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Enhancement of the Wastewater Effluent Quality by Alum Sludge

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Abstract

The Alum sludge produced from drinking water purification plants represents a burden in its disposal for several reasons, including the quantities and contents, in another track, the influent of wastewater treatment plants with a large organic load that must be reduced to improve treatment and the specifications of the effluent wastewater, BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) and TSS (Total Suspended Solid) are the main organic loads that present in domestic wastewater. This study aims to investigate the efficiency of chemical treatment of wastewater using dried Alum sludge, hence solving these two environmental problems by using dried Alum sludge to treat the effluent of wastewater plants and enhance its quality. Two different wastewater treatment plants were selected to investigate the efficiency of chemical treatment with Alum sludge. Raw wastewater samples were treated with dried slurry at 105^{0}C. The results showed the reduction efficiency in the Ramla and El-Hawamidia wastewater plants ranging from 97% to 81% for different wastewater pollutants. These results confirmed the potentiality of Alum Sludge from water plants for future application in wastewater treatments.

Keywords: Wastewater treatment plant; Total Suspended Solids; Chemical Oxygen Demand; Biochemical Oxygen Demand; Alum Sludge.

1. Introduction

To sustainably develop an ecosystem and promote human health, water is a crucial resource for urbanization, industrialization, and population growth freshwater resources are in ever-increasing demand. **(Bagatin et al., 2014).** According to the "business as usual" scenario, there would be a 40% global water shortfall by 2030 **(Seghairi et al., 2017).** Due to population increase, more water will be needed for socioeconomic activities. In Egypt, an emerging market nation and the largest in population in Africa, water use in everywhere **(Malik et al., 2018).** Pollution of water bodies is a big obstacle in the exploitation of water resources in different activities.

Alum sludge is produced, such as, water treatment plants annually create 18,000 tons of dry solids from Ireland, 34,000 tons from the Netherlands, and 182,000 tons from the UK **(Boaventura, 2000).** In Egypt water treatment plants produces more than a million tons of Alum sludge on annual bases. Globally, according to the available literature, 10,000 tons of waterworks sludge are produced every day **(Chen et al., 2011).** The available options for disposal of Alum sludgeare through landfills or land application in industrialized countries due to recent regulatory developments. But, in underdeveloped nations, it is main route by disposalin water bodies or sanitary sewers **(Nair and Ahammed, 2013).** Alum sludge released into bodies of water has been documented to be hazardous to aquatic life **(El-Bestawy et al., 2005)** due to the number of contaminants in it (organic, inorganic) (**Ishikawa et al., 2007).** The reusing of Alum sludge may be aviable option, in recent years, several research initiatives, have been made Alum sludge in a variety of useful ways as building and construction materials, cement-based materials **(Shamaki et al., 2021).** Construct Build Matter (275:122047) and wastewater treatment **(Zhao et al., 2021; Babatunde and Zhao, 2007; Nair and Ahammed, 2013).**

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A technical generation of a proportional amount of by-product Alum sludge is produced which is brought through a dewatering process. It is passed through treatment steps before the final disposal to reduce its amount **(Tony and Lin 2020).**

Alum sludge is generated because of adding aluminum sulfate [$A1_2(SO_4)_3.14H_2O$] as a flocculating agent in the drinking water treatment process **(Ahmad et al., 2016).** The resultant alum sludge is a two-phase mixture of solids and water, and its water content is generally in the level between 99% (before thickening) and 95% (after thickening).

Coagulation is defined as the addition of chemicals and mixing of the particles and some dissolved contaminants are aggregated by the domination of Van der Waals and other adhesive forces or decreasing repulsion forces into larger particles that can be removed by solids removal processes, **(Yang, et al. 2017),** as clarification and filtration. Traditional coagulation is the primary purpose of removing suspended materials and organic matter with minimal sludge production to decrease turbidity.

Many studies have demonstrated Alum sludge ability and considerable capacity as a low-cost adsorbent for P immobilization. In addition, other elements of contaminants in wastewater have been tested for adsorption by Alum sludge in recent years. **(Zhao et al. 2021)** reported the use of Alum Sludge for arsenic immobilization, another study, also used Alum Sludge for fluoride removal.

Domestic wastewaters contain significant number of pollutants, mainly expressed as (COD, BOD5, and TSS) reduction of these pollutants will allow more efficient reuse of the treated wastewater.

This study aims at enhancing the influent of wastewater treatment plants using dried Alum sludge as a physical/chemical treatment, rather than biological treatment, discovering the potentially and benefit as dual benefit method (removing pollutant and disposal of Alum sludge). Two different wastewater treatment plant were selected to investigate the efficiency of chemical/physical treatment with Alum sludge.

2. Materials and Methods.

2.1. characterization of Alum sludge:

The digested Alum sludge solution was analyzed for metals using inductively coupled plasma atomic emission spectrometry (ICP-Perkin-Elmer optima 8300) and pH was determined using a pH meter (Hach Portable Meter).

The ignition at 550 ^{0}C was used to determine the total volatile organic solids in the Alum sludge (SMWW, 2023). The water content of collected Alum sludge is determined by weighing 1 g, drying at 105 ^{0}C for 2 hours, reweighing, and calculating water content using the equation (eq.1).

$$\text{Water content \%} = \frac{\text{sludge weight before drying} - \text{sludge weight after drying}}{\text{sludge weight before drying}} \times 100$$

(eq.1)

The characteristics of Alum sludge are strongly dependent on the operation of the water treatment plants and the water quality being treated, resulting in differences in the type and concentration of organic matter present in the Alum sludge. However, it is important to note that the Alum sludge is relatively clean, without harmful and toxic elements in most cases, except for the instances where the source water contains specific elements, such as fluoride and arsenic. In general, SiO_2 constitutes the majority of the sludge, followed by Al_2O_3.

2.2. Selection of WWTPs and characterization of wastewater.

A study was conducted on El-Hawamidia sewage plant in Giza and EL-Ramla sewage plant (Banha) in Qalyubia. The samples were taken from the influent and effluent of WWTPs. The Ramla sewage plant was chosen to enhance its removal efficiency with Alum sludge because its treatment quality is deteriorated and its final sewage was not compatible, as the plant operates with the traditional activated sludge system. The design capacity is 70,000 m3/day and the actual capacity is 75,000 m3/day, meaning that the plant has an increase in the amount of water entering the plant over its design, thus makes load on the plant, resulting its effluent not in compliance with the Egyptian law for drainage on drains law 48/1984. The plant discharges the final waste into the Talha drain. Initially, treatment is carried out by water entering the treatment plant using posters, then to mechanical strainers, from there to the primary sedimentation basins, then to biological basins (aeration basins), in which the biological treatment of wastewater takes place, and from there to final sedimentation basins, finally to Chlorination stage (sterilization) then to the drain. El-Hawamidia WWTP serves El-Hawamidia city and its dependent villages (including industrial wastewater from the adjacent sugar factories) with 20,000 m3/day current design capacity **(Rabie, et al. 2019).**

Wastewater from the two treatment plants were analysed before and after the treatment. Analyzed parameters were Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD_5), and Chemical Oxygen Demand (COD) analyzed according to standard techniques described in the Standard Methods for the Examination of Water and Wastewater **(SMWW,2023).** After treatment, the selected parameters were analyzed to determine their residual levels at each exposure time and their removal efficiency was estimated to reveal the efficiency of the treatment process as the below equation.

Removal Efficiency (RE%) = $[(C_0 - R_C)/C_0] \times 100$ **(eq. 2)**

Where C0 = Initial concentration.
RC= Residual concentration.

The effluent is either reused or disposed in land or water streams. The effluent water should fulfill a lower concentration of organic matter to avoid eutrophication phenomena in the water streams. The discharge of treated water is conducted depending on the nature and properties of the water body. When the effluent is discharged into water streams, there must be proper vertical mixing to prevent foaming **(Evuti and Lawal 2011).**

2.2.1. Sampling.

Samples were taken from the effluent of and El-Hawamidia and EL- Ramla secondary treatment plant after chlorination process to be analyzed for BOD5, COD, and TSS according to **(Rice et al., 2023)** at the reference laboratory for the wastewater (Accredited ISO 17025). 12 samples were taken during 2022 and divided into 4 quarters (**Q_1, Q_2, Q_3,** and **Q_4**) each quarter represents three months with 3 samples, the average of 3 sample represent: **Q_1** from January to March; **Q_2** from April to June; **Q_3** from July to September; **Q_4** from October to September.

The samples were analyzed for COD, BOD5, and TSS to determine the efficiency of the treatment plants and to evaluate the possibility of using dried Alum sludge in treatment of wastewater.

2.2.2. Biochemical oxygen demand (BOD_5).

BOD_5 is an indirect method to measure organic pollution by measuring the difference between DO initial and final presented in the sample contained (DO, bacteria, and dilution water). BOD_5 was defined as the amount of oxygen needed to oxidize organic matter by aerobic bacteria at 20 °C for 5 days. BOD_5 was measured by preparing dilution water and transferring it to BOD_5 bottles (300 ml) inside the incubator at 20 °C for 5 days. BOD_5 depended on measuring the difference between initial dissolved oxygen (initial DO) and final dissolved oxygen (final DO) **(Rice et al., 2023)** according to eq. 3.

To determine the value of BOD_5 in mg/l using the following equation.

BOD_5mg/l = [(initial DO – final DO) x 300] /volume of sample. **(eq.3)**

2.2.3. Chemical Oxygen Demand (COD).

Method 5220 D was used to determine COD by Colorimeter (DR/890). Low-range COD vials (0-150 mg/l, HACH, USA) were used for effluent, and medium-range COD vials were used for influent (0-1500mg/l, HACH, USA). The used hermos-reactor was CR3200 (WTW, Germany) at 150 0C for two hours for sample digestion, and after that, they were cooled to room temperature. After the digestion, vials were measured in mg/l directly by programming the HACH Colorimeter (DR-890, HACH, USA) to program for low-range vials and program for medium-range vials. The color developed in the samples as well as blank and standards was measured as COD concentration at 620 nm **(Rice et al., 2023).**

2.2.4. Total Suspended Solids (TSS).

According to 2540 D standard techniques for water & wastewater examination TSS was assessed. A well-mixed sample (25 ml) was filtered through a weighted standard glass-fiber filter (47 mm circles), and the solid residue that was retained on the filter was dried to a consistent weight at 103-105°C. The total suspended particles are represented by the filter's weight gain. The difference between total dissolved solids and total solids was used to compute the total suspended solids **(SMWW, 2023)** according to **eq. 4.**

Calculation.
Mg total suspended solids/L = (A-B) X 1000 / sample volume ml **(eq.4)**
Where:
A = weight of glass fiber filter + dried residue, mg
B = weight of the glass fiber filter, mg

2.3. Treatment method.

2.3.1. Alum sludge preparation.

Alum sludge sample was collected from the October water treatment plant that treat raw water from the Nile using alum as a coagulant, after drying oven at 105^0C for 24 hours, mashed with a mortar and pestle, and a quantity of 1kg was grinded and sieved by 2 mm screen, the fraction passing through the screen being collected and used for the treatment. The same batch (1 kg) was mixed to ensure the homogeneity of it and all the treatment experiments were done using this amount.

2.3.2. Alum sludge treatment methodology.

Alum sludge was added by a dose ranged from 50 – 300 mg to 1 liter jar tester. A series of jar tests were carried out on the grab samples taken from the influent of the Wastewater Treatment Plants (WWTPs.) They were coagulated at 100 rpm for 1 min then slow mixing by 30 rpm for 20 min. The samples were settled for 30 min, pH ranging from 7.5 to 9.0.

3. Results.

3.1. Characterization of Alum sludge

Alum sludge was characteristic to identify the present different parameters and metals. Aluminum was found to be maximum concentration, while the other metals were found to be a minimum likely, it seems to be not detected, this indicates the potentiality of using Alum sludge in water treatment without having a great concern from heavy metals **(Sharma and Ahammed 2023).** Table (1) shows the main metals detected in Alum sludge.

Table 1: Alum sludge metals contents analysis (expressed by mg per gram)

Metal	Al	Ba	Co	Cr	Cu	Zn	Fe
Conc (mg/g of dried sludge)	133.4	0.13	0.02	0.13	0.05	0.11	22.1
Metal	**Li**	**Mn**	**Ni**	**Pb**	**Sr**	**V**	
Conc (mg/g of dried sludge)	0.01	1.8	0.04	0.087	0.165	0.12	

3.2. Wastewater monitoring

The samples taken from the raw sewage of the two WWTPs, “El-Hawamidia and El-Ramla”. Samples were taken monthly, and the average values were expressed for each season. Each sample was measured three times, and the average was reported. Three different tests were performed to assess the amount of pollution entering the WWTPs which are TSS, BOD_5, and COD and the removal efficiency of each parameter were calculated to determine the efficiency of the WWTPs.

To determine the reduction efficiency of the (COD, BOD_5, and TSS) of the WWTPs influent and effluent concentration were measured respectively. In general, the influent concentration depends on the type of wastewater (i.e. industrial, domestic or combination). The domestic waste mostly has lower organic concentration than industrial waste. The habit and regular uses of water also determine the quality of influent. The more polluted the influent of WWTPs, the lower expected removal efficiency.

3.2.1. Total Suspended Solids (TSS) monitoring in WTTPs **influent**

As shown in figure 1, there was a gradual increase in the TSS from quarter 1 to 4 in El Ramla WWTP, three samples were taken each three months which is not the case in El-Hawamidia WWTP as there were fluctuations in the TSS values throughout the year. These values indicate the quality and amount of suspended matter in the raw sewage which differ from one area to another. This indicates also that the TSS is site and time specific which is related to the activities in the areas served by the WWTP. These findings agree with **(Kuśnierz and Wiercik, 2016).**

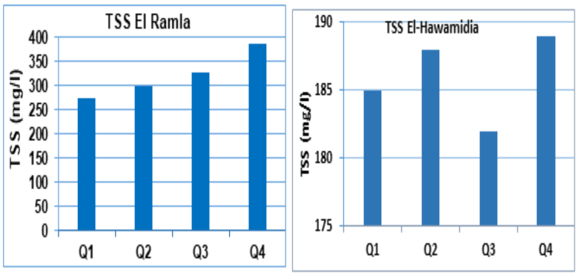

Figure 1: TSS (mg/l) in the influent of El-Hawamidia and El Ramla WWTPs in the four quarters.

3.2.2. BOD5 and COD monitoring in WTTPs influent.

The results shown in Figure 2, confirm that the amount of pollution in the two WWTPs are mostly biodegradable organic matter. This finding emphasis that the biological treatment of domestic wastewater would be efficient in dealing with the variations in the quality of raw sewage throughout the four quarters of the year. Our findings agree with the published data by **(Muserere et al., 2014).**

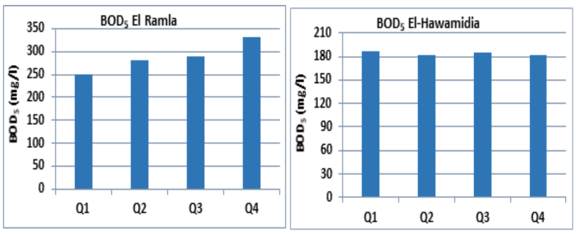

Figure 2: BOD5 (mg/l) in the influent of El-Hawamidia and El Ramla WWTPs in the four quarters.

Concerning COD, figure 4 shows the COD measurements for the raw sewage in the two WWTPs and the results show a gradual increase in the results of El Ramla WWTP as in the TSS which indicates that the detected suspended solids were of organic nature.

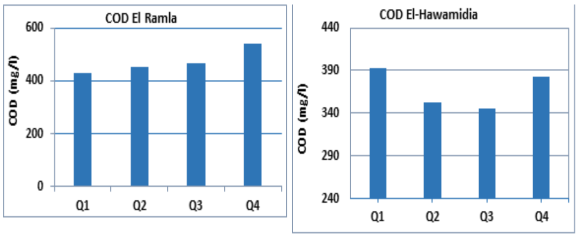

Figure 3: COD (mg/l) in the influent of El-Hawamidia and El Ramla in the four quarters.

3.3. Efficiency of the WWTPs.

3.3.1. Removal efficiency of COD:

As shown in figure 4, the removal efficiencies differ throughout the four quarters and each WWTP has its unique trend. The best removal efficiency was in the third quarter in El Ramla (82%) and in the second quarter El-Hawamidia WWTP (81%). That reflects the different operating conditions, which were not stable throughout the year and performed well in the shown quarters. On the other hand, the minimum COD removal efficiency was in the fourth quarter in both WWTPs.

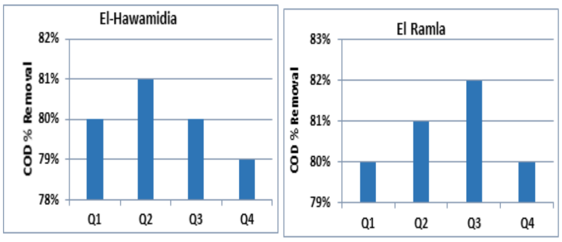

Figure 4: COD Removal Efficiency of El Ramla and El-Hawamidia WWTPs in the four quarters.

3.3.2. Removal efficiency of TSS:

Figure 5, reveals the same finding as on COD, showing the efficiency of TSS removal which tells that the major fraction of suspended matter is of organic origin.

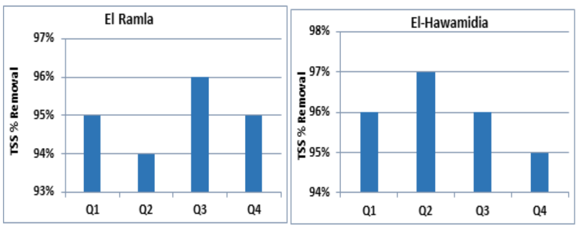

Figure 5: TSS Removal efficiency of El Ramla and El-Hawamidia WWTPs in the four quarters.

3.3.3. Removal efficiency of BOD5

The following figure shows that the maximum removal efficiency for biodegradable organic matter was reported in the second quarter for El Ramla WWTP while it was in the second quarter for El-Hawamidia WWTP. That could be due to the operational conditions in these quarters being optimum **(Baharvand& Mansouri, 2019).**

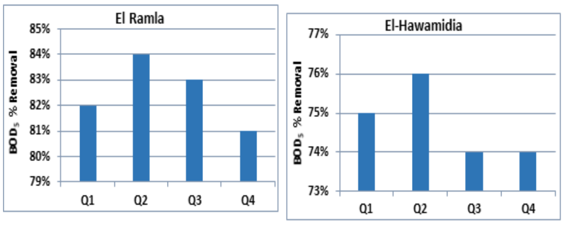

Figure 6: BOD5 Removal efficiency of El Ramla and El-Hawamidia WWTPs in the four quarters.

TSS, COD, and BOD5 removal efficiency in WTTPs via biological treatment indicates that it records the highest removal for TSS, BOD, and COD with average removal 95%, 82%, and 80%, respectively.

3.4. Use of Alum sludge in Removal of COD, BOD5 and TSS.

3.4.1. Optimum Alum sludge dose determination

Figures 7-12 show the optimum doses of Alum sludge recorded 150 mg/l which prove the best removal efficiencies for the TSS and COD and BOD5 for both WWTPs. That agrees with the findings reported by **(Nansubuga et al., 2013).**

Many studies have demonstrated Alum sludge ability and considerable capacity as a low-cost adsorbent. In addition, other elements of contaminants in wastewater have been tested for adsorption by Alum sludge in recent years **(Zhao et al., 2018)** reported the use of Alum sludge for arsenic immobilization, finding that the maximum adsorption capacities ranged from 0.61 to 0.96 mg-As/g when the pH of the arsenic solution was varied from 9.0 to 4.0.

Recently, **(Kang et al., 2021)** investigated the use of liquid Alum sludge in animal farm wastewater treatment as this type of wastewater is a major concern due to the high concentration of chemical oxygen demand (COD) and suspended solids (SS). Treatment of such strong wastewater needs a significant reduction in the pollutants during the primary stages, e.g., coagulation/flocculation and sedimentation, before biological treatment. The removal efficiencies of TSS (total suspended solids), PO43-, and TOC of 87.76%, 96.88%, and 62.14%, respectively, were obtained; thus, this provides a cost-effective way for high strength wastewater coagulation.

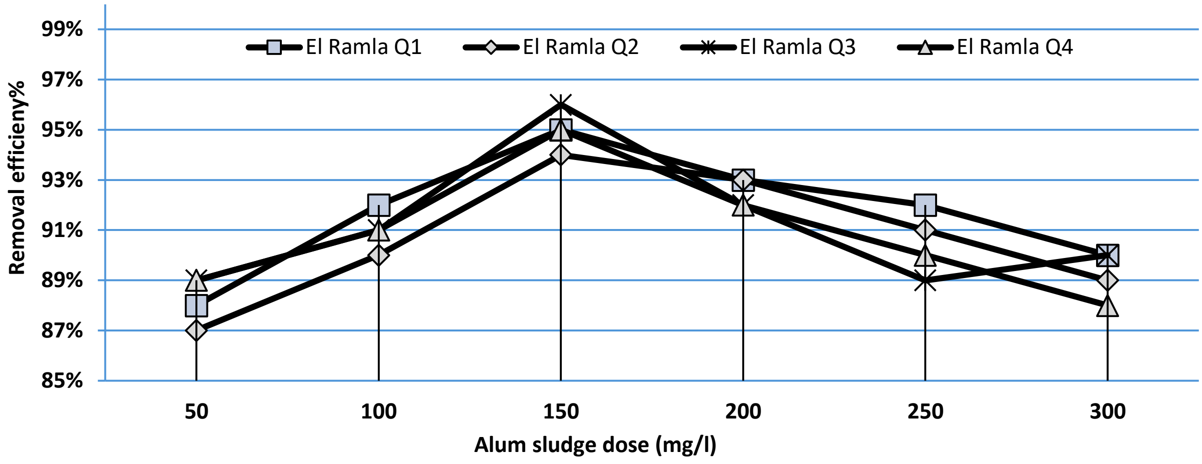

Figure 7: Removal efficiency of TSS for the four quarters in El-Hawamidia WWTP using different alum sludge doses (mg/l).

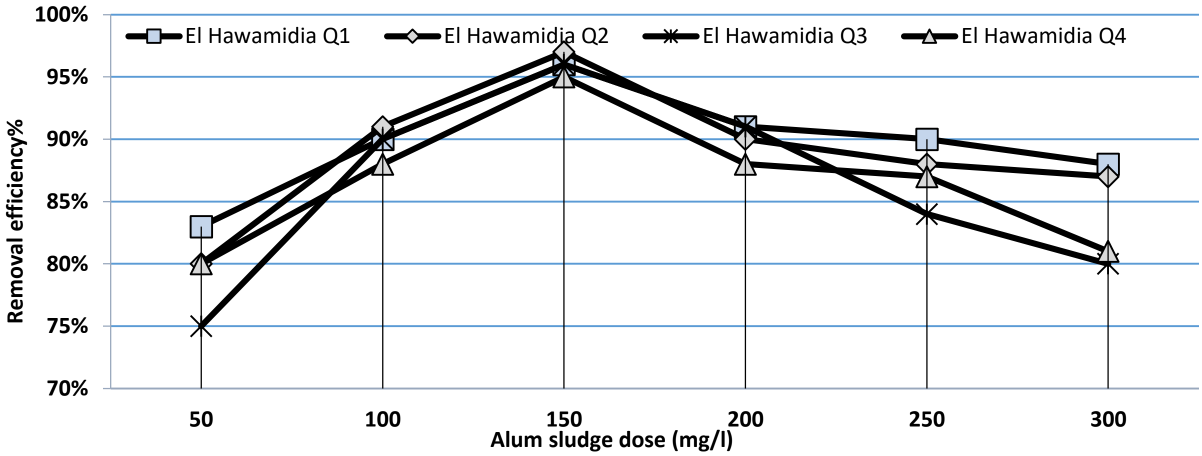

Figure 8: Removal efficiency of TSS for the four quarters in El Ramla WWTP using different alum sludge doses (mg/l).

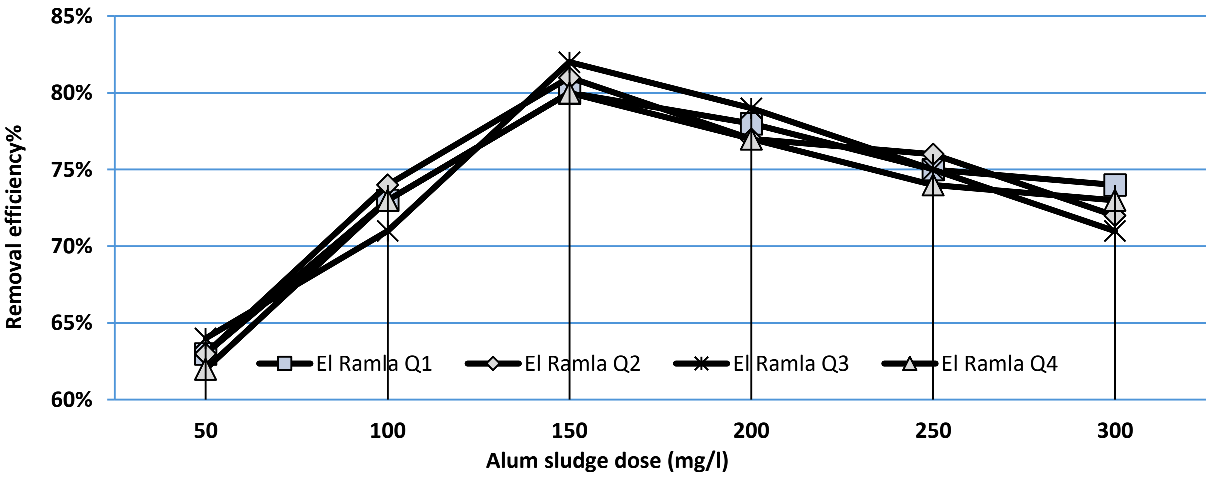

Figure 9: Removal efficiency of COD for the four quarters in El-Hawamidia WWTP using different alum sludge doses (mg/l).

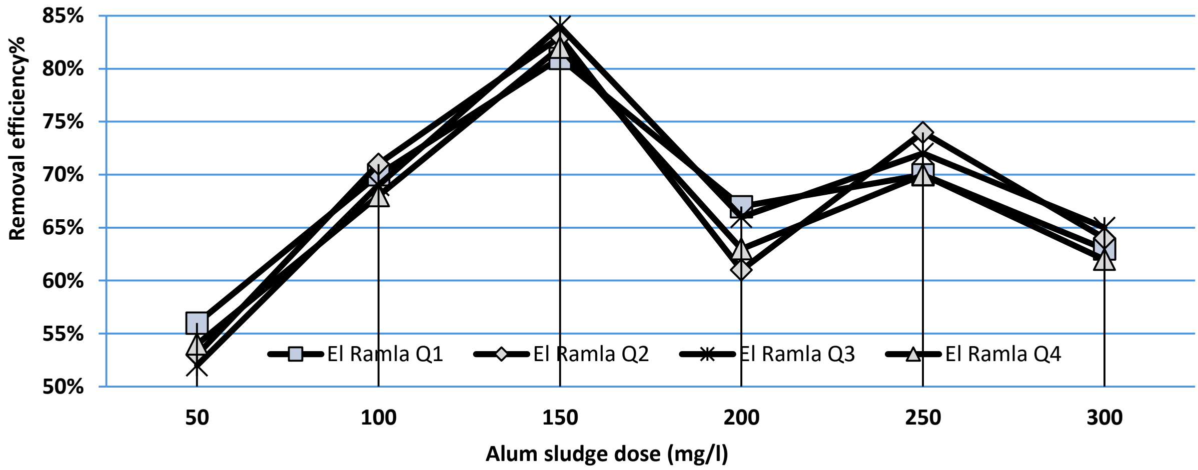

Figure 10: Removal efficiency of COD for the four quarters in El Ramla WWTP using different alum sludge doses (mg/l).

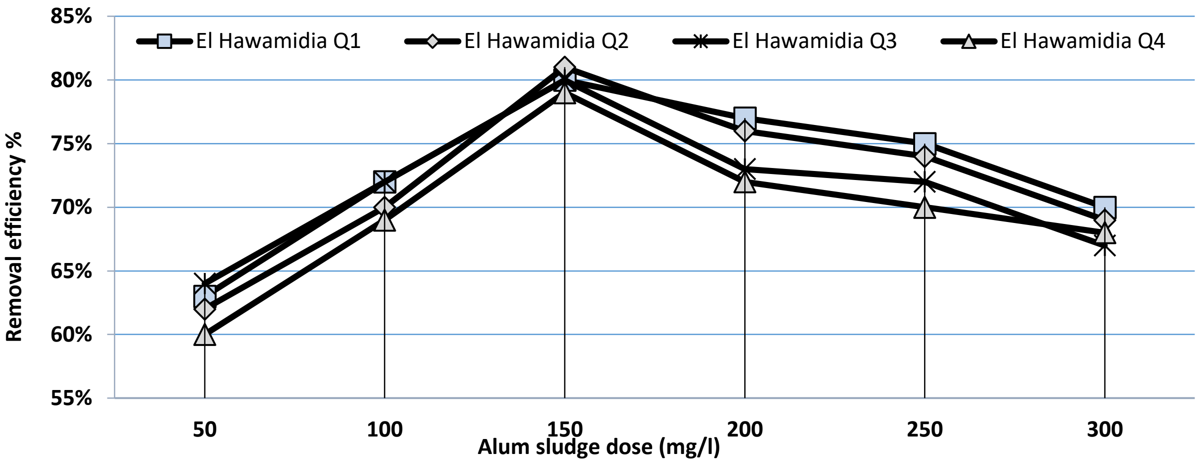

Figure 11: Removal efficiency of BOD5 for the four quarters in El-Hawamidia WWTP using different alum sludge doses (mg/l).

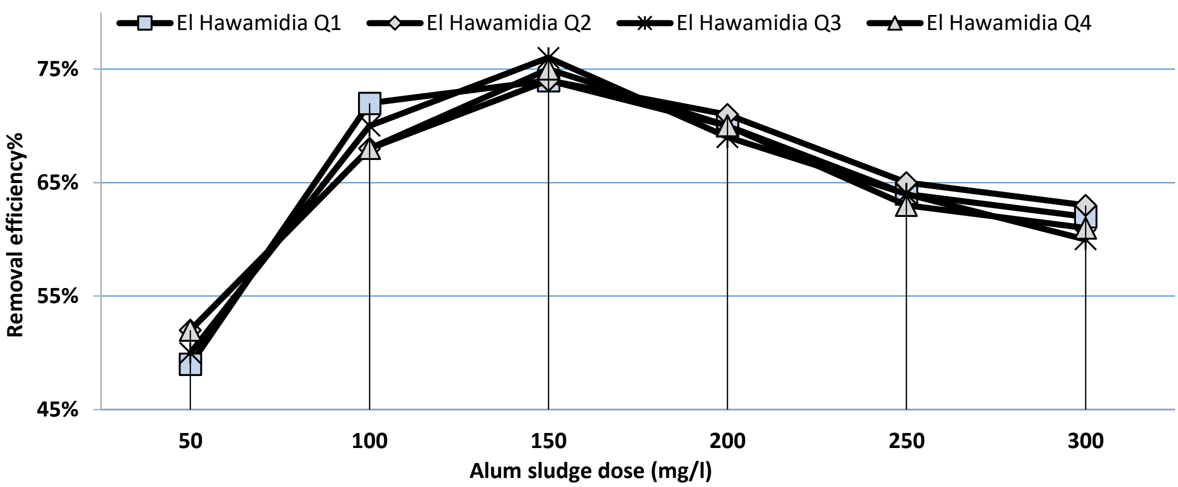

Figure 12: Removal efficiency of BOD5 for the four quarters in El Ramla WWTP using different alum sludge doses (mg/l).

The maximum removal efficiency was achieved at dose of 150 mg/l, the removal efficiency recorded average for the two WWTPs by 95%, 85%, and 80% for TSS, COD, and BOD respectively. These results proof the potentiality of Alum sludge to be used for treating wastewater prior to biological treatment.

4. Discussions

4.1. Alum sludge characterization

Alum sludge characteristics of residuals from water treatment plants vary with the quality of source water, treatment operation used, and dose and type of chemical coagulant used. Thus, the composition of residuals generally measured in terms of solid content, metals, and inorganic and organic contents varies from plant to plant. The main compounds found are Al and Fe while Beryllium (Be), Silver (Ag), Cadmium (Cd), and Molybdenum (Mo) levels were all below detectable levels. The Alum sludge contains a high percentage of Al and Fe. Other metals were of very low concentration that indicates the suitability for using Alum sludge in treatment of wastewater having no concern about heavy metals. Potential organic matter in Alum sludge will also be detected as apart of COD and BOD5 measurement of wastewater after treatment.

4.2. WTTPs efficiency.

Sewage characterization was investigated through TSS, COD, and BOD5. In general, the average TSS in the two treatment plants is way below the limits (800 mg/l), which indicates no abnormalities in the system and no possibility of the presence of industrial waste. However, the TSS in El-Ramla is almost double its value in El-Hawamidia treatment plant. This could be attributed to the nature of waste received by the latter having an excessive water load from El-Hawamidia sugar cane factory. Ramla's influent characteristics are nearer to normal domestic waste.

The concentration of El-Ramla's average BOD5 is almost double that of El-Hawamidia influent which is owed to as mentioned before of receiving of El-Hawamidia of excessive water from sugar cane factory waste.

The same trend of TSS was repeated in the COD values for El-Hawamidia WWTP which shows the same significance mentioned for El Ramla WWTP. That reveals organic matter removal will affect the TSS as well. This was confirmed through the study done by **(Muserere et al, 2014).**

Investigation the removal percentage of COD cleared that it was minimum in the fourth quarter this was attributed to the heavy suspended matter load in the influents in the fourth quarter due to the minimum use of domestic water in winter as shown in figure1 **(Baharvand& Mansouri, 2019).**TSS removal was recorded with minimum efficiency in winter due to the lowest sewage collected in this period with the concentration of the pollutants in the collecting networks **(Baharvand& Mansouri, 2019).**

4.3. Alum sludge removal efficiency

Samples were treated with dried slurry at 105 0C. The results showed highest removal efficiency in the Ramla plant at 96, 84, and 82% for TSS, BOD5, and COD, respectively, and the lowest removal efficiency was 94, 81, and 80% for TSS, BOD5, and COD, respectively in the four quarters, while the highest removal efficiency in El-Hawamidia plant was 97, 76, 81% for TSS, BOD5, and COD, respectively and the lowest removal efficiency was 95, 74, 79% for TSS, BOD5, and COD, respectively in the four quarters. These results confirmed the potentiality of using dried Alum sludge from water plants for future application in wastewater treatments. Comparing to the efficiency of WTTPs by biological treatment and Alum sludge could be comparable to its efficiency as a pure physical/chemical treatment for wastewater that offer the same efficiency at lowest time and lower treatment plant footprint.

5. Conclusion

Alum sludge is a solid waste of the drinking water treatment plants that has hazard environmental impact. Because of its high Al content as aluminum sulfate coagulant residue, it has a high potential for beneficial reuse in water and wastewater treatment. This study explored the possibility of treatment of domestic wastewater using dried Alum sludge. Raw domestic wastewater quality was monitored through analysis of COD, BOD5, and TSS in two different WWTPs (El Ramla and El-Hawamidia). The three parameters show a maximum value during the winter and lower values in the rest of the year. The efficiency of WTTPs were determined to emphasis the reduction capabilities of the different pollutants via biological treatment. The reduction efficiencies of the two WWTPs were different throughout the four quarters and differed from each other due to the varied operating conditions.

Alum sludge represents a physical/chemical potential treatment for wastewater. Some unique reuse options of Alum sludge developed in recent years for wastewater treatment procedures.

Reduction efficiency using Alum sludge with the dose of 150 mg/l was found to be the maximum for different pollutants in wastewater. The results showed highest removal efficiency in the Ramla plant with removal efficiency of 96, 84, and 82% for TSS, BOD5, and COD, respectively, and the lowest removal efficiency was 94, 81, and 80% for TSS, BOD5, and COD, respectively in the four quarters, while the highest removal efficiency in El-Hawamidia plant was 97, 76, 81% for TSS, BOD5, and COD, respectively and the lowest removal efficiency was 95, 74, 79% for TSS, BOD5, and COD, respectively in the four quarters.

Comparing the efficiency of WTTPs by biological treatment and Alum sludge is comparable to its efficiency as a pure physical/chemical treatment for wastewater that offer the same efficiency at lower time and treatment plant footprint. In conclusion, Alum sludge is a cheap coagulant and adsorbent for reducing organic matter and suspended solids in raw sewage in the two WWTPs in the study. Further investigation should be carried out to determine the adverse effect that could be associated with the bacteriological analysis.

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