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PERFORMANCE EVALUATION OF WATER QUALITY AND RESIDUAL SLUDGE PROPERTIES FROM AL-WIHDA WATER TREATMENT PLANT BASED ON EXPERIMENTAL WORK

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ABSTRACT

Evaluation of residual sludge and water quality of a treatment plant is an integrated activity through the analysis of physical and chemical properties related to health, environment, and specific water used. This study aimed to address the characteristics and properties of the raw water, treated water, and the residual sludge from Al-Wihda water treatment plant (WTP) based on two stage. The first is the historical data from 2018 to 2023 and the results showed that the maximum amount of sludge produced was 259.2 kg/1000 m3 exceeded the reported limit, while turbidity and TSS have a significant contribution to the amount of sludge produced by Al-Wihda WTP. The second, experimental tests were carried out for the residual sludge in the sedimentation tank for the duration (15 July-15 December, 2023) and the results showed that the maximum TSS in residual sludge was about 1585 m3/d, while the maximum COD was about 200 mg/L which exceeded the Iraqi standard limit (100 mg/L). The study concluded that residual sludge is dependent on the amount of TSS contained in the raw water and contains high amount of COD that could be used for the treatment of saline wastewater.

KEYWORDS

Al-Wihda WTP, Artificial neural network, Residual sludge, Water treatment plant, Water quality.

1. INTRODUCTION

There is a constant need for clean and safe water for drinking and meeting the demands of a growing population and to support the increasing efforts to provide safe drinking water to the estimated 29% of the world's population that lack access to clean water (WHO 2017). To meet the growing demand, raw water needs to be treated to get rid of suspended sediment, excess mineral content, and microbes in the water. There is a wide range of contaminants present in raw water that come from groundwater and surface water sources (rivers and reservoirs). These contaminants include colloids, organic and inorganic materials, dissolved solids, algae, tiny creatures and solids introduced during chemical treatment (Anjithan, 2016). A popular technique for eliminating colloids and suspended particles from raw water involves adding metal salts to start the coagulation and flocculation process. This process produces enormous amounts of a sludge waste known as water treatment residuals (WTRs), which need to be treated and disposed of or reused at the end of process, usually between (10 - 30 mL) of WTRs for every liter of treated water (Dasanayake et al., 2015). Most surface water treatment plants that employ conventional treatment processes as shown in Fig.1 such as coagulation, flocculation, sedimentation, filtration, aeration, and disinfection produce large amounts of sludge (Anjithan, 2016).

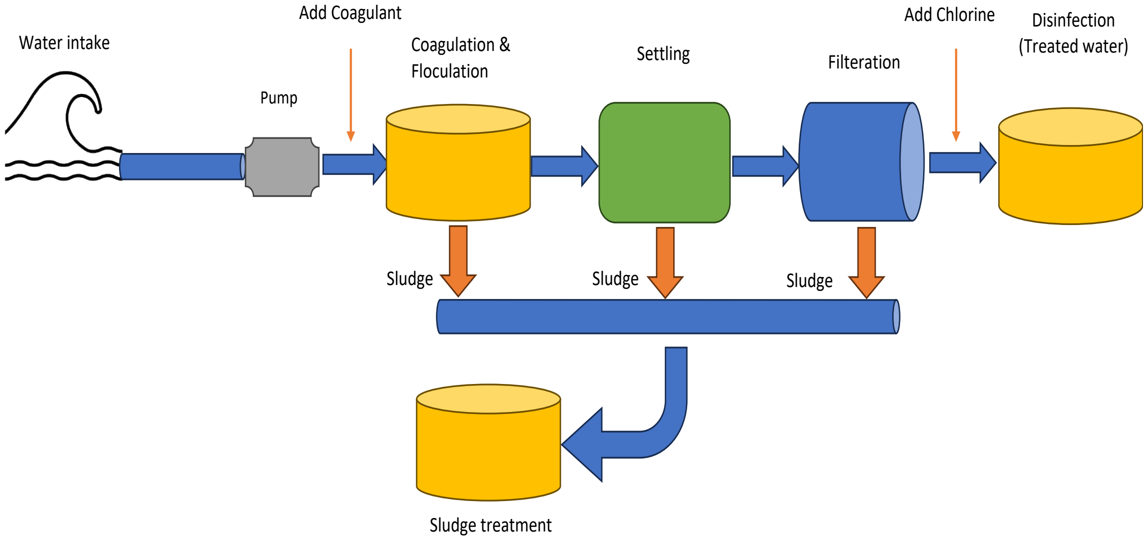

Fig.1. Conventional water treatment plant process.

A wide range of residual products are made through water treatment processes to produce water safe for drinking which include liquid, solid, semi-solid, and gaseous phase by-products. The residual source, the raw water, the chemicals used for treatment, and the types of unit operations employed all affect these quantity and quality residuals. Water treatment sludge (WTS) is a significant byproduct of conventional water treatment processes that cannot be avoided

(Nguyen et al., 2022). The quality of the raw water, the kind of chemical used, and the dosage used in the water treatment process all affect significantly on the composition of WTS, which varies seasonally and amongst treatment facilities (Ahmad et al., 2016). Depending on the location and the raw water quality that is supplied, the treatment technique being used, and the duration of treatment throughout the year, WTS contain a varied range of microorganisms as oocysts and blisters of protozoa, and infections removed during the treatment procedure were presented in the sludge produced from the coagulation process.

The properties, type and source of the treated raw water, the rate at which the water is produced, the type and dosage of coagulant added during the water treatment process, the degree of contamination in the source water and the operating conditions of treatment plants can significantly impact on volume, properties, and characteristics of the water treatment sludge (WTS) (Turner et al. 2019). Water treatment residuals (WTRs) do not have a crystalline structure because they are amorphous, or lack a distinct shape or form, according to chemical analysis of the materials using X-ray diffusion (XRD). However, it was established that WTRs contain quartz, feldspar, calcite, illite/smectite, feroxyhyte, albite, and kaolinite (Ahmad et al. 2018). In addition, significant amounts of nitrogen and phosphorus are present in municipal sludge and biosolids, which are beneficial for landscaping, forestry, reclamation, and agriculture. The type of sludge processing and water treatment used in the municipality, as well as input sources, all have an impact on the amount of each nutrient in biosolids (Enviseng Environmental Consulting Services, 2012).

Adopting advantageous sludge reuse and recovery process becomes crucial as the world's population grows and leads to increase production of water treatment sludge (WTS). This is because disposal options for WTS have been limited by environmental and economic pressures. The reduction in moisture content of the water treatment sludge is a crucial stage in its processing. It would be difficult and completely impractical to manage and treat the sludge if this step is not completed. The quantity and properties of the sludge have an impact on the methods and costs associated with handling its treatment, transfer, and ultimate disposal (Anjithan, 2016). Reducing the sludge amount by raising the solids concentration is crucial for achieving economical management of the sludge which could be accomplished with an appropriate type of treatment. The sludge treatment and disposal methods fall into the following categories: thickening, conditioning (chemical, physical), dewatering (non-mechanical, mechanical), solids minimization, solids recovery and final disposal and landfilling (Qrenawi and Rabah, 2021).

In coagulation-flocculation treatment, the treatment process includes adding different coagulants such as chemical, non-chemical, man-made material or green coagulants (Nayeria and Mousavi, 2022). The chemical salts as iron ($FeCl_2$, $FeCl_3.6H_2O$, $FeSO_4.7H_2O$), and alum ($Al_2(SO_4)_3.18H_2O$), and poly-aluminum chloride (PAC) were used as conventional inorganic coagulants in research. The coagulants enhance the accumulation of particles in the raw water and subsequent sedimentation, so, the total suspended solids (TSS) in the raw water, the type and optimum dose of the coagulant, and the effectiveness of sedimentation process all affect how much solids are produced during coagulation (Nayeria and Mousavi, 2022). In the sedimentation basin, between 60 and 90 percent of the total solids are typically removed, and, in the filters, the leftover solids are eliminated. Total suspended solids (TSS) and turbidity units (NTU) do not necessarily correlate in an absolute sense. Typically, the range of TSS to NTU ratios is between 0.5 and 2. Total solids from an alum coagulation facility have been reported to range from 8 to 210 kg/per 1000 m^3 of treated raw water (Sayed et al., 2000). The residues from drinking water treatment include suspended solids, organic material, and some dissolved ions such as Ca^{2+}, Fe^{2+}, Mn^{2+}. The landfill is the residue end of the water treatment plant, and this causes environmental risks due to the probability of chemicals leaching such as aluminum. The residues can be reused in different ways as aggregates material in the construction field, employed to make environmental treatment materials and as coagulants for treating wastewater (Dias et al., 2023). There are different methods to recover coagulant from sludge of water treatment such as acid digestion (most applied), alkalization, ion exchange and membrane separation Fig.2 (Nayeri and Mousavi, 2022). In addition, a sustainable cold mix asphalt (CMA) with zero carbon emissions is successfully developed for use in road and highway surfacing from using wastewater sludge that would otherwise be disposed of in landfills (Al Nageim, 2024).

Artificial neural network (ANN) is a soft computing technique used to predict the optimum coagulant dosage for effective raw water treatment process. The ANN model setup includes input of water quality parameters of raw water from the Parvati water treatment plant such as turbidity, pH, temperature, and alkalinity. The creation of the ANN model for the prediction of optimum dosage of coagulant showed it effectiveness as the best performing technique (Sawalkar et al., 2024). In addition, another research used ANN model to estimate the optimum coagulant dose required for raw water treatment and the results present that the ANN models can be used for water quality predictions and the optimization of water treatment plant operations (Omondi, et al., 2024). Furthermore, ANN models were utilized to assess water quality and calculate ammonium toxicity in order to efficiently manage wastewater discharge.

The results showed that the ANN model was effective through the analysis of the obtained values (R^2 = 0.9686) for the prediction of the harmful effects of ammonium on aquatic life (Trach et al., 2024).

This research has aimed to study the physico-chemical characteristics of the raw and treated water and the sludge residual to evaluate the water quality and residual sludge properties from water treatment plant based on historical data and experimental work based on artificial neural network (ANN).

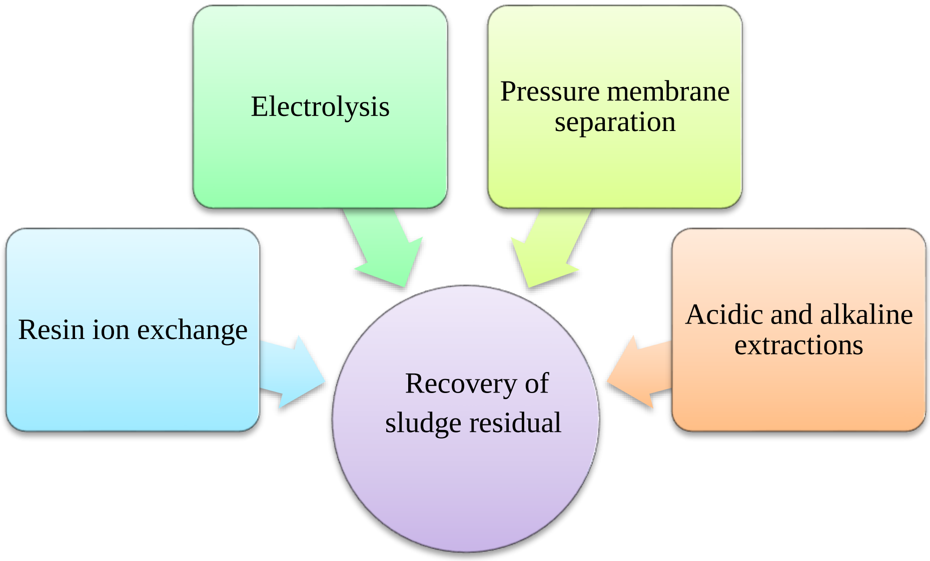

Fig. 2. Recovery of sludge residual from drinking water treatment (DWT).

2. MATERIAL AND METHOD

2.1. Water treatment plants in Baghdad

The Tigris River divides Baghdad, a flat city of around 900 km^2 with 9 million people living in it, into two parts, known as Karkh and Risafa. It will require 4,250,000 m^3/day to produce 500 L/capita /day of drinkable water. Installed and actual capacity are 2,553,000 m^3/day and 2,140,000 m^3/day. Table 1 and 2 provided by the following facilities which are all supplied from Tigris River.

Table 1. WTP capacity and distance properties (Baghdad Mayoralty).

Source	Installed Capacity m^3 /d	Actual Capacity m^3 /d
Al-Karkh	1,365,000	1,150,000
East of Tigris	540,000	500,000
Al-Qadisia	135,000	100,000
Al-Rasheed	67,000	50,000
Al-Wathba	70,000	60,000
Al-Karama	204,000	180,000
Al-Dora	112,000	100,000
Al-Wihda	60,000	50,000
Total	2,553,000	2,140,000

Table 2. Water treatment plant specifications in Baghdad (Baghdad Mayoralty).

No.	Project	Construction year	Design discharge (m^3/hour)	Capital supply percentage	Distance from Al-Karkh Project (km)
1	Al-Karkh	1988	492000	55.80%	0
2	East Tigris	1985	194000	20%	31
3	Al-Karama	1980	58000	7.50%	42
4	Al-Wathba	1978	28000	3.50%	45.5
5	Al-Qadisia	1978	42000	4.90%	57.5
6	Al-Dora	1980	36000	3.80%	61
7	Al-Wihda	1952	24000	2.80%	68
8	Al-Rasheed	1969	160000	1.70%	71

2.2. Study Area

The study area, the Tigris River inside Baghdad City, is located between latitudes 33°14' and 33°25' N and longitudes 44°31' and 44°17' E in the Mesopotamian alluvial plain, at an elevation of 30.5 to 34.85 meters above sea level (a.s.l). The river flows from north to south as shown in Fig. 3, dividing the city into two sections: the left (Risafa) and the right (Karkh). The region experiences dry, burning summers and chilly winters due to its arid to semi-arid environment, with an average annual rainfall of roughly 151.8 mm.

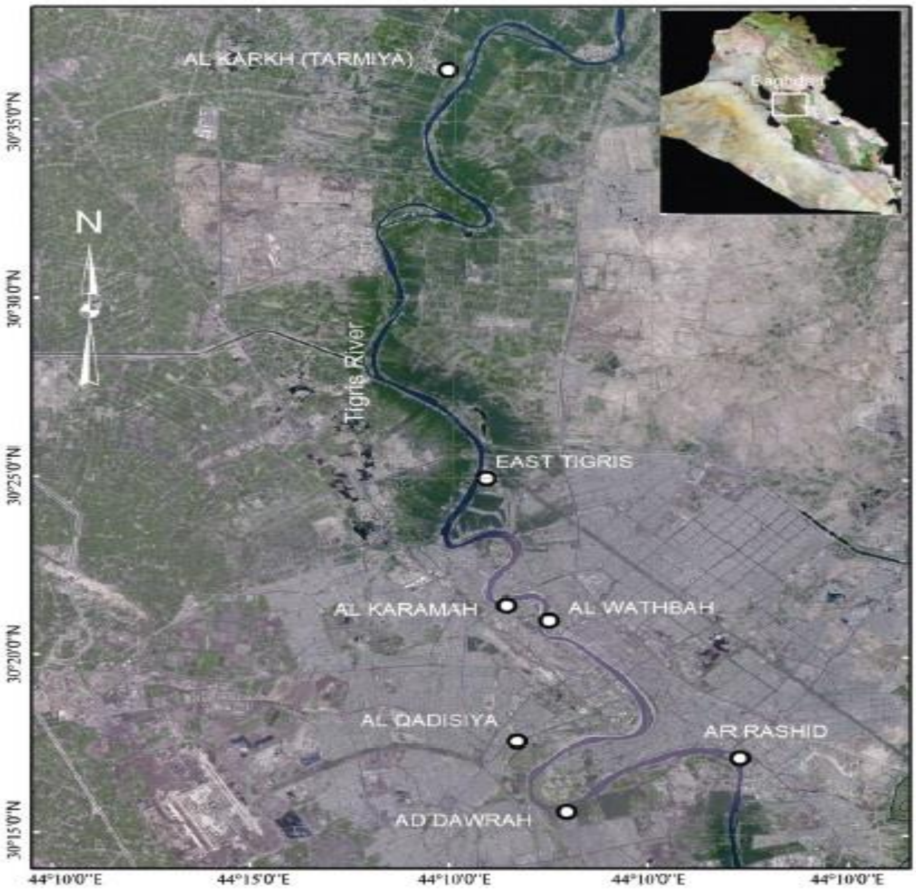

Fig. 3. Sampling locations across Tigris River, Baghdad City.

2.3. Al-Wihda Water Treatment Plant (WTP)

The location of Al-Wihda WTP in the neighborhood for the General Company of Vegetable Oils is at the entrance of Street Almusbah. It consists of two water treatment projects: the first, finished in 1942, supplies water to the Arsat Alhndiaa neighborhood and portions of the Karrada district and industrial district, which are situated between the Al-Rasheed Camp and the Uqba Bin Nafeaa area and its surroundings, and the second, finished in 1959, supplies water to the Camp Sara neighborhood in Riyadh, Industry Street, University of Technology, 52 Street, and surrounding areas. Since the plant is one of the oldest water purification facilities in Iraq, it was completed during the monarchy and has not seen any attempts to keep up with industrial development. High consumption of water is common in these regions, especially during the day due to high population density. This presents a significant deficit and raises important questions about the possibility of providing these areas with enough drinking water.

The water intake is situated nine meters down the Tigris River, and floating debris and algae are kept out by a rubber guard. The pump station consists of three pumps; two of them are in use while the third is in reserve. The maximum capacity of the pumps operating during the summer and the high consumption during the day is to run standby pumps in addition to the main pumps with the intention of bridging the growing consumption during that period. Each pump has a total energy of 680 m3/h and a pressure head of 40 m of water. The rapid mixing basin is intended to receive the water raised from the river by means of these pumps. To manage the quantity of water extracted from the river, a well-organized system is located close to the lift station.

2.3.1. The Purification Process

After water is received from a river, it is first treated in rapid mixing basins. There are no blenders in these basins, and the plant does not use a slow mixing procedure either. Instead, the coagulant (alum) is added at the fastest possible speed (by center minutes in advance) and combined by the hydraulic force of the water flow. Subsequently, the water was carried straight from the rapid mixing speed basins to the clarifier with dimensions (22 m x 23 m), which known as a sedimentation basin with a scraper at the bottom for removing floating materials and clays. Then, the water was transferred to the secondary sedimentation basin, that has the same dimensions as the first basin but without a scraper. The depth of both basins is the same, measuring 3 meters at the sides and 5 meters in the middle. Gates positioned in the center for this reason are used to draw out the sludge that has gathered there.

2.4. Sample Collection

The data used in this paper for analyzing sludge properties were provided by Baghdad Mayoralty (Amanat Baghdad) and covers the period from 15 July to 30 December in 2023. Sludge samples have been collected out of the sedimentation tanks and washing the filters in a 5-liter sterile plastic container, mixed, and the samples were taken according to the specifications of each test. Shortly after being collected, samples were examined for heavy metals and chemical and physical characteristics. The data were recorded every two weeks and compared the results with the Iraqi standard limits. For evaluating the sludge properties and its effect on the environment, a set of eleven water quality parameters and eleven heavy metals have been chosen considering the availability of data as well as the significance of the parameters. These parameters are Temperature, Total Suspended Solids (TSS), pH, COD, BOD, F, Cl^-, $SO^{-2}{}_4$, $NO^-{}_3$, PO_4, $NH^+{}_4$, Pb, As, Cu, Ni, Se, Cd, Zn, Cr, CO, Fe and Mn. The sampling and analysis were conducted according to the standard methods (APHA, 2012). In addition, the data of raw and treated water samples were used for analyzing the quality of raw and treated water of Al-Wihda WTP and were provided by Baghdad Mayoralty for the period from 2018 to 2023. The data were combined (monthly average values for each parameter) to achieve a data set that covered six years for two parameters of raw water (the Tigris River before treatment) and drinking water (after treatment).

2.5. An artificial neural network model (ANNM)

An artificial neural network (ANN) model was employed to estimate the effect of the tested parameters (Cl^-, pH, Temperature, NO_3, NH_4, BOD, COD, PO_4, F and SO_4^{-2}) of the sludge on the value of the total suspended solids (TSS) concertation. The model was developed through multiple tests, training, and holdout trials. The first model consisted of 11 experimental samples and were randomly distributed into three groups: training (7), testing (2), and holdout (1). While the second model consisted of 19 samples and were randomly distributed into three groups: training (13), testing (4), and holdout (2). The rescaling method for data is standardization, and the hidden layer is 3. The ANN model was used to estimate the mathematical relationship between the independent and the dependent variables. The coefficient of determination R^2 was used to assess the degree of similarity and identify the connection between the recorded and predicted values (IBM SPSS Neural Networks, 2011).

3. RESULTS AND DISCUSSIONS

3.1. Raw and Treated Water Quality

it might be challenging to distinguish between turbidity and suspended solids (tss) because the terms are frequently used synonymously. Water is defined as having a certain degree of transparency and clarity, which decreases with the amount of suspended particles in it. Therefore, total suspended solid (TSS) is a quantifiable measurement of suspended particles in water, whereas turbidity is a measure of how well light can penetrate through water. High turbidity readings are generally correlated with high TSS levels. Particle size, shape, and refractive index, for example, can all affect this connection (Serajuddin et al., 2019). The ratios between TSS and turbidity were estimated for the average data from 2018 to 2023. As a result, the average values of total suspended solids (TSS) in treated water produced from Al-Wihda WTP were measured based on the correlation with turbidity, as shown in Fig. 4. This result is in consistent with (Abed and Khudair, 2023), as they found that there was a relationship between TSS and turbidity with R^2 (0.802). Syed et al. (2000) reported that the total suspended solids (TSS) and the turbidity units do not correlate in an absolute sense, the typical ratio of TSS to turbidity ranges from 0.5 to 2. The turbidity in the raw water entered Al-Wihda WTP in May and August were about 622 and 42 NTU, respectively, as shown in Fig.5. While the highest turbidity in treated water in May and August were about 4.3 and 4.2 NTU, respectively as shown in Fig. 4. The values are almost similar despite that the entered turbidity value are highly different, even in cases where the treated water's turbidity levels satisfy Iraqi standards, if pumping is carried out without conducting continuous cleaning operations, materials accumulate and are subsequently re-suspended at high velocity due to the population's fluctuating daily demand, as mentioned by (Abed and Khudair, 2023). These results showed that turbidity and TSS have a high contribution to the amount of sludge produced from Al-Wihda WTP. Because suspended solids and turbidity have a connection, it is possible to predict how much suspended solids should contribute to the total amount of sludge (Crittenden et al., 2012).

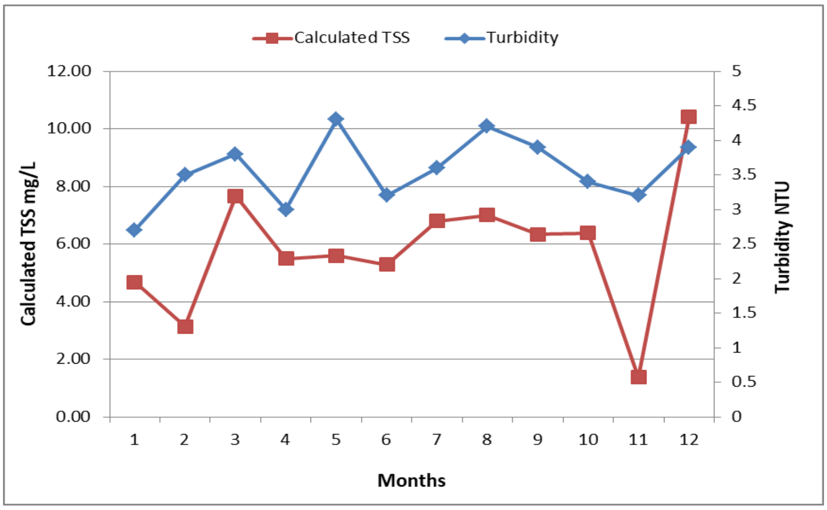

Fig.4. Average values of turbidity and calculated TSS of treated water.

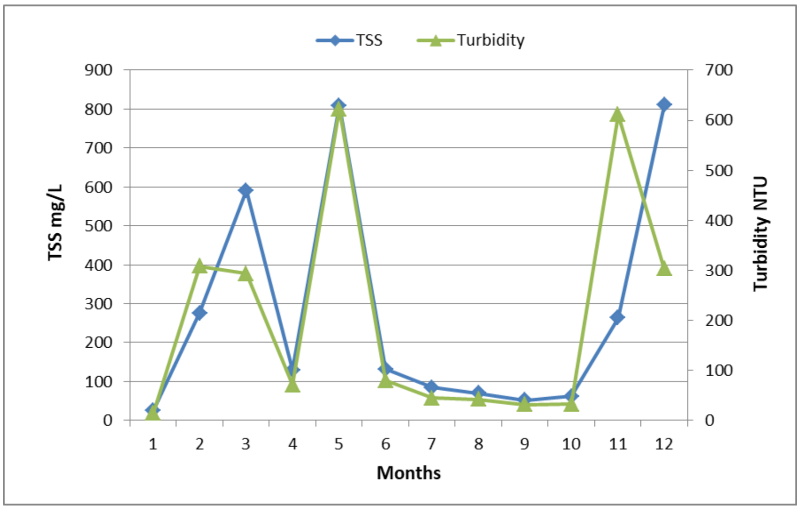

Fig.5. Average values of turbidity and TSS of raw water.

3.2. Residual Sludge Quality

The physical and chemical quality of residual sludge were estimated based on some parameters such as TSS, pH, Cl, SO_4^{-2}, NO_3, COD, BOD and temperature. Syed et al. (2000) reported that from 8 to 210 kg/1000 m^3 total solids of treated raw water can be obtained from an alum coagulation unit. Data analysis results for the period from 2018 to 2023, showed that the maximum quantity of sludge produced was 259.2 kg/1000 m^3 which exceed the reported limit due to the lack of water discharges from the Tigris River, which led to an increase in the concentrations of mud and other organic and inorganic materials, and the average quantity of sludge produced was 88.32 kg/1000 m^3, which is within the reported limit in Syed et al. (2000). According to the design calculation for the period from 2018 to 2013, the maximum TSS volume in sludge produced from the sedimentation and filtration processes in Al-Wihda water treatment plant was about 567 m^3/d, while the maximum TSS volume in sludge produced from Al-Wihda WTP for the period from 15 July to 15 December 2023 was about 1585 m^3/d, as shown in Fig. 6. This increase occurred in October due to an increase in the river flow rate with high amount of silt and suspended matter led to an increase in water turbidity.

In addition, COD values exceeded the Iraqi standard limit during the period of study of sludge quality, as shown in Fig.7. This could be because there is not any organic material present to encourage anaerobic conditions or active decomposition, consequently, the sludge is sometimes left to build up in sedimentation basins for days or months before being periodically removed (Syed et al., 2000). This type of sludge that contain high amount of COD may called aerobic granular sludge (AGS) which could be used for the treatment of saline wastewater at different salinities, due to its compact form and resistance to chemical loadings (Xiao et al., 2024). Fig.8 shows temperature decreasing steadily during the period of study due to winter season and this could effect on the sludge drying process as the total precipitation and evaporation rate will decrease (Syed et al., 2000). While Fig.9 shows the change in concentration of the other parameters presented in the sludge sample**,** the change were moderately during the period of study and within the allowable Iraqi limit.

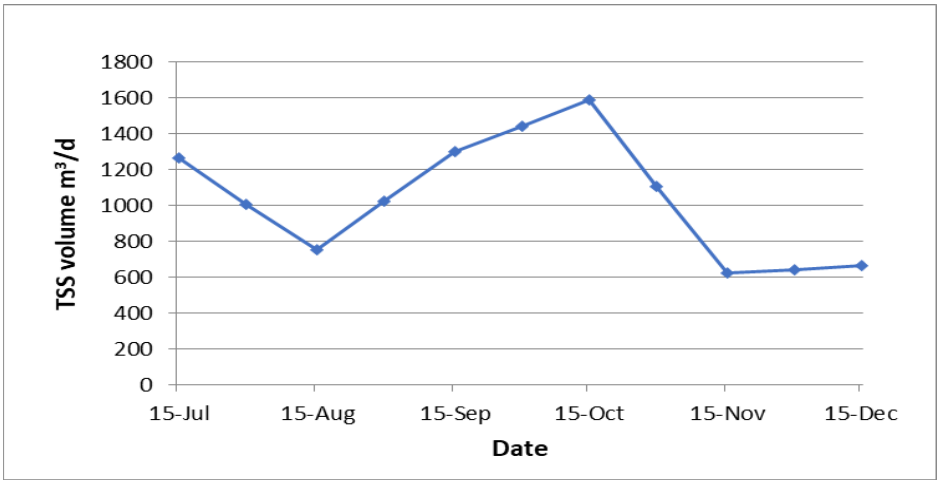

Fig.6. TSS volume in sludge during fixed Date.

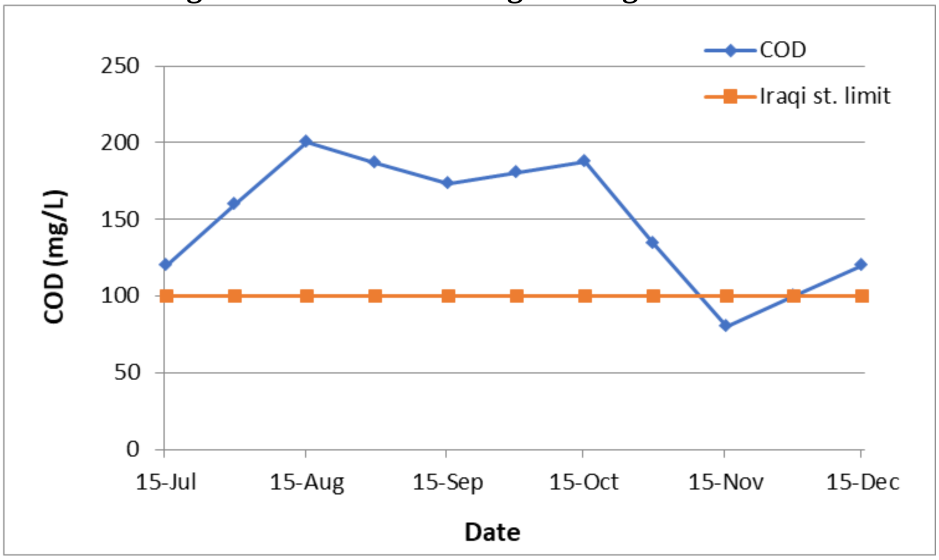

Fig.7. COD concertation in sludge during fixed Date.

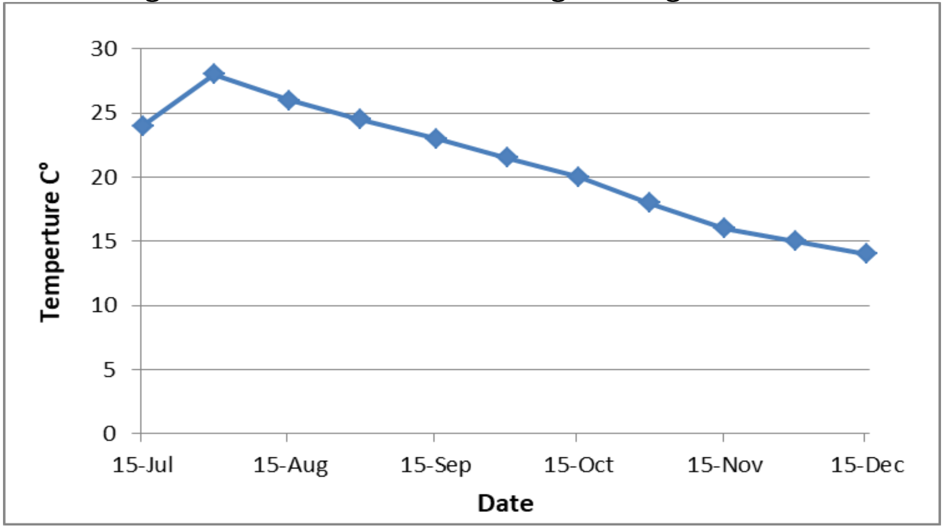

Fig.8. Changing the temperature of sludge during fixed Date.

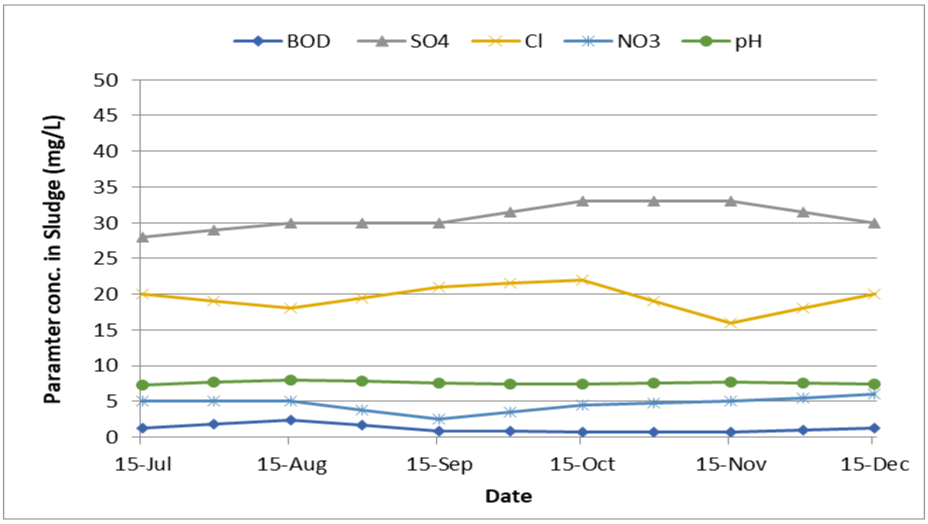

Fig.9. Water parameter concertation in sludge during fixed Date.

3.3. Artificial Neural Network (ANN)

ANN modeling was applied for the input data to estimate the output value of the dependent variable TSS as shown in Fig.10. The results showed that the relationship between the observed and predicted TSS value with the highest determination coefficient R^2 (0.993) and the model was successful, as shown in Fig.11. The influence of the various values of the independent variables on the value of the predicted model is explained by the importance of the independent variables (Kukreja et al., 2016). In this research, the parameter that mostly effect on the predicted TSS value was the ion of chloride Cl^- in both models, as shown in Figs. 12 and 13 that consistent with the previous study carried out by Mohsin and Khudhair (2021).

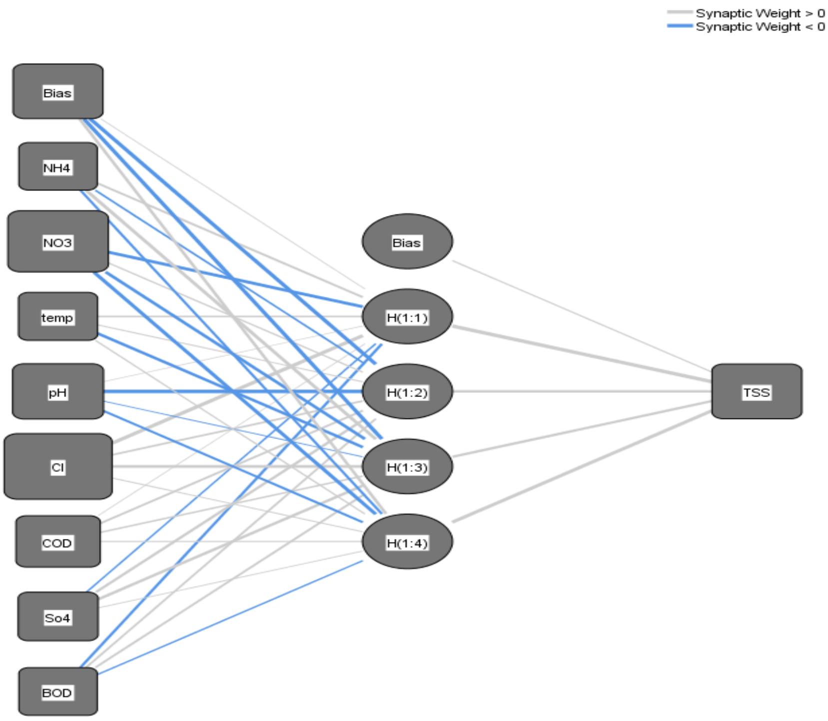

Fig.10. ANN model with layers of input and output variables.

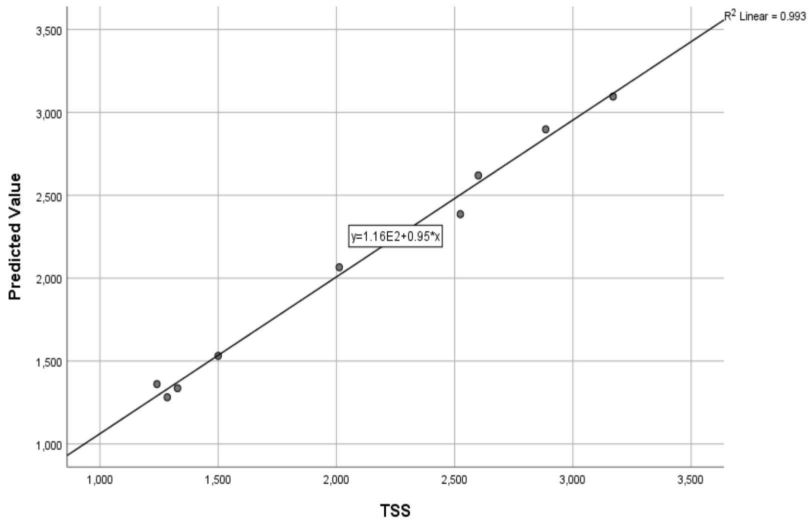

Fig.11. Predicted and observed value of TSS for the first model.

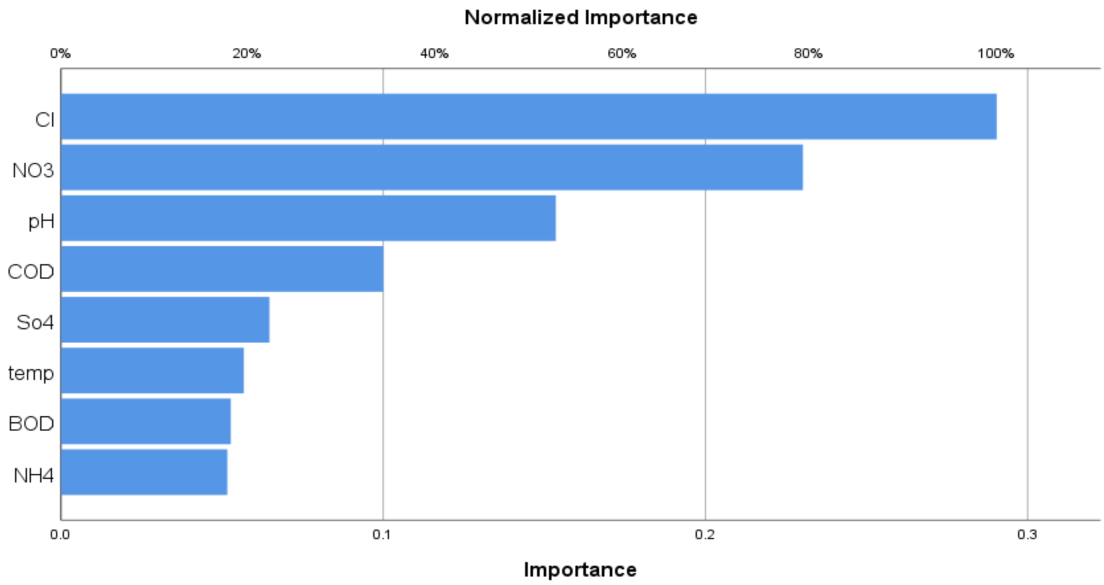

Fig.12. The importance of water parameters affecting TSS value.

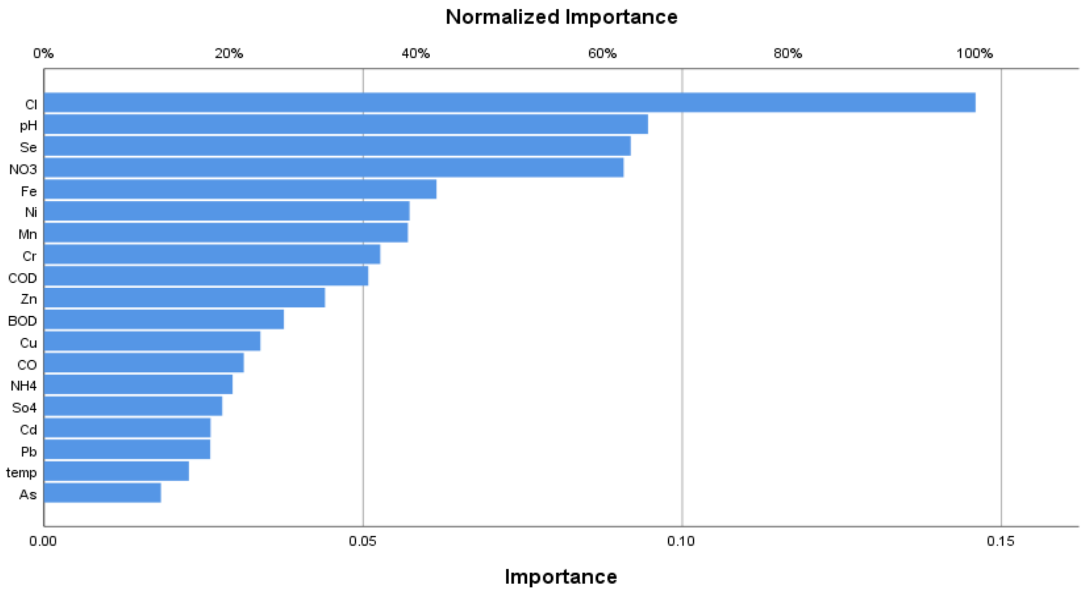

Fig.13. The importance of water parameters and heavy metals affecting TSS value.

4. CONCLUSION

Residual sludge and water quality are evaluated as part of a combined procedure for water treatment plant that involves examining physical and chemical characteristics associated with the environment, human health, and the water being used. This study concluded that turbidity and TSS have a high contribution to the amount of sludge produced from Al-Wihda WTP. In addition, the maximum amount of sludge produced was 259.2 kg/1000 m^3 exceed the reported limit because there were insufficient Tigris River water discharges, the concentrations of mud and other organic and inorganic components increased. While the results of analyzing sludge samples showed that the maximum TSS volume in sludge produced from Al-Wihda WTP for the period from 15 July to 15 December 2023 was about 1585 m^3/d. Furthermore, COD values exceeded the Iraqi standard limit during the period of study of sludge quality 45 More work should be done regarding developing technical instructions in many industries based on research studies to promote the reuse, recycling, and recovery applications of WTS. Due to limitation study of effect using residual sludge contained high amount of COD need to for more research for sustainable environment.

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