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Research Article

Experimental study based on the usage of polymers for greywater treatment

Hoda Kamal Soussa[1], Mostafa E.Y. Ahmed[2], Moawad M. Taha[1], Mohammed N. Ali[3*]

[1] Department of Hydraulics and Irrigation, Faculty of Engineering, Ain Shams University, Egypt
[2] Department of Civil Engineering, Pyramids Higher Institute for Engineering and Technology, Egypt
[3] Department of Environmental and Sanitary Engineering, Faculty of Engineering, Beni-Suef University, Egypt.

[*]corresponding author: dr.mohamednabil8080@gmail.com

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Abstract

Water scarcity presents a pressing challenge in Egypt, exacerbated by factors such as population growth, urbanization, and climate change impacts. With over 95% reliance on the Nile River for freshwater supply, Egypt's water resources are strained, particularly with a population exceeding 100 million. Egypt's arid climate intensifies water scarcity, necessitating sustainable management strategies. This study explored greywater treatment as a solution to alleviate water scarcity in Egypt, investigating its technical feasibility, economic viability, and environmental benefits. Greywater, derived from domestic activities, is an underutilized resource that can be reclaimed and treated for reuse, reducing demand for freshwater sources. Through greywater treatment systems, households and communities can recycle water, conserve resources, and mitigate pollution. The study investigated using polymers as a coagulant in greywater treatment, examining its efficacy in removing contaminants and improving water quality. Experimental trials were conducted to evaluate the performance of polymer addition in greywater treatment compared to conventional methods. Results demonstrate that polymer addition reduces turbidity, suspended solids, and organic pollutants in greywater. Poly aluminum chloride (PAC) polymer, in particular, exhibits strong coagulation capabilities, versatility across pH ranges, and high efficiency in contaminant removal. Additionally, PAC offers operational advantages such as low dosage requirements and reduced sludge production.

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Introduction

Water scarcity poses a significant and escalating challenge in Egypt, driven by a combination of factors, including rapid population growth, urbanization, and climate change impacts (El-Sadek, 2009). The country's water resources are inherently limited, primarily reliant on the Nile River, which accounts for over 95% of Egypt's freshwater supply (Mohamed, 2007). With a burgeoning population exceeding 100 million and increasing industrial and agricultural demands, Egypt's water resources are under immense strain (Abd Ellah, 2020).

The Nile River, while vital, faces challenges such as pollution, sedimentation, and upstream developments that impact downstream flow patterns and water quality (Abdelhafez et al., 2020). Furthermore, groundwater reserves, which serve as a crucial supplement to surface water supplies, are being depleted at unsustainable rates due to over-extraction and inefficient irrigation practices (Abdel-Shafy et al., 2002; Abd Ellah, 2020; El-Rawy et al., 2020). Egypt's limited rainfall and arid climate exacerbate water scarcity issues, making efficient water management practices imperative for the country's sustainability and development (El-Rawy et al., 2020).

As Egypt grapples with these water scarcity challenges, innovative solutions and sustainable management strategies are essential to ensure water security for present and future generations. This paper aimed to explore one such solution - the treatment of greywater - as a means to alleviate water scarcity in Egypt.

One promising approach to address water scarcity is through the treatment of greywater. Greywater, originating from domestic activities such as bathing, laundry, and dishwashing, represents a significant yet underutilized resource (Chrispim and Nolasco, 2017; Vuppaladadiyam et al., 2018) Traditionally considered wastewater, greywater can be reclaimed and treated for reuse, reducing the burden on freshwater sources and augmenting water availability (Albalawneh, 2016).

Greywater treatment offers a sustainable means to alleviate water scarcity in Egypt. By implementing greywater treatment systems, households and communities can recycle and reuse water that would otherwise be wasted, thereby reducing the demand for freshwater supplies (Abdel-Shafy et al., 2009). This not only conserves precious water resources but also mitigates pollution and eases pressure on existing water infrastructure.

In the context of Egypt's water scarcity challenges, exploring the potential of greywater treatment as a sustainable solution is crucial. This paper aimed to delve into the technical feasibility, economic viability, and environmental benefits of greywater treatment, offering insights into its role in mitigating water scarcity and enhancing water security in Egypt (Chen et al., 2024). Greywater treatment presents a promising avenue for mitigating water scarcity, particularly in regions facing increasing water stress, like Egypt. Among the myriad of treatment methods, the utilization of polymers has emerged as a viable and efficient solution for improving the quality of greywater. This approach involves using various polymer-based materials to facilitate the removal of contaminants and pollutants from greywater, thereby enhancing its suitability for reuse in non-potable applications (Mahmoud, 2019).

Polymers offer several advantages for greywater treatment. Firstly, they exhibit high efficiency in capturing and removing suspended solids, organic matter, and other impurities present in greywater (Bolto and Xie, 2019). This is achieved through coagulation, flocculation, and sedimentation, where polymers act as coagulants or flocculants to aggregate and facilitate the settling of suspended particles (Bolto et al., 1998). Moreover, polymers can aid in the removal of pathogens and bacteria through disinfection processes. Certain polymer-based materials possess antimicrobial properties or can be combined with disinfectants to effectively eliminate harmful microorganisms present in greywater (Ali et al., 2021). This is crucial for ensuring the safety and suitability of treated greywater for reuse in irrigation, toilet flushing, or other non-potable applications. Additionally, the use of polymers in greywater treatment can enhance the overall efficiency and performance of treatment systems. By optimizing the coagulation and flocculation processes, polymers help to improve the clarity and quality of treated greywater, resulting in water that meets or exceeds regulatory standards for reuse (Bharti et al., 2016).

Furthermore, polymer-based treatment methods offer versatility and adaptability to different greywater compositions and treatment requirements. Various types of polymers can be tailored to target specific contaminants or adjust treatment parameters based on the characteristics of the greywater source (Wang et al., 2020). This flexibility makes polymer-based treatment systems suitable for diverse applications, including households, commercial buildings, and decentralized wastewater treatment facilities.

In this experimental research, the main objective of this study was to examine the performance of polymers such as Poly Aluminum Chloride (PAC) polymer for greywater treatment and compare its performance with conventional treatment methods such as activated sludge technology.

Materials and Methods

Raw greywater sample collection

Four plastic containers, each capable of holding 25 liters, were utilized to collect raw greywater samples. Before filling the plastic containers, sterilization was conducted to maintain sample integrity. The samples were acidified to preserve relevant levels before being transported to the experimental site, where a small-scale model was set up. This sample was analyzed at the National Research Center in Cairo, and the greywater characteristics are listed in Table 1.

Table 1. Greywater characteristics.

Parameters	**Units**	**Sample raw water**
pH	--	7.39
Turbidity	NTU	466.3
Total suspended solids	mg/L	421.4
Chemical oxygen demand	mgO_2/L	1997
Biochemical oxygen demand	mgO_2/L	782
Total Kjeldahl nitrogen	mg/L	43.68
Ammonia	mg/L	0.56

Experimental setup

Two experimental trials were performed in this laboratory study (Table 2) to investigate the performance of using polymers as coagulation in the process of greywater treatment. This first experimental run was the control one where no additives were added to the greywater, and the greywater treatment was performed based only on the aeration process to oxidize any organic matter found in the greywater. In the first trial, as shown in Figure 1, raw greywater was added to a sedimentation tank with standard dimensions of (50×30×30 cm) and settled for 3 hours to settle any suspended organic or inorganic matter found in greywater, then greywater was passed under gravity to an aeration tank with the same dimensions of the sedimentation tank equipped with air blowers to provide water with the required dissolved oxygen required for the biodegradation of organic matter. The aeration process extended into 12 hours. After the biodegradation of organic matter, the greywater was fed into a final settling tank where all the inorganic substances produced from the aeration process settled in this stage under gravity, and this treatment stage was extended to 2 hours. A chlorine dose of 5 mg/L was added to the greywater to get rid of the microorganisms found in the greywater.

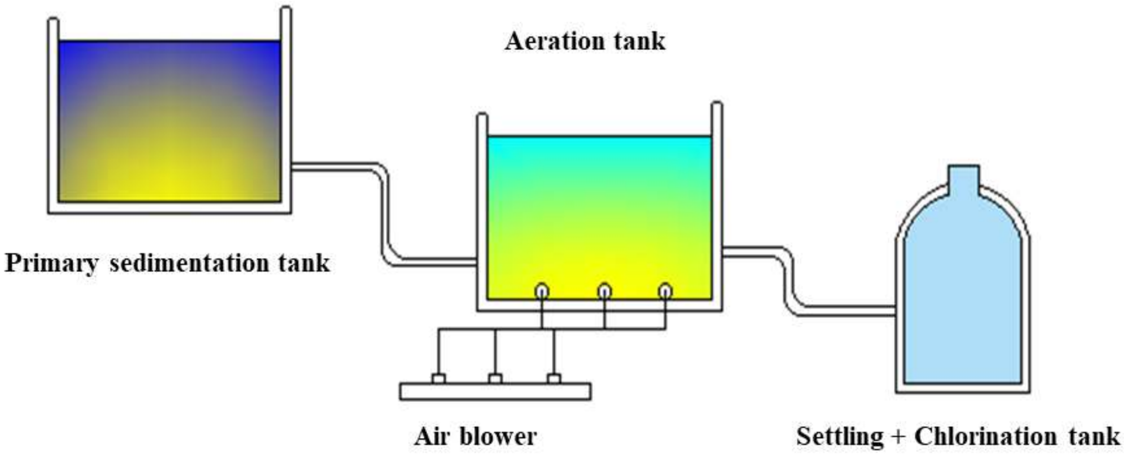

Figure 1. The first experimental trial (control trial).

As illustrated in Figure 2, The second trial was different from the first trial. In this experimental run, Poly-aluminum chloride polymer was used as a coagulant. This type of polymer is characterized by fine powder, uniform particles, easy dissolution in water, good flocculation effect, high efficiency and stability of purification, low dosage, and low cost. Raw grey water was added to the primary sedimentation tank and settled for 3 hours to minimize the total suspended solids concentrations (TSS) besides the participated portion of organic substances. Water was fed into a coagulation tank where aluminum chloride polymer with a dose of 0.4 g/L was added and mixed at 50 rpm to get enough time for the coagulant to react with the colloids found in greywater. Greywater passed into the aeration tank for 12 hours and then passed into a final settling tank for 2 hours, where chloride with a dose of 0.5 g/L was added.

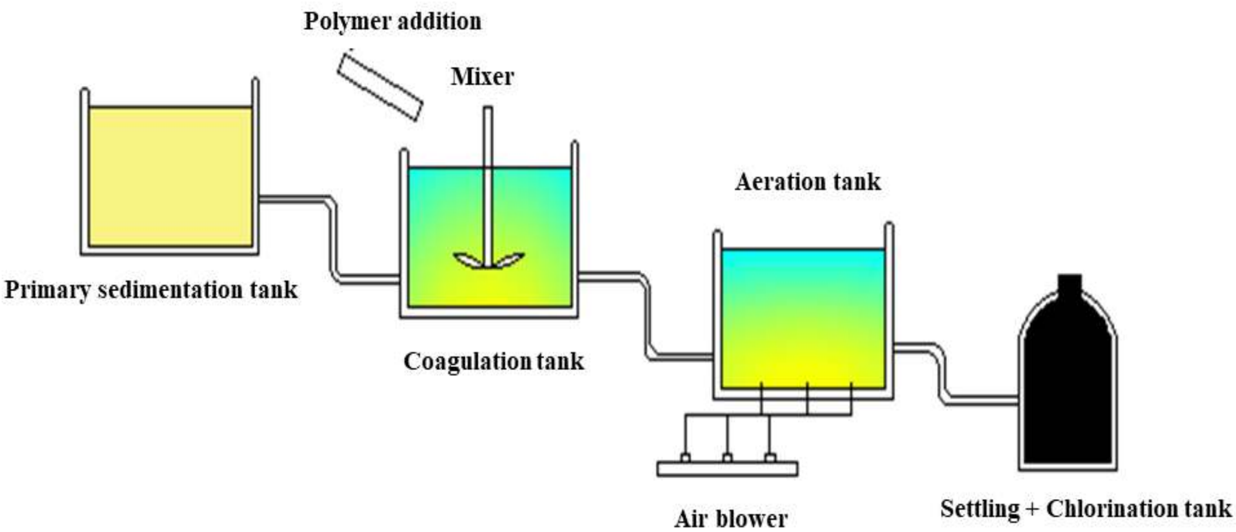

Figure 2. Second experimental trial (polymer addition).

Table 2. The laboratory pilot.

Treatment tanks	Parameters	Values
Primary sedimentation tank	Length	0.5 m
	Width	0.3 m
	Depth	0.3 m
	Tank volume	0.045 m^3
	Wet depth (water depth)	0.25 m
	Water volume	0.0375 m^3
	Hydraulic retention time	3 h
Aeration tank	Length	0.5 m
	Width	0.3 m
	Depth	0.3 m
	Tank volume	0.045 m^3
	Wet depth (water depth)	0.25 m
	Water volume	0.0375 m^3
	Hydraulic retention time	12 hours
Air blower	Air flow rate	400 L/h
Coagulation Tank	Length	0.5 m
	Width	0.3 m
	Depth	0.3 m
	Hydraulic retention time	0.5 hr.
Final Settling and Chlorination tank	Plastic bottle	Chlorine dose of 5 g/L Settling time is 2 hours

Analytical methods

Grab samples were collected after each step of treatment to determine the characteristics of the influent and effluent of each tank. Temperature (T °C) was measured every day before collecting wastewater samples. BOD, COD, TKN, TP, and heavy metals contents were performed according to standard methods for the examination of water and wastewater.

Results and Discussion

Performance of the addition of polymer on greywater characteristics

Tables 3 and 4 illustrate the physiochemical characteristics of raw greywater during the treatment process for the two experimental steps. From Table 3, it was clear that the aeration process without any polymer addition was within the range of the performance stated in the other studies. The COD, BOD, TN, and ammonia of the raw greywater were 1997 mg/L, 782 mg/L, 43.68 mg/L, and 0.56 mg/L. After passing to the primary sedimentation tank, the greywater characteristics have been improved as an action of settling process and reduced to 1972 mg/L, 771 mg/L, 40.32 mg/L, and 0.56 mg/L, respectively. While greywater exited from the aeration tank, the concentrations reached 183.6 mg/L, 1744 mg/L, 688 mg/L, and 35.48 mg/L, and finally, the effluent characteristics from settling and chlorination were 182 mg/L, 64 mg/L, 856 mg/L, and 312 mg/L.

The typical aeration process of greywater is known to accomplish four specific goals: primarily to decrease BOD_5, COD, and suspended solids within the greywater system while also successfully eliminating pathogens and nutrients. The scenario where aeration is performed without any polymer addition to the water has been widely researched and tested, and the efficiency level of the method can be high or low, depending on the circumstances. Jefferson et al. (2000) presented research that critically focused on comparing the efficiency of various aeration systems in treating greywater.

Table 3. Greywater characteristics (first experimental trial).

Parameters	Units	Sample raw water	After Sedimentation Tank (12 hours)	Aeration Tank (12 hours)	Settling + Chlorination
pH	--	7.39	7.29	7.05	7
Turbidity	NTU	466.3	425	323	182
Total suspended solids	mg/L	421.4	336.1	183.6	64
Chemical oxygen demand	mgO_2/L	1997	1972	1744	856
Biochemical oxygen demand	mgO_2/L	782	771	688	312
Total Kjeldahl nitrogen	mg/L	43.68	40.32	35.48	28.15
Ammonia	mg/L	0.56	0.56	1.12	0.87

The study revealed that the systems can provide the following COD and BOD removal efficiencies: 60-80% and 70-90%, respectively. From these results, it can be proved that aeration of grey water lends itself to this study, and it can be treated without the use of polymers which are employed to accelerate the flocculation and sedimentation of the grey water. Also, Friedler et al. (2005) involved an aeration system for greywater treatment in a residential building. The study found that COD removal efficiencies were at about 75% and BOD removal efficiencies were about 85%, and these results are in congruence with Jefferson et al. (2000). This shows that the efficiency of greywater treatment by aeration as a treatment method is valid.

Furthermore Lamine et al. (2012) reviewed a study that aimed at evaluating the efficiency of a submerged aeration bioreactor in treating greywater. The study obtained a COD removal efficiency of seventy-eighty-two percent, while the BOD removal efficiency was eighty-eight percent, more proof of aeration ignoring polymer addition. Taken altogether the findings from these studies reveal the great potential of aeration in reducing the levels of organic pollutants and suspended solids.

By comparing the previous results, upon reviewing the preceding findings, it became evident that the efficacy of the aeration process closely paralleled that observed in prior investigations. This alignment can be attributed to the heightened hydraulic retention time (HRT), which augmented the Mixed Liquor Volatile Suspended Solids (MLVSS), thereby optimizing biological activity. Throughout the aeration phases, heterotrophic microorganisms metabolize organic matter for energy, facilitating the removal of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) (Maroneze et al., 2014). Previous studies have investigated the impact of Hydraulic Retention Time (HRT) on the removal of organic matter, yielding an average removal efficiency of 93.88% over a 12-hour HRT (Haydar et al., 2007). These pilot findings align closely with these results regarding the removal of COD and BOD. In this study, the fluctuation in NH_3-N concentrations can be attributed to the absence of anoxic conditions in this pilot setup, where both nitrification and de-nitrification processes occurred within a single tank. Additionally, the nitrification rates in this pilot system were likely compromised due to insufficient time for the slow-growing nitrifying bacteria to establish themselves adequately. Furthermore, another contributing factor to the low NH_3-N removal is the pH conditions observed. At the onset of the second aeration cycle, the pH levels measured 8 and 10, respectively, exceeding the optimal pH range conducive to the nitrification process.

Table 4. Greywater characteristics (second experimental trial).

Parameters	Units	Sample raw water	After Sedimentation Tank (12 hours)	Aeration Tank (12 hours)	Settling+ Chlorination
pH	--	7.39	7.29	2.60	8.4
Turbidity	NTU	466.3	425	187.6	175.2
Total Suspended Solids	mg/L	421.4	336.1	266	198
Chemical Oxygen Demand	mgO_2/L	1997	1972	190	35
Biochemical Oxygen Demand	mgO_2/L	782	771	<5	<5
Total Kjeldahl Nitrogen	mg/L	43.68	40.32	72.8	17
Ammonia	mg/L	0.56	0.56	N.D	N.D

N.D = not deteted.

As illustrated in Table 4, the effectiveness of poly aluminum chloride (PAC) polymer in greywater treatment can be a remarkable solution to minimizing the greywater characteristics. As shown in Figure 3, the effluent of greywater in the case of adding poly aluminum chloride (PAC) as a coagulant was 175.2 mg/L (turbidity), 198 mg/L (TSS), 35 mg/L (COD), and less than 5 mg/L (BOD).

Firstly, PAC is known for its strong coagulation and flocculation capabilities, enabling it to effectively bind with suspended solids, colloidal particles, and organic matter present in wastewater (Zhang et al., 2023). This process facilitates the formation of larger aggregates or flocs, which settle more readily during sedimentation, leading to improved clarification and turbidity reduction in treated wastewater. Additionally, PAC exhibits excellent performance across a wide range of pH values, making it suitable for use in diverse wastewater treatment applications (Zhu et al., 2018). Its versatility allows for the effective treatment of wastewater with fluctuating pH levels without compromising treatment efficiency.

Moreover, PAC is known for its rapid action and high efficiency in removing various contaminants from wastewater, including heavy metals, phosphates, and organic pollutants (Zhang et al., 2023). This capability contributes to the overall effectiveness of wastewater treatment processes, ensuring that treated effluent meets regulatory standards and environmental requirements.

Furthermore, PAC offers operational advantages such as low dosage requirements and reduced sludge production compared to traditional coagulants like aluminum sulfate (alum) (Zhu et al., 2018). This not only improves treatment efficiency but also reduces costs associated with chemical usage and sludge disposal, making PAC an economically viable option for wastewater treatment plants.

Based on the results reported by previous studies, COD and BOD are two parameters that can be used to quantify the organic load, and it is important to minimize these parameters in greywater treatment. According to research done by Amuda and Alade (2006), PAC could remove COD at a percentage of 70-80 % while treating greywater. This is quite in agreement with the results of a study carried out by Kassa et al. (2024), wherein BOD removal efficiencies of 85% were achieved by employing PAC in domestic wastewater treatment. Such findings reflect the fact that PAC adds high value as an effective ameliorative for the removal of organic contaminants.

By comparing the results of PAC with the aeration process without polymers, it is found that PAC offers better benefits for the system. This is true mainly because, as mentioned before, aeration alone was reported to range from 60% to 90% in removing both COD and BOD (Jefferson et al., 2000; Lamine et al., 2012). On the other hand, the employment of PAC continually yields improved overall removal efficiencies, particularly of SSD and OM.

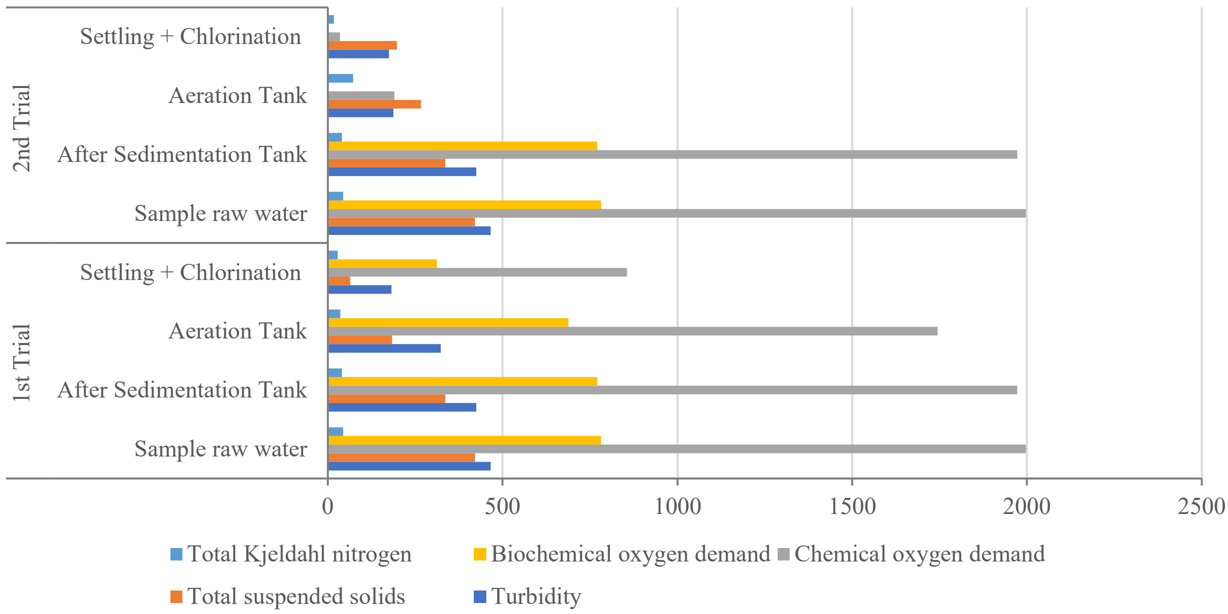

Figure 3. Comparison between both experimental trials.

Conclusion

In conclusion, the water scarcity crisis in Egypt necessitates urgent and innovative solutions to ensure sustainable water management and alleviate the strain on existing water resources. The reliance on the Nile River, coupled with challenges such as pollution and over-extraction of groundwater, underscores the urgency of adopting effective water conservation measures. Greywater treatment emerges as a promising solution to mitigate water scarcity by reclaiming and treating wastewater for reuse, thereby reducing dependence on freshwater sources.

The utilization of polymers in greywater treatment presents a practical and efficient approach to improve water quality and enhance treatment processes. Through processes such as coagulation, flocculation, and disinfection, polymers effectively remove contaminants and pathogens from greywater, making it suitable for various non-potable applications. The flexibility and adaptability of polymer-based treatment methods make them well-suited for addressing the diverse water quality challenges faced in Egypt and other regions experiencing water scarcity.

Overall, the implementation of polymer-based greywater treatment represents a significant step towards achieving water security and ensuring the availability of clean water for future generations in Egypt and beyond. Continued research and investment in innovative water treatment technologies are essential to address the complex challenges posed by water scarcity and safeguard the planet's precious water resources.

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