

## Techno-Economic Analysis and Use of Potable Water Treatment Sludge as Coagulant for the Treatment of Brewery Industry Wastewater

Pelin Yapıcıoğlu<sup>\*1</sup>, Mehmet İrfan Yeşilnacar<sup>1</sup>

<sup>\*1</sup> Harran Üniversitesi Mühendislik Fakültesi Çevre Mühendisliği, ŞANLIURFA

(Alınış / Received: 29.04.2025, Kabul / Accepted: 26.08.2025, Online Yayınlanma / Published Online: 31.12.2025)

### Keywords

Groundwater,  
Sludge,  
Coagulant,  
Industrial Wastewater

**Abstract:** The main objective of this study was the techno-economic assessment of use the potable water treatment sludge as a coagulant for the treatment of brewery industry wastewater. Within the scope of circular economy principles, a techno-economic analysis was performed of the use of sludge obtained after coagulation of groundwater as a recovered secondary resource instead of coagulant in the treatment of brewery wastewater. Alum ( $Al_2(SO_4)_3 \cdot 18H_2O$ ) was used as the coagulant for the potable water treatment. As a result, an alum-depended sludge was ensured at the end of coagulation process. The alum-depended sludge was used as the coagulant instead of ferric chloride ( $FeCl_3$ ) and addition to ferric chloride for the coagulation process of brewery industry wastewater. The use of sludge as a coagulant ( $24.5 \pm 1.5$  mL dewatered sludge/L wastewater) enhanced the organic materials removal efficiency 14.5%. An economic reuse index (ERI) was calculated depended on estimated and virtual sludge disposal and handling and chemical use as of  $FeCl_3$ . The results showed that the use of sludge as a secondary source decreased the operational costs by 68.75% for the brewery industry wastewater treatment plant.

## İçme Suyu Arıtma Çamurunun Bira Endüstrisi Atıksuyunun Arıtımı için Koagülant Olarak Kullanımı ve Tekno-Ekonomik Analizi

### Anahtar Kelimeler;

Yeraltı Suyu,  
Çamur,  
Koagülant,  
Endüstriyel Atıksu

**Öz:** Bu çalışmanın temel amacı, bira endüstrisi atık suyunun arıtımı için içme suyu arıtma çamurunun koagülant olarak kullanımının tekno-ekonomik değerlendirmesidir. Döngüsel ekonomi prensipleri kapsamında, yeraltı suyunun koagülasyonu sonrası elde edilen çamurun geri kazanılmış ikincil kaynak olarak bira atıksuyunun arıtımında koagülant yerine kullanımının tekno-ekonomik analizi yapılmıştır. İçme suyu arıtımında koagülant olarak alum ( $Al_2(SO_4)_3 \cdot 18H_2O$ ) kullanılmıştır. Sonuç olarak, koagülasyon işleminin sonunda alum bazlı bir çamur elde edilmiştir. Alum bazlı çamur, bira endüstrisi atık suyunun koagülasyon işlemi için demir (III) klorür ( $FeCl_3$ ) yerine koagülant olarak ve  $FeCl_3$ 'e ilaveten kullanılmıştır. Çamurun koagülant olarak kullanılması ( $24,5 \pm 1,5$  mL susuzlaştırılmış çamur/L atık su) organik maddelerin giderim verimliliğini %14,5 oranında artırdı. Çamur bertarafı ve işleme ve kimyasal kullanımına ( $FeCl_3$ ) dayalı olarak tahmini ve sanal bir ekonomik yeniden kullanım indeksi (ERI) hesaplandı. Sonuçlar, çamurun ikinci bir kaynak olarak kullanılmasının işletme maliyetlerini bira endüstrisi atıksu arıtma tesisi için %68,75 oranında azalttığını gösterdi.

## 1. Introduction

Sludge consists as a by-product in the result of chemical or physicochemical treatment processes of potable water, and its management is very important in the operation of potable water treatment plants (PWTPs) from not only an economic perspective but also environmental sustainability [1]. Sludge is rich in organic and inorganic substance, nutrients and other macro and micronutrients and salts making it an efficient feedstock as a secondary source [1,2,3]. Organic and inorganic fractions could be regarded as the opportunities for resource recovery, recycling, and sustainable waste management in recent years. Development of policies and methods on sludge recovery than the application of disposal methods for the sludge management could be encouraged [6,7]. PWTPs should care about sustainable sludge management due to larger volumes and higher disposal costs of generated sludge [8]. An efficient sludge management can reduce the operational costs for a potable water treatment plant and contribute to the zero-waste management systems in terms of circular economy policies. Also, coagulation process uses chemicals which can destroy the aquatic ecosystems.

Coagulation aims to deal with the forces stabilizing the suspended particles in the potable water. In coagulation, which is the mostly used physicochemical operation in potable water treatment, coagulants are used for the reduction of the electrical charge among the suspended particles [9]. The large amounts of sludge generation are reported at PWTPs in the result of coagulation process [5,6,7,8]. The utilization of potable water treatment sludge has been encouraged to obtain the sustainable waste management [10,11]. It ensures not only waste minimization but also reduction of operational costs in these plants. Generating potable water produces a huge amount of sludge which consumes energy and should be controlled [12]. From this perspective, this study investigated the use of the potable water treatment sludge as a coagulant for an industrial wastewater treatment. Reusing treated water sludge could enhance the sustainability of the water treatment sector, reduce the quantity of sludge disposed into the environment, mitigate the greenhouse gas emissions and use of chemical [12,13,14]. Potable water treatment sludge could be an effective and low-cost substance for environmental practices [10,15]. From this point of view, potable water treatment was applied using coagulation process by using alum ( $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ ) as the coagulant, in this study. So, the alum-depended sludge was collected in the end of coagulation process. The alum-depended sludge was reused as the coagulant instead of ferric chloride and their combination with it for the brewery industry wastewater treatment.

Therefore, the present study concentrated on the investigation of an innovative reagent depended on natural waste materials such as the potable water treatment sludge. This study mainly aimed to investigate the reuse of alum-depended sludge as the coagulant for brewery wastewater treatment. In this study, the virtual operational costs were figured out depended on predicted chemical consumption (ferric chloride and alum use) and predicted sludge transfer and disposal practices of the brewery industry wastewater treatment. An economic reuse index (ERI) was developed related to these virtual operational costs by considering the lab-scale study. In the literature, similar studies were performed in this topic. Ahmad et al. (2016) investigated the use of water treatment sludge as a coagulant [5]. Gülhan et al. (2023) investigated the potential reuse of water treatment sludge for high rate activated sludge systems. They reported similarly positive impacts on using sludge for activated sludge system [16]. Abo-El-Enein et al. (2017) performed a study on the reuse of potable water sludge as an adsorbent for heavy metal removal [17]. Kang et al. (2022) investigated using of alum-depended water treatment sludge as a coagulant in order to treat the animal farm wastewater [18]. They similarly reported the efficient pollutant removal [18]. Katrivesis et al. (2019) performed a study on the use of potable water sludge as a coagulant for the turbidity removal from surface water [11]. Letshwenyo investigated the recycle of water treatment sludge to the coagulant for phosphorus removal from wastewater [15]. Sajath et al. (2022) investigated the use of potable water treatment sludge as a coagulant for another potable water treatment [19]. Lebogang et al. (2023) used the potable water treatment sludge as a coagulant for the treatment of raw water [20]. Apart from these studies, this study is unique that groundwater treatment sludge was used as a coagulant for brewery wastewater treatment. This study also recommended a trading off pollution reduction between drinking water and brewery sectors.

## 2. Material and Method

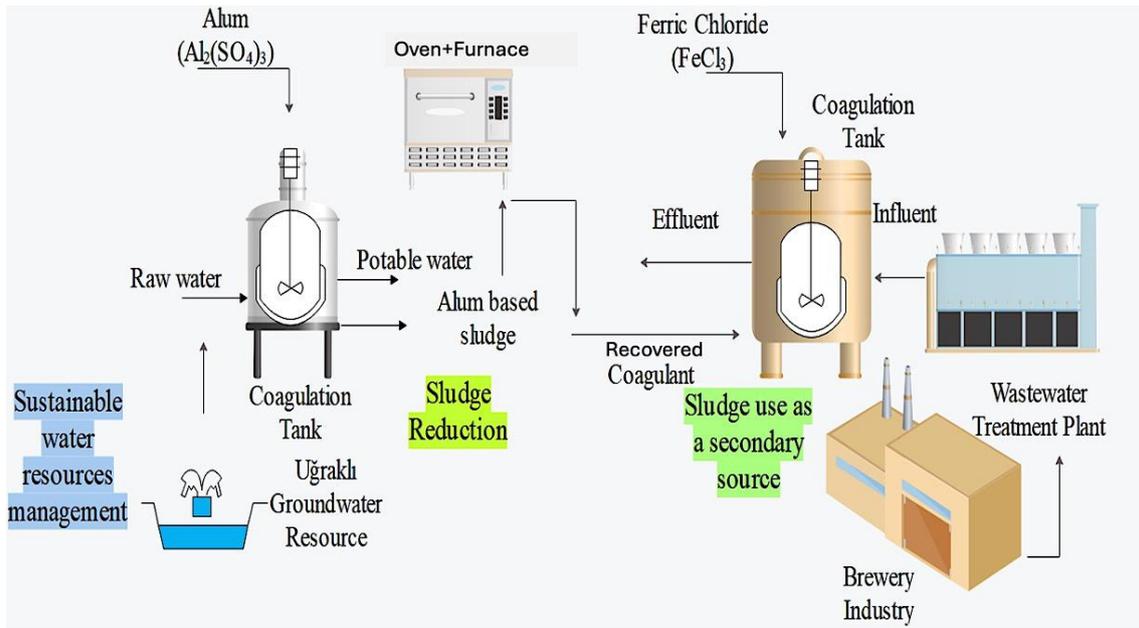
### 2.1. Sludge, Water and Wastewater Characterization

Water was sampled from Uğraklı groundwater resource which located at Harran Plain. The characterization of raw water was given in Table 1. A lab-scale coagulation tank was used for the coagulation of groundwater. A magnetic stirrer (350 rpm) was used for the rapid mixing in the process for 90 minutes. Batch coagulation tests were applied. For the coagulation process of groundwater, alum ( $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ ) which was supplied by Merck in analytical purity. Stock solution of the coagulant was prepared at concentrations of 5 g/L was used in the dose of 20 mL/L water to remove nitrate ( $\text{NO}_3^-$ ) and arsenic (As) from groundwater. The flowrate was 1L/d for two

treatment systems. Then the alum-depended potable water treatment sludge was dried at 103°C for 2 days at an oven and then dewatered at 550 °C for 8 minutes at a furnace. The dewatered sludge was grinded into dust matter form and distilled water was mixed by the ratio of 1:1. Then, this mix was used as the coagulant for the brewery industry wastewater. The influent characterization of brewery wastewater was given in Table 1. The wastewater and water analyses were performed using the standard methods [21, 22]. pH, total organic carbon (TOC), ( $\text{NO}_3^-$ ) and (As) analyses were done for raw water. Chemical oxygen demand (COD), pH, total suspended solid (TSS) were applied as the wastewater analyses. Elemental analyses were performed to determine the major characterization and physiochemical structure of the potable water treatment sludge as a coagulant. The conceptual framework of the study was given in Figure 1. The sludge recovery rate as the coagulant in the end of drying process was 92.9%.

**Table 1.** Water and wastewater characterization

Parameter	Groundwater (Raw water)	Brewery wastewater (Influent)
pH	7.29	6.83
TOC (mg/L)	17.5	-
$\text{NO}_3^-$ (mg/L)	47.5	-
COD (mg/L)	-	5478
TSS (mg/L)	-	2498
As ( $\mu\text{g/L}$ )	3.89	-



**Figure 1.** Flow diagram of the research

## 2.2. Experimental Design (ED) and Statistical Analysis

This study is based on three experimental designs (Table 2). The ED-1 was the industrial wastewater treatment using only alum-depended potable water treatment sludge as the coagulant. The ED-2 was the industrial wastewater treatment using only  $\text{FeCl}_3$  as the coagulant. The ED-3 was the industrial wastewater treatment using combination of potable water treatment sludge and  $\text{FeCl}_3$  as the coagulant.

**Table 2.** Experimental Planning

Experimental Design (ED)	Coagulant
ED-1	Potable water treatment sludge
ED-2	FeCl <sub>3</sub>
ED-3	Potable water treatment sludge + FeCl <sub>3</sub>

Box-Behnken design methodology was used in order to define the optimum coagulant dosage for the brewery industry wastewater treatment. In this study, coefficients were defined using the Box-Behnken design method. The major independent variables were contact time (T) (x<sub>1</sub>), COD (x<sub>2</sub>), and TSS (x<sub>3</sub>). The objective function of the system was shown in Eq.1. in the result of sensitivity analysis. The multiple regression models were used as the objective function by the MATLAB. The empirical interaction between optimum parameters and independent variables were derived by multi-regression analysis of experimental data. The optimum coagulant dose (y) could be determined by the second-order regression formulation which was ensured by ANOVA in Eq.1.

$$y = 2.061x_1^2 - 2.039x_2 - 2.021x_3 \quad (1)$$

### 2.3. Cost Analysis

The virtual operational costs (OC) were figured out based on virtual and estimated chemical consumption (OC<sub>c</sub>) and virtual sludge transfer and disposal practices (OC<sub>s</sub>) of the of brewery industry wastewater treatment plant (Eq.2.). The data were estimated for the full-scale treatment plant virtually. The data related to lab-scale study was adapted and derived for the full-scale plant by considering the water volume treated (the flow rate). The sludge amount and chemical consumptions of the plant were derived by considering of lab-scale study, and virtual values were estimated for the full-scale brewery industry wastewater treatment plant. The economic reuse index (ERI) (%) was derived by using these virtual operational costs (Eq.3.). The sludge disposal and transfer and the chemical costs were assumed as 5000 TL/ton sludge and 500 TL/L chemical, respectively. The treatment capacity of the full-scale brewery industry wastewater treatment was assumed as 5000 L/d, respectively.

$$OC = OC_c + OC_s \quad (2)$$

$$ERI = (OC_1 - OC_2) / OC_1 \quad (3)$$

In Eq.3., OC<sub>1</sub> defined the sum of virtual sludge transfer and disposal costs and the virtual costs of chemical (FeCl<sub>3</sub>) purchase of the industrial wastewater treatment plant as the coagulant. OC<sub>2</sub> described the virtual operational costs of the industrial wastewater treatment plant when sludge was used as the coagulant (TL/month). There is another limitation in this study. In the cost analysis, the costs related to energy consumption of sludge dewatering and handling process (decanter or filter press) and sludge preparation process for the coagulant achievement (energy consumption of oven and furnace) were ignored. Also, the environmental impacts of chemical consumption and coagulant preparation process were ignored.

## 3. Results

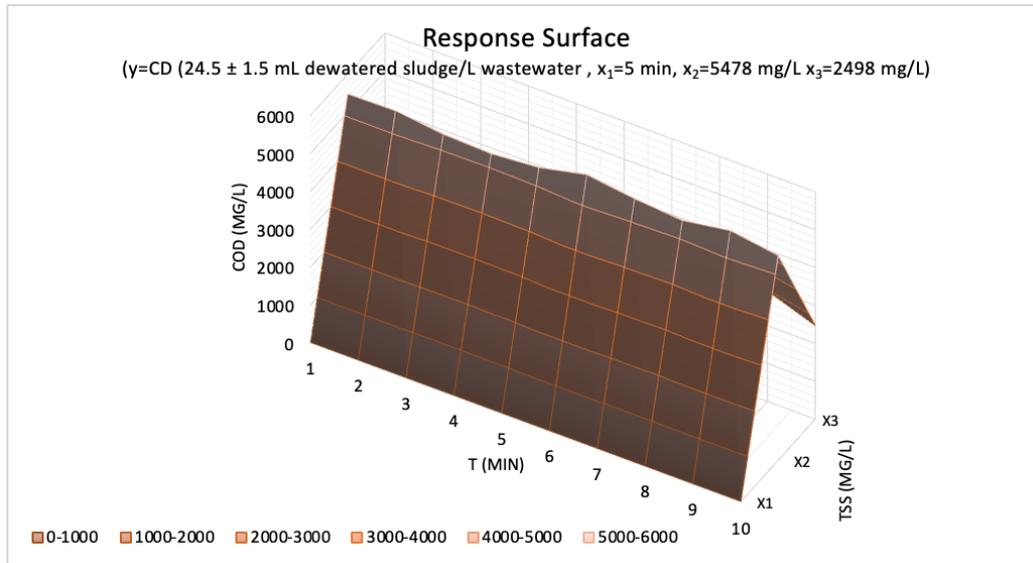
### 3.1. Results of Statistical Analysis

The optimum coagulant dose for the maximum pollutant removal was determined statistically by Box-Behnken design method. According to Box-Behnken Method which was depended on 10 runs, the optimum coagulant dose was  $24.5 \pm 1.5$  mL dewatered sludge/L wastewater. Also, the optimum COD and TSS were 5478 mg/L and 2498 mg/L, respectively for the maximum pollutant removal efficiency (Table 3). And also, contact time with sludge was 5 minutes for the coagulation process of brewery industry wastewater. The R<sup>2</sup> was 99.8% and the standard deviation is 0.0051 related to these values (Table 3). Table 3 showed the experimental matrix of Box-Behnken design. Figure 2 and 3 demonstrated the response surface analysis and normal probability plot of the analysis. These higher R<sup>2</sup> showed that the converge plot and probability distribution were fitted for the analysis. In full-scale studies, this dose could be used by considering the flow rate.

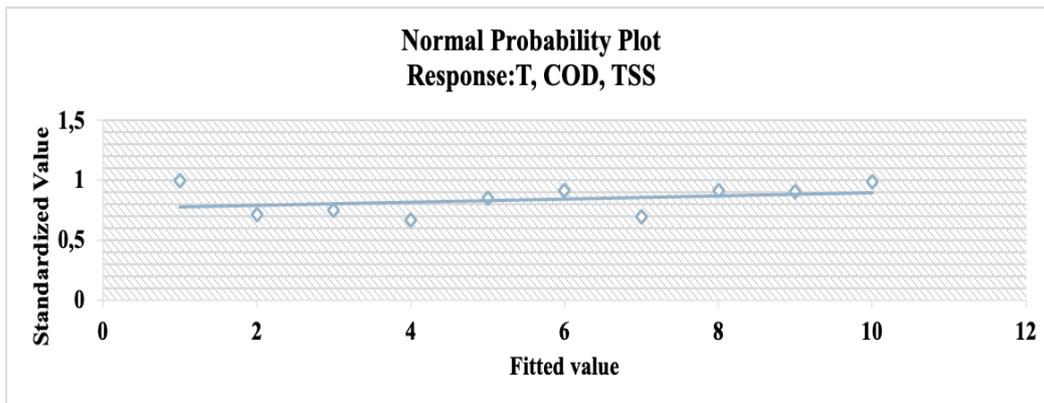
There is a limitation in this study. This study was applied as a lab-scale plant. But the wastewater and water samples were not synthetic, they were sampled from the full-scale plant and in-situ groundwater supply, respectively. Further research should be performed to validate this study.

**Table 3.** Experimental design matrix

Run Order	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	R <sup>2</sup>	Standard Deviation
1	5	5478	2498	0.998	0.0051
2	4	5500	2500	0.710	0.0085
3	6	5347	2621	0.750	0.0083
4	4	5300	2790	0.670	0.0086
5	6	5400	2400	0.850	0.0081
6	7	5678	2771	0.910	0.0059
7	10	5510	2800	0.690	0.0071
8	5	5400	2801	0.910	0.0059
9	3	5600	2921	0.900	0.0065
10	5	5410	2471	0.988	0.0091



**Figure 2.** Response surface methodology



**Figure 3.** Normal probability plot

**3.2. Results of Using Sludge as the Coagulant**

This study revealed that groundwater treatment sludge in the result of coagulation process could be used as the coagulant for brewery industry wastewater. The dewatered alum-depended sludge had aluminum (49.5%), carbon (22.5%), nitrogen (13.5%) and oxygen (4.9%) according to the elemental analysis. This context can trigger the treatment ability of the sludge as a coagulant.

According to the experimental assays, 24.5 ± 1.5 mL dewatered sludge/L wastewater could ensure the removal efficiency of organic materials (66.5% of TSS, 59% of COD removal). Figure 4 showed the removal efficiencies related to each experimental scenario. According to the organic materials removal from brewery industry

wastewater, the highest COD (85%) and TSS (83.5%) removal efficiency related to the ED-3 which using the combination of sludge and ferric chloride as the coagulant. The scenario of ED-2 which used the only FeCl<sub>3</sub> had lower treatment efficiencies (73% of TSS, 69% of COD removal). From these results, it is obvious that alum-dependent sludge enhanced the industrial wastewater treatment performance. The sludge addition improved the treatment performance in the amount of 12% in terms of COD removal. Also, the sludge addition triggered the suspended solids materials removal in the amount of 14.5%. These amendment values confirmed that potable water treatment sludge could be an efficient coagulant for the industrial wastewater treatment.

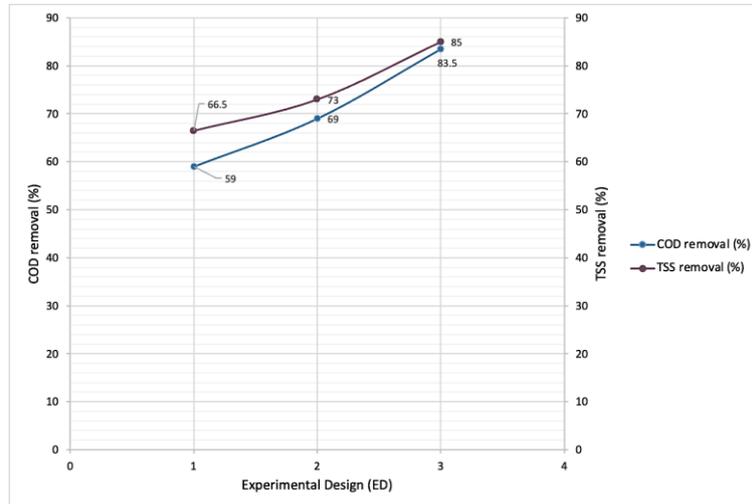


Figure 4. COD and TSS removal efficiencies

### 3.3. Results of Cost Analysis

An economic cost analysis for three experimental scenario was performed by considering the virtual operational costs and the data of brewery industry wastewater treatment plant. The highest operational costs related to the sludge transfer and disposal costs (Table 4). Also, Table 4 showed the detailed cost analysis. The ERI was 0.6875 for all the systems.

Table 4. Results of detailed cost analysis for the brewery industry wastewater treatment

ED	Sludge Amount (kg/d) (Lab-scale)	Virtual Sludge Disposal and Transfer Costs (TL/month)	Chemical Consumption (mL/L wastewater) (Lab-scale)	Virtual Costs of Chemical Use (TL/month)
1	0.02	15 000	0	-
2	0.20	150 000	20	50 000
3	0.05	37 500	10	25 000

According to the detailed operational cost analysis, the highest operational costs related to the sludge disposal and transfer costs. The energy consumption was ignored in this study while calculating the virtual operational costs for the plants. The result showed that sludge using as a coagulant could decrease the sludge management costs in considerable amounts. Also, costs of chemical use (coagulant cost) could be decreased by using the sludge as the coagulant for the brewery industry wastewater treatment plant. The virtual operational costs while using no sludge was 200 000 TL/month. The virtual operational costs while using sludge additionally as a secondary source was 62 500 TL/month. A virtual reduction was 68.75% on the operational costs. Also, a saving on virtual operational costs for potable water treatment plant nearly was 300 000 TL/month while considering the treatment capacity of 10 000 L/d. The sludge disposal costs would be zeroized by using sludge as a coagulant for the potable water treatment plant.

### 4. Discussion and Conclusion

This study revealed that alum-dependent sludge could be used as a coagulant for the brewery industry wastewater treatment. The natural structure of the alum-dependent sludge could trigger the coagulation process and uptake

capacity of organic substances in the brewery industry wastewater. Also, the costs of operations in the treatment plants could be reduced by using sludge as a coagulant in terms of contributing to the circular economy and zero-waste management principals. In the literature, similar studies were done. A study by Nair et al. (2017) [23] was performed on coagulant recovery from potable water treatment sludge. They reported the coagulant recovery ranging from 62.5 to 74.5 % for alum-depended sludge [23]. In this study, all produced alum-depended sludge was recovered as the coagulant. Moghaddam et al. (2010) investigated the dye removal from wastewater by using ferric chloride-depended potable water treatment sludge [24]. They found similarly that sludge could be a low-cost material with the value of 96.53% of dye removal from wastewater [24]. In this study, alum-depended sludge was used and up to 83.5% of organic materials removal by this recovered coagulant. Zhou et al. (2018) reported the ultrasonic coagulation by reusing potable water treatment sludge [25]. They found the effective dissolved organic materials by using potable water treatment sludge [25]. In this study, TSS and COD removal were evidenced by alum-depended sludge. Castro-Jiménez et al. (2024) confirmed and used an alum-depended water treatment sludge for turbidity removal from raw water [26]. In this study, TSS removal reached up to 85% by alum-depended sludge. Nomanifar et al. (2024) investigated the ferric based sludge use as a coagulant for tannery wastewater treatment [27]. They reported 40% of COD and 85% of TSS removal efficiencies using this coagulant [27]. In this study, higher COD removal efficiencies were reported. Liu et al. (2024) investigated the recovery of coagulant from potable water treatment sludge, and they reported higher TSS and organic materials than using polyaluminum chloride (PAC) coagulant [28]. Similarly, up to 85 and 83% of treatment efficiencies were reported for TSS and organic materials, respectively. Benalia et al. (2024) used the alum-depended water treatment sludge as a low-cost coagulant for dye removal from wastewater [29]. They calculated and simulated the 94.44% of dye removal using alum-depended water treatment sludge as the coagulant [29]. In this study, alum-depended sludge was used for TSS and COD removal from brewery industry wastewater. Ndagijimana used the sludge containing biochar and ferric chloride as the coagulant for turbidity and humic acid removal from synthetic wastewater [30]. They reported higher turbidity removal using this novel coagulant [30]. In this study, the wastewater samples were taken from a full-scale plant and alum-depended sludge and similarly ferric chloride were used. Gülhan et al. (2023) performed a techno economic investigation on using of water treatment plant sludge at high rate activated sludge systems [16]. They reported the 11% of reduction on operational costs in the plant by using iron sludge as the coagulant [16]. In this study, higher 68.75% of decrease on virtual operational costs were reported by using alum-depended sludge as the coagulant.

The results revealed that using of potable water treatment sludge as a coagulant in brewery industry wastewater treatment could obtain dual benefits for not only PTWTPs but also brewery industry wastewater treatment plant. In the result of the study, averagely 68.75% of decrease on virtual operational costs for treatment plants was reported by using sludge as a coagulant. Therefore, case studies based on practical applications of potable water treatment sludge use in industrial wastewater treatment plants should be increased in near research in terms of circular economy model for the reuse of this valuable waste as a coagulant. The potable water treatment sludge could be used as a secondary source for the coagulation of brewery wastewater.

## References

- [1] Krause, M. J., & Bronstein, K. E. 2024. Estimating national sludge generation and disposal from US drinking water and wastewater treatment plants. *Journal of Cleaner Production*, 453, 142121.
- [2] Widłak, M., Stoińska, R., & Kowalik, R. 2023. Preliminary assessment of phosphorus mobility in sewage sludge for their potential leaching from soil. *Desalination and Water Treatment*, 288, 208-214.
- [3] Herzel, H., Krüger, O., Hermann, L., & Adam, C. 2016. Sewage sludge ash—A promising secondary phosphorus source for fertilizer production. *Science of the Total Environment*, 542, 1136-1143.
- [4] Kacprzak, M., Neczaj, E., Fijałkowski, K., Grobelak, A., Grosser, A., Worwag, M., & Singh, B. R. 2017. Sewage sludge disposal strategies for sustainable development. *Environmental research*, 156, 39-46.
- [5] Ahmad, T., Ahmad, K., & Alam, M. 2016. Sustainable management of water treatment sludge through 3 'R' concept. *Journal of Cleaner Production*, 124, 1-13.
- [6] Wasserman, J. C., de Oliveira Silva, L., de Pontes, G. C., & de Paiva Lima, E. 2018. Mercury contamination in the sludge of drinking water treatment plants dumping into a reservoir in Rio de Janeiro, Brazil. *Environmental Science and Pollution Research*, 25(28), 28713-28724.
- [7] Samanta, N. S., Das, P. P., Sharma, M., & Purkait, M. K. 2023. Recycle of water treatment plant sludge and its utilization for wastewater treatment. In *Resource Recovery in Drinking Water Treatment* (pp. 239-264). Elsevier.
- [8] Yapicioğlu, P., & Demir, Ö. 2017. Life cycle assessment of sewage sludge treatment-an overview. *Harran Üniversitesi Mühendislik Dergisi*, 2, 78-92.

- [9] Katrivesis, F. K., Karela, A. D., Papadakis, V. G., & Paraskeva, C. A. 2019. Revisiting of coagulation-flocculation processes in the production of potable water. *Journal of Water Process Engineering*, 27, 193-204.
- [10] Yapıcıoğlu, P., & Yeşilnacar, M. İ. 2021. Investigation of energy costs for sludge management: a case study from dairy industry. *Environmental Research and Technology*, 4(3), 277-283.
- [11] Katrivesis, F. K., Karela, A. D., Papadakis, V. G., & Paraskeva, C. A. 2019. Revisiting of coagulation-flocculation processes in the production of potable water. *Journal of Water Process Engineering*, 27, 193-204.
- [12] Bensitel, N., Haboubi, K., Azar, F. Z., El Hammoudani, Y., El Abdouni, A., Haboubi, C., & El Kasmi, A. 2023. Potential reuse of sludge from a potable water treatment plant in Al Hoceima city in northern Morocco. *Water Cycle*, 4, 154-162.
- [13] Ahmad, T., Ahmad, K., Ahad, A., & Alam, M. 2016. Characterization of water treatment sludge and its reuse as coagulant. *Journal of Environmental Management*, 182, 606-611.
- [14] Nayeri, D., & Mousavi, S. A. 2022. A comprehensive review on the coagulant recovery and reuse from drinking water treatment sludge. *Journal of environmental management*, 319, 115649.
- [15] Letshwenyo, M. W., & Mokgosi, S. 2021. Investigation of water treatment sludge from drinking water treated with Zetafloc 553I coagulant for phosphorus removal from wastewater. *Journal of Environmental Management*, 282, 111909.
- [16] Gulhan, H., Dizaji, R. F., Hamidi, M. N., Abdelrahman, A. M., Basa, S., Kurt, E. S., & Ozturk, I. 2023. Use of water treatment plant sludge in high-rate activated sludge systems: A techno-economic investigation. *Science of The Total Environment*, 901, 166431.
- [17] Abo-El-Enein, S. A., Shebl, A., & El-Dahab, S. A. 2017. Drinking water treatment sludge as an efficient adsorbent for heavy metals removal. *Applied Clay Science*, 146, 343-349.
- [18] Kang, C., Zhao, Y., Tang, C., & Addo-Bankas, O. 2022. Use of aluminum-based water treatment sludge as coagulant for animal farm wastewater treatment. *Journal of Water Process Engineering*, 46, 102645.
- [19] Sajath, S. H. M., Nihmiya, A. R., & Arachchige, U. S. P. R. 2022. Handling the Sludge When Using Polyaluminum Chloride as a Coagulant in the Potable Water Treatment Process. *Nature Environment & Pollution Technology*, 21(2).
- [20] Lebogang, K., Ntuli, F., Lekgoba, T., Kandjou, V., & Tsie, M. 2023. Characterization and utilization of water treatment sludge for coagulation of raw water. *Water Science & Technology*, 87(7), 1587-1599.
- [21] American Public Health Association; American Water Works Association. *Standard Methods for the Examination of Water and Wastewater*; American Public Health Association: Washington, DC, USA; American Water Works Association: Denver, CO, USA, 1999.
- [22] Metcalf & Eddy *Wastewater Engineering: Treatment and Resource Recovery*, 5th ed.; McGraw-Hill: Boston, MA, USA, 2014.
- [23] Nair, A. T., & Ahammed, M. M. 2017. Influence of sludge characteristics on coagulant recovery from water treatment sludge: a preliminary study. *Journal of Material Cycles and Waste Management*, 19, 1228-1234.
- [24] Moghaddam, S. S., Moghaddam, M. A., & Arami, M. 2010. Coagulation/flocculation process for dye removal using sludge from water treatment plant: optimization through response surface methodology. *Journal of hazardous materials*, 175(1-3), 651-657.
- [25] Zhou, Z., Yang, Y., Li, X., Li, P., Zhang, T., Lv, X., & Zheng, D. 2018. Optimized removal of natural organic matter by ultrasound-assisted coagulation of recycling drinking water treatment sludge. *Ultrasonics Sonochemistry*, 48, 171-180.
- [26] Castro-Jiménez, C. C., Saldarriaga-Molina, J. C., & García, E. F. 2024. Physical-chemical characterisation of an alum-based water treatment sludge in different raw water turbidity scenarios. *Heliyon*, 10(17).
- [27] Nomanifar, N., Davoudi, M., Ghorbanian, A., Najafpoor, A. A., & Hosseinzadeh, A. 2024. Fe recovery from drinking water treatment sludge for reuse in tannery wastewater treatment: Machine learning and statistical modelling. *Journal of Water Process Engineering*, 60, 105224.
- [28] Liu, J., Zhang, J., Dai, Z., Li, B., Chen, X., & Meng, X. 2024. Recycling aluminum from polyaluminum chloride sludge through acid dissolution and cation resin separation/purification. *Water research*, 262, 122096.

- [29] Benalia, A., Derbal, K., Baatache, O., Lehchili, C., Khalfaoui, A., & Pizzi, A. 2024. Removal of dyes from water using aluminum-based water treatment sludge as a low-cost coagulant: use of response surface methodology. *Water*, 16(10), 1400.
- [30] Ndagijimana, P., Rong, H., Duan, L., Li, S., Nkinahamira, F., Hakizimana, J. C., & Naidu, R. 2024. Synthesis and evaluation of a novel cross-linked biochar/ferric chloride hybrid material for integrated coagulation and adsorption of turbidity and humic acid from synthetic wastewater: Implications for sludge valorisation. *Environmental Research*, 255, 119134.