in removing BOD, TDS, and EC with mean percent removal of 77.54±4.21%, 47.74±17.62%, and 45.84±16.96%, respectively. Simultaneously, this system achieved good elimination of Turbidity, COD, NH_3, and OP with mean removal rates of 86.14±10.49%, 84.76±1.77%, 74.5±16.11%, and 71.77±8.12%, successively. Moreover, it has substantially removed some microbiological characteristics from the grey wastewater without disinfection and attained removal rates of 94.42% and 69.33% for E. coli and TBC, respectively.

Keywords: Activated carbon; Fired clay; Grey Wastewater Treatment; Rice straw; Sand and gravel.

INTRODUCTION

Water is the most important natural resource on earth, also the scarcest. This minimal amount of freshwater is now being used. Because of causes such as fast population expansion, urbanization, and unsustainable water usage in agriculture and industry, water is being used at an alarming rate (Ghalwa *et al.*, 2023). Due to the increasing scarcity of water in many regions of the world, new water sources are being developed; seawater desalination and exploitation of more distant (surface water) and deeper (groundwater) sources. An alternative to improve the efficiency in the use of water, promote water-saving measures and reuse water as an alternative resource (Friedler *et al.*, 2005).

When water is used for various human activities, it becomes polluted or changes its properties and becomes wastewater (Ghosh, 2019). Sewage (domestic wastewater) includes wastewater discharged from residential, commercial, institutional, and public facilities that exist in the area. Subtypes of sewage are grey wastewater (generated from sinks, bathtubs, showers, dishwashers, and washing machines) and black wastewater (generated mainly from toilets) (Von Sperling, 2015). Domestic wastewater treatment is vital in treating wastewater and reusing it for recreational and agricultural activities (Kumar, 2021). Population growth, urbanization, industrialization, and changes in consumption patterns have resulted in increasing global demand for freshwater resources (Sun *et al.*, 2016).
Water reuse is the use of treated wastewater for beneficial purposes, increasing a community's available and reliable water supply during drought. Reusing this water would directly increase the nation's total water supply (Chang *et al.*, 2017). Reusing grey wastewater is one of the best options to ensure a safe environment and promote public health (Amoatey and Bani, 2011). The composition of wastewater is 99.9% water, with the remaining 0.1% removed. Grey wastewater is considered the potential source of point source water reuse, accounting for approximately 50-80% of total water use (Jamrah *et al.*, 2006). The most common applications for wastewater reuse in urban areas are flushing toilets and irrigating green spaces in parks, firefighting, campuses, cemeteries, car washes, floor cleaning, and golf courses (Sushmitha *et al.*, 2019).

Grey wastewater treatments include chemical, physical, and biological techniques such as activated carbon adsorption, sand filtration, and membrane bioreactors. However, because they cannot remove highly concentrated dissolved chemicals and need pretreatment, standard physical methods like sand filtration and disinfection are limited (Chrispim and Nolasco, 2017).

Rice straw is a potential alternative source that can be developed to replace or reduce reliance on fossil fuels. It has been used as animal feed, erosion control material, paper making material, biofuel, biogas, fertilizer, and growth medium in many Asian countries (Rosmiza *et al.*, 2014). The utilization of rice straw has the potential to tackle the problem of rice straw disposal while also reducing pollution caused by open field burning. Straw management can offer economic value to farmers and the local community causing a bigger village economy to grow by generating companies and adding supplemental values to the farm environment (Muliarta, 2019).

Sand filters are a common filtration method that is

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low-cost, easy to use and requires little maintenance. They consist of sand or other media beds that treat grey wastewater by physically filtering pollutants or bio-filtration. These filters do not eliminate the pathogens (Edwin *et al.,* 2014). Fine particles remove ions through adsorption and ion exchange mechanisms, whereas coarse particles aid in removing suspended solids (Crini and Lichtfouse, 2019).

Organic sand filters can remove organic pollutants in the form of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) from laboratory wastewater. Biological sand filter is one of the developments of slow sand filter specially designed for wastewater treatment investigated by Primasari *et al.* (2020). Moreover, the performance of the smaller particle size sand filter is significantly better than the coarse particle size sand filter (Singh *et al.*, 2021). Another method of filtering is activated carbon, which is treated with oxygen to make it porous enough to absorb contaminants from grey wastewater on a microscopic level. However, after all of the pores are filled, the filter must be replaced and it does not eliminate all forms of contaminants (Edwin *et al.*, 2014).

Water filters are still commonly used to improve taste or to eliminate any undesired matters. Various filters have been developed to be more suitable for third-world countries such as pottery jugs (fired clay) that filter microorganisms and other pollutants from water. These filters had ability to reduce turbidity by 90% and bacteria by 60% (Hasballah, 2018). Agricultural waste is generally available in most poor nations, and their full incorporation into existing treatment systems should be investigated. Studies have investigated the treatment of grey wastewater using natural materials such as *Cissus quadrangularis* creeper (Ramaswamy *et al*., 2020) and agricultural waste like rice husks and coconut coir in bio-filtration systems (Samat *et al*., 2021).

The use of treated wastewater for irrigation purposes is common in many countries as it helps to support plant growth and soil health. However, studies have shown that some soils may contain relatively low or high amounts of macro- and micro-elements. Despite this, research has demonstrated that using treated wastewater for irrigation can still lead to positive impacts on the vegetative development characteristics of plants (Seaf Elnasr *et al.,* 2017). Some treatment methods are expensive, such as activated carbon adsorption and reverse osmosis, while others require large areas such as wetlands. Therefore, this study aimed to investigate a simple and economical treatment system such as rice straw with sand and gravel, in comparison with activated carbon, sand, and gravel, and pieces of pottery (fired clay) to treat the grey wastewater in the residential areas, and make it reusable.

MATERIALS AND METHODS

Sampling sites and collection technique

Grey wastewater samples were collected from three homes located in different residential areas of Damietta Governorate, Egypt - Kafr Al-Manazala village, Mit Abu Ghalib City, and New Damietta City - during the period from November 2020 to January 2021.

A total of twelve samples were obtained from the homes under investigation (one sample per home for each of the four treatment systems). Each sample was collected from various sources, including shower tubs, kitchen sinks, and washing machines. The composite samples were prepared by mixing these different sources together. For organic matter analysis as well as COD and BOD testing, high-quality Pyrex glass bottles were used to collect grey wastewater samples. On the other hand, high-density polyethylene bottles were employed for collecting wastewater samples meant for analyzing other parameters. Before collection of actual samples commenced, all capped glass bottles underwent pre-treatment with 0.5 N HCl followed by rinsing with tap water and distilled water respectively before being air-dried and then rinsed thrice with the sample itself. Approximately two liters of wastewater was taken from each source which was later mixed to form about six liters that was homogenized prior to further analyses. Once the samples had been collected, they were kept cool in an ice box to maintain the samples' integrity until transported to the water research laboratory. Approved methods of preservation were followed when required (APHA, 2017).

Methods of Analyses

The collected grey wastewater samples were analyzed for physico-chemical characteristics; in terms of temperature, pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), BOD, COD, orthophosphate (O.P), and ammonia (NH_3) according to Adams (1990), APHA (2017). These analyses were carried out at the Water Laboratory of the Environmental Sciences Department, Faculty of Science, Damietta University. All the used chemicals were of analytical-grade reagents. Microbiological characteristics, including total bacterial count (TBC), total coliform (TC), and *Escherichia coli*, were also carried out in the Joint Laboratory of the Ministry of Health in Damietta City. Some parameters were measured immediately *in situ*, such as the temperature, pH, EC, TDS, and turbidity. The mean values of the analyzed data for the three investigated homes' grey wastewater samples were calculated for the four applied treatment systems before and after treatment.

Grey Wastewater Treatment Systems

The grey wastewater treatment was based mainly on down-flow slow filtration. The filtration was carried out through a column packed with filtration media, and the process was operated under gravity. Four types of packing were applied and investigated, namely treatment systems types (A, B, C, and D). Sand and gravel were the basic filtration media used among other media in the four investigated treatment systems. Whereas rice straw, activated carbon, small pieces of fired clay (SPF Clay), and medium pieces of fired clay (MPF Clay) were the filtration media used in the treatment systems (A, B, C, and D), respectively, as shown in Figure (1) and Table (1) in successive.

Experimental grey wastewater treatment systems Design

The treatment system was set up on a laboratory scale to treat the grey wastewater. The system was principally composed of a settling tank with a capacity of 4 L and a glass column with a height of 68.5 cm, an outer diameter of 6.9 cm and an inner diameter of 6.7 cm, and a perforated disc at the bottom of the column attached with a tap at its end to collect the treated effluent and transfer it to the treated wastewater storage reservoir.

Treatment System Type (A)

Packing materials of the treatment system type (A) are shown in Table (1). Rice straw was obtained from a field in Mit Abu Ghalib, Kafr Saad district, Damietta governorate. A special machine was used to cut the straw into small pieces called "a straw chopper". Then, the rice straw was washed with clean tap water only. The rice straw was dried in the air for three days. The size and height of every layer in the treatment column were described in Table (1) and Figure (1A).

Treatment System Type (B)

Packing materials of the treatment system type (B) are shown in Table (1). The size of the packing materials (sand and gravel) was measured by laboratory shaking sieves. Table (1) and Figure (1B) describe the size and height of every layer. Before packing the column with the small and medium gravel, they were washed three times, first with clean tap water to remove any salts or impurities on the gravel grains, then twice with distilled water and dried in the oven for two hours at 105^{o}C. The gravel was reused throughout the same treatment system.

Treatment System Type (C)

Packing materials of the treatment system type (C) are shown in Table (1). The activated carbon (granular charcoal 10-18 mesh, BDH Chemicals Ltd, Poole, England) was used in the treatment system type (C). Table (1) and Figure (1C) describe the size and height of each layer.

Treatment System Type (D)

Packing materials of the treatment system type (D) are shown in Table (1) and Figure (1D). The pottery pieces (fired clay) used in the treatment system were purchased from El-Gharbia Governorate. The pottery was washed and filled with distilled water for one day, and then the water was removed, dried in an oven, and crushed into small and medium pieces of pottery (SPF Clay and MPF Clay).

Washing procedures and the scheme of replacing the treatment media

After packing the columns with the treatment media and before starting the treatment processes, the packing materials inside the columns were washed twice with distilled water. They were washed first with about 500 ml of distilled water in a fast flow, followed by another 500 ml in a slow flow. At each time using the treatment systems (A, B, C, and D) to treat a new sample, fresh layers of rice straw, fine and coarse sand, activated carbon, and small and medium pieces of fired clay were used in each system successively.

Grey wastewater treatment system

Initially, the collected six liters of grey wastewater samples were equally divided. The first three liters were used for the different analyses before the treatment, while the other amount was kept for the treatment experiment. The settling tank was filled with three liters of raw grey wastewater at the beginning of the treatment process. The wastewater was retained in the tank for about one hour to facilitate the settling of some suspended solids at the bottom of the settling tank. Then, about half a liter of the grey wastewater was drained from tank's tap, above the level of the settled suspended solids. This quantity of grey wastewater was allowed to pass through the packed column in a batch mode as down-flow slow filtration at a flow rate of 6.5 - 6.8 ml/min. After the filtration of the first batch (half a liter of grey wastewater), the other batches of the sample were followed in the same manner until the rest was filtered, and collected for analysis. The experiment was carried out the same way for the treatment systems types (A, B, C and D) shown in Figure (1).

Calculation of Water Quality Index

WQI is useful for comparing differences in water quality across a region or monitoring changes in water quality over time. In the present study, WQI was calculated using the equation developed by Tiwari and Manzoor (1988). The following relation can obtain the quality rating (qi) for the water quality parameter:

$$qi=100Vi/ Si.$$

Where Vi is the observed value of the parameter at a given sampling site, and Si is the stream wastewater quality standard.

This equation confirms that qi = 100 if the observed value equals its standard value. Thus, the larger value of qi revealed polluted water.

To calculate WQI, the quality rating qi corresponding to the parameter, can be determined using as follow:

$$WQI=\Sigma qi$$

Where i=1

However, the average water quality index (AWQI) for n parameters was calculated using the following equation:

$$AWQI=\Sigma qi/n$$

Statistical Analysis

To explore the significance and relationships among all the investigated physico-chemical characteristics of the treated grey wastewater using treatment systems types A, B, C, and D, the Pearson’s correlation coefficient was identified using the IBM SPSS version: 29.

RESULTS AND DISCUSSION

Physico-chemical Characteristics

pH values of the four treatment systems

Table (2) shows that prior to treatment, the mean pH values for grey wastewater samples were 8.97±0.87, 9.48±0.60, 9.52±0.49 and 9.68±0.07 for system A, B, C and D, respectively. Post-treatment results revealed that these values were reduced to 7.8±0.22, 8.58 ± 0.61, 7 .81±0 .08 and 8 .08 ± 0 .26 for each respective treatment system types (A, B, C, D). It was observed that treatment systems (A) and (C) had similar pH values due to the adsorption force between straw particles used as filter in system type (A) and the chemical processes altered by activated carbon functional group in system type (C), respectively (Samayamanthula *et al*., 2019).

The obtained results indicated that all effluent samples from treatment systems A-D fell within the permissible limits set by Egyptian Standard Limits (ESL) for sewer discharge according to Ministerial Decree No. 44/2000 which amends Executive Regulations of Law No. 93/1962 regarding liquid waste discharge (DMH, 2000), these ESL standards specify an acceptable pH range between 6.00 and 9.5.

Turbidity Values of the Four Treatment Systems

The initial mean values of turbidity before treatment were 243±142.63, 306 ± 243.93, 319.66 ±190.65 and 507.33±492.87 NTU, and they were reduced significantly after the treatment to 29.28±26.13, 5.33±4.13, 53.46 ±19.85 and 312.39±400.99 NTU, for treatment systems (A, B, C and D), respectively, as shown in Table (2). The systems achieved removal efficiencies of 86.14%, 96.99%, 80.65%, and 52.86% for treatment systems (A, B, C, and D), respectively. Treatment system (B) was slightly more efficient in removing turbidity than systems (A and C). This is possibly due to mechanisms within the sand filter that reduce suspended, colloidal, and fine dispersions of contaminant that cause turbidity in the sample (Sehar *et al.*, 2011). The slightly lower removal rate of turbidity using systems (A and C) compared to system (B) might result from escaping some very fine particles of rice straw activated from the treatment system to the treated water during the filtration process. Moreover, a better removal efficiency of turbidity was achieved using the treatment system type (A) in comparison with system type (C) although the active carbon used in system type (C) is known for its remarkable ability to adsorb impurities as turbidity from aqueous environments (Malekm-ohammadi *et al.,* 2016).

TDS and EC Values of the Four Treatment Systems

The mean concentrations of detected TDS in the influent grey wastewater were 1158.68±530.63, 1137.67 ±492.19, 787 ±251.3 and 1154 ±27.51 mg/L for the four systems A, B, C, and D, respectively. Meanwhile the mean concentration values of effluent were: 605.67 ±296.78, 879.33 ±335.96, 695 ±235.28, and 957 ±213.75 mg/l, for these same systems sequentially with a percentage removal efficiency of 47.74 ±17.62, 20.86 ±6.98, 12.21 ±6.87, and 17.24 ±17.48%, respectively as shown in Table (2).

The system type (A) that contained rice straw had a higher efficiency for TDS removal, which may be owing to the mixture's high adsorption capacity, porous structure, and the quantity of accessible adsorption sites on the adsorbents' surfaces (Hegazy, 2008). The mean recorded levels of influents' EC were 2427.67±1084.02, 2021.33 ±870.16, 1343.67 ±419.12 and 2173.33 ±94.52 µS/cm, respectively. In contrast, the EC of the effluents were 1320.67 ±635.05, 1624 ±691.94, 1213.67 ±410.37, and 1818 ±350.55 µS/cm, with a percent removal efficiency of 45.84 ±16.96%, 19.38 ±1.86%, 10.35 ±5.20%, and 16.33 ±16.19%, for treatment systems (A, B, C, and D), respectively, as illustrated in Table (2). The obtained TDS removal efficiency closely correlates with these EC results.

NH_3 detected values

In the present research, the mean values of NH_3 before treatment were 1.97±1.18, 0.96±0.31, 0.98 ± 0.32, and 1.97±1.42 mg/l, while the means after treatment were 0.56±0.59, 0.079±0.078, 0.63±0.10 and 0.51±0.54 mg/l, for treatment systems (A, B, C, and D) respectively, as shown in Table (2). According to the current study, treatment systems (A, B, and D) have proven an effective removal of NH_3 from grey wastewater. The order of NH_3 removal using the applied treatment systems was as follows: B (93.12 ± 6.26%) > D (77.60±8.62%) > A (74.5±16.11%) > C (33.25 ± 10.53%). The high NH_3 removal efficiency of grey wastewater is mostly a fundamental benefit of a sand filter, because it can remove not just suspended solids and particles from wastewater but also other chemicals such as micro-pollutants, heavy metals, and nitrogen compounds (NH_3) because of the effect of empty bed contact time in removing NH_3 with a removal percentage reaches to 98.3% (Hasan *et al.*, 2019). The treatment system type (C), which incorporated activated carbon, exhibited the lowest efficiency in removing NH_3. This decrease in removal efficiency was attributed to a decline in ammonia nitrogen absorption per unit mass and a reduction in the adsorption driving force (Ren et al., 2021).

The achieved good reduction of NH_3 concentrations from the investigated grey wastewater using treatment system type (A) might indicate a good adsorption capacity of the rice straw in addition to the sand and gravel media. The results of the current study revealed a high removal efficiency of NH_3 using treatment systems (A, B and D) in comparison with the results indicated by Wardani *et al.* (2021), who demonstrated that the removal rates of NH_3 after utilizing a multi soil layering method by three reactors' relative to treat household wastewater with a percent removal of 49 and 51%.

Orthophosphate detected values

In Table (2), shows the mean concentrations of O.P before treatment, which were measured as 2.5±1.06, 1.26±0.59, 1.19±0.28, and 6.29±7.26 mg/l for systems A, B, C, and D, respectively. After treatment, the mean concentrations of O.P decreased to 0.65±0.17, 0.14± 0.06, 0.471±0.29, and 0.69±0.29 mg/l. The corresponding mean percent removal efficiencies were calculated as71 77 ±8 12, 88 96 ±2 92, 58 9±28 54, and 84.25±8 93% for the respective treatment systems (A, B, C, and D). These results clearly indicate that system B exhibited the highest removal rate among all four investigated treatment systems while system C

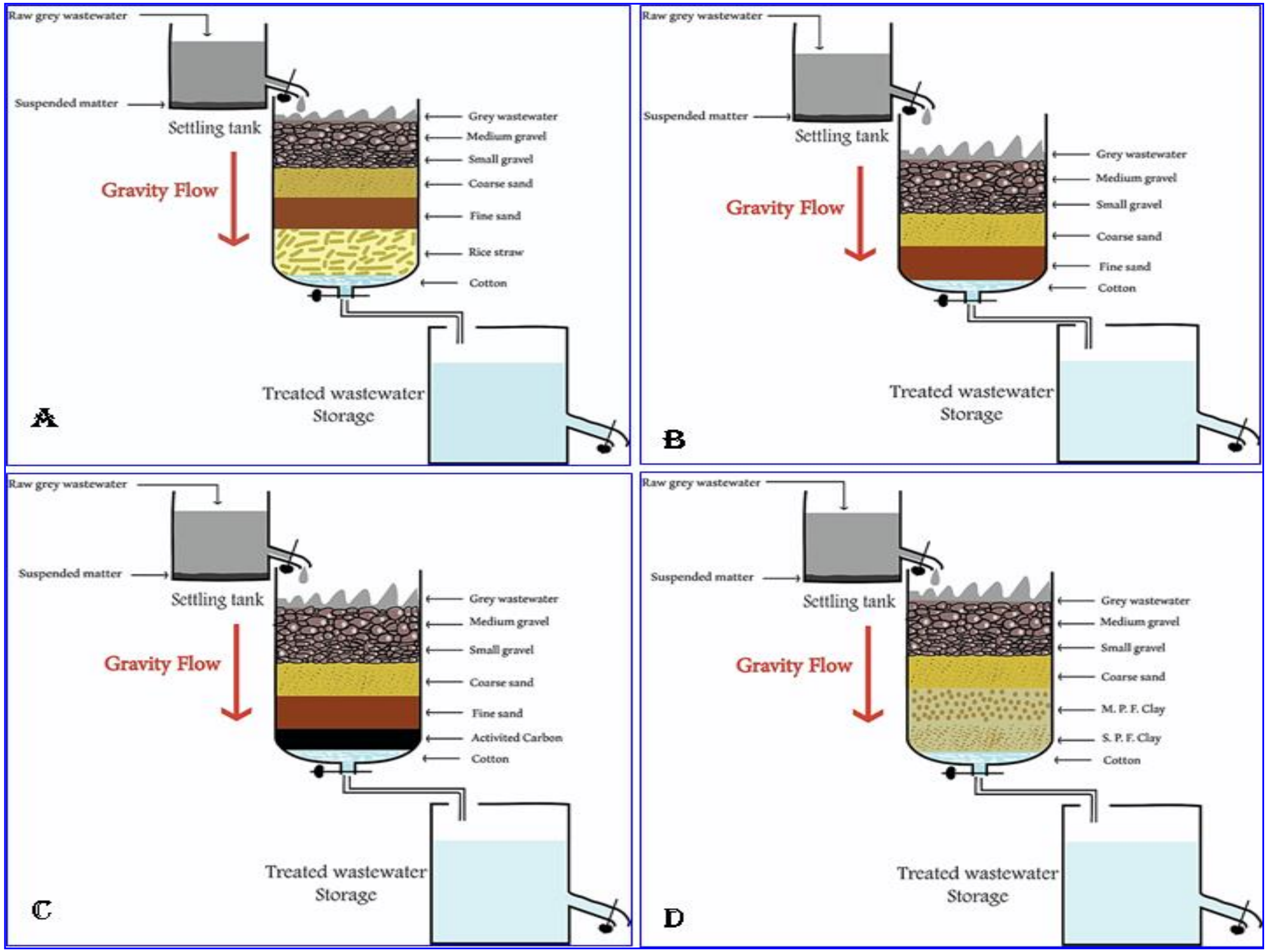

Figure (1): Comparison of different treatment systems for Grey Wastewater: packing materials and layer characteristics. A, is the treatment system type A; in which rice straw material is used; B, is the treatment system type B; C, the treatment system type C in which activated carbon is used and D, is the treatment system type D in which clay materials are used.

Table (1): Characterization of packing materials used in different treatment systems.

Materials used †	Packing materials															
	Size of the packing particles (mm)				**Volume (cm^3)**				**% Volume**				**Layer height**			
	System Type††															
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
Cotton wad	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rice straw	5 - 15	-	-	-	896.97	-	-	-	44.44	-	-	-	25	-	-	-
Activated carbon	-	-	1-2	-	-	-	74.75	-	-	-	6.25	-	-	-	2	-
SPF Clay	-	-	-	1.4 - 2	-	-	-	186.86	-	-	-	14.29	-	-	-	5
MPF Clay	-	-	-	5-10	-	-	-	186.86	-	-	-	14.29	-	-	-	5
Fine sand	0.36 - 0.50	0.36 - 0.50	0.36 - 0.50	-	186.87	186.87	186.87	-	9.26	16.66	15.62	-	5	5	5	-
Coarse sand	0.5 – 1	0.5 – 1	0.5 – 1	0.5 - 1	186.87	186.87	186.87	186.86	9.26	16.66	15.62	14.29	5	5	5	5
Small gravel	2 – 4	2 – 4	2 – 4	2 – 4	373.74	373.74	373.74	373.74	18.52	33.33	31.25	28.57	10	10	10	10
Medium gravel	10 - 15	10 - 15	10 - 15	10 - 15	373.74	373.74	373.74	373.74	18.52	33.33	31.25	28.57	10	10	10	10

† Different packing materials used in each treatment system types; ††, treatment system type used.

demonstrated the lowest efficiency in removing O.P contaminants. The superior removal efficiency observed in system B can be attributed to the effective adsorption of dissolved phosphorus onto sand and gravel particles present within this specific type of treatment media (Bali and Gueddari, 2019).

Organic wastes, are often of agricultural origin, are used as inexpensive sorbents to remove P contamination from water and wastewater. Some of these agricultural wastes mentioned in work by Nobaharan *et al.* (2021) are wheat straw, soybean hulls, and pine cones. Moreover, the dried agricultural waste (rice straw) that is used as a filtering medium might act as a low-cost sorbent to remove P from the grey wastewater. The current results agreed with those of Mohamed *et al.* (2013), who observed that O.P removal ranged from 36 to 99.9% by treating kitchen wastewater by percolation, a bio-treatment system that comprises a gravel-sand pre-treatment layer followed by a layer of natural peat is used. Also, the study results agreed with Wurochekke *et al.* (2016), who treated grey wastewater by employing B. braunii microalgae in another investigation of institutional structures (a men's dormitory), and their obtained removal of O.P was 77.52%, which is consistent with the current study results. Besides, Rodgers *et al.* (2005), who investigated two stratified filter columns containing layers of coarse and fine sand, and pea gravel as they achieved a high removal percent (96%) of O.P from grey wastewater, which is closed to the removal percent achieved by the existing treatment systems (B and D).

BOD detected values

According to the results shown in Table (2), the concentrations of BOD before treatment had mean values of 437.67±164.21, 440.67±75.96, 342.67±31 and 341±81.28 mg/l, while the BOD of the samples after treatments were 98.33 ±43.15, 149.67 ±23.29, 84±44.58, and 201.33±51.08 mg/l, with mean percent removal of 77.54 ±4.21%, 65.69 ±5.84%, 74.05 ±12.27% and 40.45 ±12.43%, for the treatment systems (A, B, C and D), respectively. These results showed the superiority of treatment system (A) in removing BOD from the grey wastewater compared to the other applied treatment systems. Thus, rice straw outperformed activated carbon and others despite being an inexpensive agricultural waste. The substantial removal efficiency of BOD from the grey wastewater using treatment system type (A) might be due to the effectiveness of rice straw, sand, and gravel to filter and adsorb the organic load from the grey wastewater effluent. In addition to providing adsorption sites, rice straws could serve as a site for biofilm formation to digest the organic matter or simply as strainers. Large size rice straw particles were proposed to provide more reactive sites for microbes due to their enormous specific surface area and very porous structure. Accordingly, it enabled biofilm formation, a larger microbe community, and, as a result, higher organic digestion (Lap *et al.*, 2021). The achieved removal efficiencies for BOD using treatment systems (A, B and C) were close to the results obtained by Gross *et al.* (2006), who investigated a percent removal of 60-80%, by physical treatment systems, which usually involved some coarse filtration followed by disinfection of the filtrate for the treatment of grey wastewater. On the other hand, treatment system type (D) was found to be ineffective in removing biodegradable organic matter as indicated by its mean BOD removal rate of 40.45±12.43%. This may be attributed to the number and interconnectedness of pores within the filter matrix (Efeovbokhan *et al.*, 2019). Conversely, results showed that treatment systems A and B were effective in reducing BOD values to comply with Egyptian Code (501/2015) "Class D" standards for treated wastewater reuse in agriculture where maximum allowable BOD_5 is set at 350 mg/l according to ECP (2015). The untreated grey wastewater had initial concentrations ranging from ≈437.67 - ≈440.67 mg/L which exceed Egyptian Code limits but after treatment using systems A and B, these concentrations reduced significantly within acceptable levels of ≈98.33-≈149.67 mg/L according to Egyptian Code (501/2015).

COD detected values

The mean concentration values of COD, as presented in Table (2), prior to treatment were 1540.67 ±225.31, 1627.03 ±506.07, 1759.33 ±384.46 and 2482.13 ±2294.27 mg/L for systems A, B, C and D respectively; while after treatment these values decreased to 234.33 ±41.05, 453.4 ±134.12, 223.6 ±95.59 and 904.03 ±1157·09 mg/L with respective removal efficiencies of 84.76 ±1.77%, 71.39 ±8.82%, 87·47 ±3·89% and 69.76 ±13·17%. The obtained outcomes suggest that although initial COD concentrations exceeded ESL (COD_{max}=1100 mg/l) (DMH, 2000), the four applied treatment systems (A, B, C, D) successfully reduced COD levels that meet the terms with ESL standards. Results from this study showed that system types (A) and (C) had similar performance as observed by Fountoulakis *et al*., (2016), who studied the effectiveness of small SMBR system on actual grey wastewater from a single home in Crete, Greece where approximately 87% COD was removed.

The high removal efficiency of the treatment system (A) in the current study could be due to the effectiveness of rice straw, which has a complex polymer crystal structure that is formed by the physical and chemical bonds among the cellulose, hemicellulose, and lignin components (Gummert *et al.*, 2020). The attained results of COD removal using rice straw (treatment system type A) showed a nearly similar removal efficiency of COD (84.76%) compared to activated carbon (87.47%) in treatment system type (C). However, rice straw is a highly available, unlike activated carbon, which is expensive and less abundant.

Microbiological Characteristics

TBC, TC, and *E. coli* recorded count revealed that TBC value in the grey wastewater sample before treatment was 225×10^3 CFU/ml, while 69×10^3 CFU/ml after treatment with a percent removal efficiency of 69.33%. Meanwhile, the TC value in the wastewater sample before treatment was 18×10^3 MPN/100 ml, and it was the same after treatment without any removal. However, the value of *E. coli* before treatment was 43×10^3 MPN/100 ml, while the value after treatment was 2.4×10^3 MPN/100 ml, with a percent removal of 94.42%. The current results revealed a superior removal of *E. coli* reached 94.42%, and good removal of TBC touched 69.33% without adding chlorine or any other disinfectant. This is because rice straw might make a natural filter for these kinds of bacteria.

In contrast, many studies used chorine or UV lamp as a source of disinfection to remove the bactrial species from water as reported by Ibraheem *et al.* (2020). Contrarily, the results of TC revealed no removal after the treatment by this treatment system type (A). As a result, except for the TC, which requires a disinfectant, it is possible to achieve reasonable removal rates in *E. coli* and TBC using the treatment system type (A) containing rice straw, reducing the cost of grey wastewater treatment.

Calculation of Water Quality Index

The WQI and AWQI in Table (3), were calculated based on DMH (2000). The results showed that AWQI values of grey wastewater samples in treatment system (A) (Before and after treatment) were 108.37 and 45.04. The concentrations of examined physico-chemical parameters of grey wastewater for the samples before and after treatment were within the standard limits, except the COD measurement, which was 1540.67mg/l for samples before treatment, while WQI and AWQI values in treatment system type (B) were 113.28, and 57.8, respectively, and in the treatment system (C) the concentrations of examined physicochemical parameters of grey wastewater for before and after treatment were within the standard limits, except the pH, and COD measurements for the samples before treatment that were 9.52 and 1759.33 mg/l, respectively. The results showed that the WQI and AWQI values of grey wastewater samples in treatment system (C): (Before and after) were 112.02 and 43.98, respectively. Moreover, in the treatment system type (D), the concentrations of the examined physicochemical parameters of grey wastewater before and after treatment were within the standard limits, except the pH and COD measurements for the samples before, which were 9.68 and 2482.13 mg/l, with the WQI and AWQI values of 134.49, and 72.24, respectively. The wastewater is categorized into one of five categories: excellent quality water (50), good (50-100), poor (100-200), very poor (200-300), and unsuitable sampled water (> 300) (Tiwari and Manzoor, 1988). The AWQI of the treated grey wastewater samples in treatment systems (A, B, C, and D) are classified as having excellent, good, excellent, and good wastewater quality, respectively.

Moreover, treatment system type (A) improved its ability in the reduction of BOD and COD concentrations, as the treated wastewater had a higher quality than the untreated grey wastewater, which may be attributed to the composition of the treatment system and its content of rice straw, which achieved high efficiency and competed with activated carbon.

Correlation Significance

The correlation matrix between the investigated physico-chemical characteristics of the treated grey wastewater using treatment systems A, B, C, and D (Table 4) revealed that pH correlated medially with TDS and EC. Simultaneously, TDS showed a highly positive liner correlation with EC. At the same time, turbidity was highly correlated with COD and medially correlated with BOD. There was also a significant medium correlation between COD and BOD.

CONCLUSION

The current investigation involved the treatment of grey wastewater from residential areas using four distinct lab-scale treatment systems. The applied systems, namely A, B, C, and D, were constructed utilizing different treatment media. System type A consisted of rice straw in combination with sand and gravel, system type B utilized sand and gravel alone, system type C incorporated activated carbon alongside sand and gravel, while system type D employed fired clay along with sand and gravel. Both the untreated raw grey wastewater samples and the treated effluents underwent thorough analysis before recording the results. All the applied treatment systems have achieved apparent reduction in the values of the investigated physico-chemical characteristics of the grey wastewater and attained compatibility with the Egyptian Standards Limits for effluents discharged to the sewer system. The results revealed a variation between the applied systems in the removal rates of the investigated physico-chemical characteristics of the grey wastewater. The treatment system type (A), which contains the cost-less agricultural waste (rice straw), has proven a superior removal rate among the other applied systems for reducing BOD, in addition to the TDS and EC from the grey wastewater. Moreover, the rice straw's treatment system has also achieved a respectable removal efficiency of Turbidity, COD, NH_3, and O.P. Besides, this system accomplished an excellent removal of E. coli and good removal of TBC from the grey wastewater without disinfection. The treated grey waste-water produced from the system of rice straw could be reused for some agricultural purposes like the irrigation of non-fruitful trees, according to the Egyptian Code No. 501/2015 for the use of treated wastewater in agriculture-class D. This is in addition to other possible applications such as street cleaning and car washing. However, further investigation is recommended to evaluate the continued effectiveness of rice straw in treating grey wastewater over consecutive days.

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Table (2): Physiochemical analyses of the grey wastewater before and after treatment using different treatment system types A, B, C, and D.

Measured Parameter	**Treatment System type**				
	Time of Observation	**A**	**B**	**C**	**D**
pH	**Before**	8.97 ±0.87	9.48 ± 0.60	9.52 ± 0.49	9.68±0.07
	After	7.80 ±0.22	8.58 ± 0.61	7.81± 0.08	8.08±0.26
Turbidity (NTU)	**Before**	243.00 ±142.63	306 ± 243.93	319.66 ±190.65	507.33 ±492.87
	After	29.28 ±26.13	5.33 ± 4.13	53.46 ±19.85	312.39±400.99
	Removal %	86.14±10.49	96.99 ± 3.81	80.65 ± 9.89	52.86±22.29
TDS(mg/l)	**Before**	1158.68±530.63	1137.67± 492.19	787 ± 251.3	1154.00 ±27.51
	After	605.67±296.78	879.33± 335.96	695.00 ± 235.28	957.00±213.75
	Removal %	47.74 ±17.62	20.86 ± 6.98	12.21 ± 6.87	17.24±17.48
EC (µS/cm)	**Before**	2427.67 ±1084.02	2021.33 ±870.16	1343.67 ± 419.12	2173.33±94.52
	After	1320.67 ±635.05	1624 ±691.94	1213.67 ± 410.37	1818±350.55
	Removal %	45.84 ±16.96	19.38 ±1.86	10.35 ± 5.20	16.33±16.19
NH$_3$ (mg/l)	**Before**	1.97 ±1.18	0.96±0.31	0.98 ± 0.32	1.97±1.42
	After	0.56±0.59	0.079±0.078	0.63 ± 0.10	0.51±0.54
	Removal %	74.5±16.11	93.12 ± 6.26	33.25 ± 10.53	77.60±8.62
O.P (mg/l)	**Before**	2.5±1.06	1.26 ± 0.59	1.19 ± 0.28	6.29±7.26
	After	0.65±0.17	0.14 ± 0.06	0.471±0.29	0.69±0.29
	Removal %	71.77±8.12	88.96 ± 2.92	58.9 ± 28.54	84.25±8.93
BOD (mg/l)	**Before**	437.67±164.21	440.67 ± 75.96	342.67 ± 31	341±81.28
	After	98.33± 43.15	149.67 ±23.29	84 ± 44.58	201.33±51.08
	Removal %	77.54 ±4.21	65.69 ± 5.84	74.05 ± 12.27	40.45±12.43
COD (mg/l)	**Before**	1540.67±225.31	1627.03 ±506.07	1759.33 ± 384.46	2482.13±2294.27
	After	234.33±41.05	453.4 ± 134.12	223.6 ± 95.59	904.03±1157.09
	Removal %	84.76±1.77	71.39 ± 8.82	87.47 ± 3.89	69.76±13.17

Table (3): Calculated quality rating (qi) for the water quality parameter, qi=100(Vi/Si), water quality index (WQI) and average water quality index (AWQI) of the investigated wastewater value as a comparison of grey wastewater before and after treatment using various systems. Data are represented in mean.

Measured parameter †		**Egyptian Standard**	**qi=100(Vi/Si)**			
			System Type			
			A	**B**	**C**	**D**
pH	Before	6.5-9.5	112.12	118.50	119.00	121.00
	After		97.50	107.25	97.62	101.00
BOD	Before	600	72.94	73.44	57.11	56.83
	After		16.33	24.94	14.00	33.55
COD	Before	1100	140.06	147.91	159.94	225.65
	After		21.30	41.22	20.33	82.18
WQI=∑qi i=1	Before	-	325.12	339.85	336.05	403.48
	After		135.13	173.41	131.95	216.73
AWQI=∑qi/n	Before	-	108.37	113.28	112.02	134.49
	After		45.04	57.80	43.98	72.24

Table (4): Correlation matrix of treated grey wastewater characteristics.

Indexed parameter	**Measured parameters**							
	pH	**TDS**	**EC**	**Turbidity**	**NH_3**	**O.P**	**BOD**	**COD**
	Correlation coefficient (r)							
pH	1							
TDS	0.610*	1						
EC	0.593*	0.970**	1					
Turbidity	0.101	0.279	0.309	1				
NH_3	-0.196	0.14	0.211	0.536	1			
O.P	-0.482	0.039	0.083	0.511	0.415	1		
BOD	0.377	0.366	0.335	0.593*	-0.152	0.219	1	
COD	0.274	0.328	0.36	0.952**	0.451	0.348	0.617*	1

*, moderate positive correlation between parameters; **, high positive correlated parameters.

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قش الأرز كوسيلة معالجة مستدامة لمياه الصرف الصحي الرمادية: دراسة حالة في دمياط، مصر

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الملخص العربـــــي

هدفت هذه الدراسة إلى تقييم جدوى استخدام المخلفات الزراعية (قش الأرز) جنبًا إلى جنب مع الرمل والحصى (نظام معالجة نوع أ) لمعالجة مياه الصرف الصحي الرمادية مقارنة بأنظمة المعالجة الأخرى (أنواع ب ، ج ، د) والتي تحتوي على أنواع مختلفة من وسائط المعالجة ، مثل الرمل والحصى فقط ، والكربون المنشط مع الرمل والحصى، والطين المحروق مع الرمل والحصى، كمرشحات لمياه الصرف الصحي. وقد تم جمع عينات مياه الصرف الصحي الرمادية من ثلاثة منازل مختارة في محافظة دمياط، مصر، ومعالجتها باستخدام أربعة أنظمة معالجة مختلفة. ووفقاً للطرق القياسية للتحاليل، فقد تم فحص بعض الخصائص الفيزيائية والكيميائية لمياه الصرف الصحي الرمادية بما في ذلك: درجة الحرارة والأس الهيدروجيني للمياه والعكارة والأملاح الكلية الذائبة والتوصيل الكهربي والأمونيا والأورثوفوسفات والأوكسجين الحيوي المطلوب والأوكسجين الكيميائي المطلوب وذلك قبل وبعد المعالجة. علاوة على ذلك، تم فحص بعض الخصائص الميكروبيولوجية مثل: العد الكلي البكتيري والبكتريا القولونية الكلية وبكتريا الإشريكية القولونية. حيث أظهرت النتائج أن الخصائص الفيزيائية والكيميائية لمياه الصرف الصحي الرمادية المعالجة من خلال أنظمة المعالجة الأربعة توافقت مع الحدود المصري المسموح بها للمخلفات السائلة التي يتم تصريفها على أنظمة الصرف الصحي. كما أظهرت النتائج أن نظام المعالجة من النوع (أ) فعال من حيث التكلفة وكان الأفضل في إزالة بعض الخصائص الفيزيائية والكيميائية مقارنة بالأنظمة المطبقة الأخرى، خاصة في إزالة الأكسجين الحيوي المطلوب والأملاح الكلية الذائبة والتوصيل الكهربي بمتوسط نسب إزالة 77.54 ± 4.21٪ و47.74 ± 17.62٪ و 45.84 ± 16.96٪ على التوالي. وفي نفس الوقت، حقق هذا النظام ازالة جيدة للعكارة والأكسجين الكيميائي المطلوب والأمونيا والأورثوفوسفات بمتوسط معدلات إزالة 86.14 ± 10.49٪ و 84.76 ± 1.77٪ و 74.5 ± 16.11٪ و 71.77 ± 8.12٪ على التوالي. علاوة على ذلك، فقد أزال بعض الخصائص الميكروبيولوجية من مياه الصرف الصحي الرمادية دون اضافة أي مطهر حيث حقق معدلات إزالة 94.42٪ و 69.33٪ للبكتريا الإشريكية القولونية والعد الكلي البكتيري على التوالي.