Water Air Soil Pollut (2025) 236:612
https://doi.org/10.1007/s11270-025-08259-6

Hydraulic Flocculation in Benha Water Treatment Plant with SPSS

E. M. Fathy · M. E. Basiouny · O. A. AboSiada

Received: 2 October 2024 / Accepted: 13 June 2025

Abstract This study investigates hydraulic flocculation within the Benha water treatment plant, utilizing the Statistical Package for the Social Sciences (SPSS) for data analysis. The surface water source examined in this research is El-Riah El-Tawfeeqi, located in Benha City, Egypt. A pilot plant, designed to simulate a conventional water treatment facility in Benha City, was employed to evaluate the performance of vertical versus horizontal baffles during the flocculation phase. In this setup, hydraulic mixing replaced mechanical mixing for rapid flash mixing, while vertical and horizontal baffles substituted mechanical gentle mixing. The primary objective of introducing hydraulic baffles was to decrease the dependency on mechanical mixing, thereby optimizing energy consumption. Additionally, the study aimed to assess turbidity reduction and identify the more effective configuration—vertical or horizontal baffles. Turbidity levels were measured using a turbidimeter, and the optimal Alum dosage was determined through jar testing. Water quality parameters were analyzed at the Qalyubia Water and Wastewater Company (QWWCO) laboratory, with samples collected between January 2021 and May 2023. Results revealed that vertical baffles exhibited superior efficiency in hydraulic mixing, achieving a 17% greater reduction in turbidity compared to horizontal baffles.

Keywords Conventional water treatment · Hydraulic flocculation · Baffles flocculation · Vertical baffles · Horizontal baffles

E. M. Fathy (✉)
QWWCO (Qalyubia Water and Wastewater Company), Qalyubia, Benha, Egypt
e-mail: em_mo2200@yahoo.com

M. E. Basiouny
Prof. of Sanitary & Environmental Engineering, Dean of Faculty of Engineering in El-Arish, Sinai University, Sinai, Egypt
e-mail: m.basiouny11@yahoo.com

O. A. AboSiada
Assistant Prof. of Sanitary & Environmental Engineering, Civil Engineering Department, Benha Faculty of Engineering, Benha University, Benha, Egypt
e-mail: eng_osa79@yahoo.com

1 Introduction

The process of flocculation enables colloidal particles to clump together and form larger flocs that are easier to separate by settling or filtering (Wang et al., 2005). The type and dosage of the coagulant, the temperature and pH of the raw water, the concentration of the pollutant in the raw water, the mixing speed, and the floc formation time are some of the main factors that determine how effective the coagulation-flocculation process is in the treatment process. Particles produced by flocculation can be eliminated by filtration or sedimentation (Howe et al., 2012). Destabilized colloidal particles aggregate as a result of flocculation, forming rapidly settling flocs. Horizontal paddles and vertical

Published online: 25 June 2025

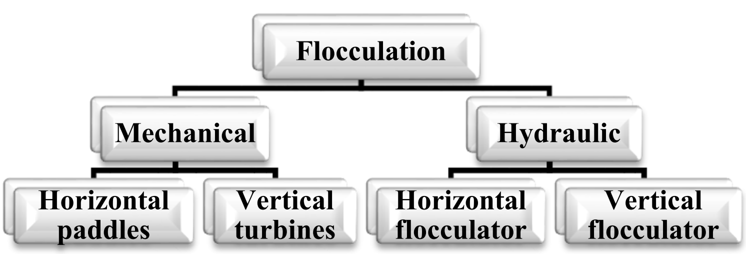
turbines are now the most used prime mover forms in mechanical flocculation; however, new developments are always being made, as Fig. 1 illustrates (Howe et al., 2012).

Hydraulically mixed flocculation is popular in developing nations because it eliminates the need for mechanical equipment. For G (gradient velocity), recommended designs vary from 20 to 70^{-1} for a 20–30-min contact duration (Liu et al., 2004). In order to avoid short-circuiting and make it easier to incorporate zones of lower energy input and tapered velocity gradients, flocculation basins are typically constructed with numerous compartments. The tapered feature can be achieved by adjusting the paddle size, number of paddles, diameter of the paddle wheels, and rotational speed (variable-speed drives) (Wang et al., 2005). Compact hydraulic flocculators are designed to be long and narrow with fewer connections to weld. This makes manufacturing and installation easier for industries where the available footprint is small but the available height is large, as discovered by (Bilde et al., 2023). (Pennock et al., 2021) used vertically baffled flocculators (VBFs) at lower flow rates (below 170 L/s) and horizontally baffled flocculators (HBFs), which are more economical for larger flow rates. Seventeen flocculators were designed using this vertically baffled hydraulic flocculator design concept, which has been proven to have reliable performance and minimal operating and maintenance costs in Central America. In the 5 L/s design example, the footprint of the VBFs was five to ten times less than that of an equivalent HBF.

(Ghawi, 2018) utilized computational fluid dynamic (CFD) in vertical baffles and showed that when the flocculation tank height to baffle spacing ratio is 22.5 and the clearance height to baffle spacing ratio is 1 with turbidity less than 1 NTU, the design of the vertical hydraulic flocculation optimization in terms of uniformity happens. (Pennock et al., 2023) used the AguaClara Hydraulic Flocculation Model which has hydraulic flocculators chosen for their sustainability in drinking water treatment plants, such as the gravity-powered plants designed by Cornell University's AguaClara program implemented in Honduras. It predicts the settled turbidity for hydraulic flocculation. The study findings demonstrated an exponential relationship between k and the sedimentation capture velocity, which appears to be related to the shape of normal particle size distributions. In order to produce micro-vortices and boost flocculation efficiency, (Wang et al., 2023) integrated vortex generators into a novel column-cone-column vortex flocculation reactor.

Two types of the environmentally friendly hydraulic slow mixing basin—horizontal and vertical—were created by (Ghawi et al., 2023) in order to configure the internal baffle, which has a capacity of 700 m^3/hour. According to the findings, a slow-moving hydraulic mixing trough with a horizontal baffle and a 98% removal efficiency might be used to enhance the performance of the former Al-Ad Diwaniyah water project while also being environmentally benign. A vertical flow tube flocculator was shown to be an extremely successful method of removing color and turbidity from the raw water used for purification (García-Ávila et al., 2023b). The maintenance of this flocculator required less time than that of hydraulic baffle flocculators. (García-Ávila et al., 2023a) investigated the differences in performance between a large-scale horizontal tubular flocculator (HTF), an easily implementable approach for the provision of drinking water, and a standard baffle flocculator. The average results showed that 98.8% of turbidity and 99.93% of color were eliminated. (de Oliveira & Costa Teixeira, 2017) investigated the performance of the helical tubular flocculator for turbidity removal. Higher removal efficiency of 86.2% to 80% was attained, outperforming flocculators with baffles, which are frequently used for purification in underdeveloped nations. (Pyakurel et al., 2024) investigated

Fig. 1 The types of flocculation



the effectiveness of a hydraulic flocculator. The filter unit maintained a consistent efficiency of 54.10% and 57.69%, respectively, both in the presence and absence of coagulation.

(Cahyana et al., 2021) achieved good results on two pipe diameter sizes: turbidity reduction efficiencies of 76.7% and 78.5% were observed in 0.625-inch pipe with a 0.4 m helix diameter, and 72.4% and 73.9% in 0.5-inch pipe with a 0.8 m helix diameter of 0.8 m, using helical (helix) spiral coiled pipe with a flow rate of 13 mL/s. The helically coiled tube flocculator (HCTF), a coagulation/flocculation device, was invented by (Oliveira & Donadel, 2024). Even in situations where dimensional hydraulic parameters exhibit significant variability, the process efficiency fluctuations range from 1.3% to 5.2%. (Kambuyi et al., 2021) used electrocoagulation for turbidity removal from surface water. The turbidity removal efficiency was 72.05% and energy consumption was 0.210 kWh/m^3. (Desye et al., 2021) discovered, using SPSS, that the water quality parameters (turbidity, residual chlorine, total coliform, and facal coliform) did not fall within the WHO drinking water quality guidelines' allowable ranges.

Principal component analysis (PCA), Pearson correlation index (PCI), and clustering analysis (CA) were among the statistical methods employed by (Ustaoğlu et al., 2020) to examine the data. The Hazard Quotient (HQ) and Hazard Index (HI) were used to evaluate the relevance of trace elements for public health risks, while the Water Quality Index (WQI) was used to evaluate the stream's water quality. The results show that the Turnasuyu Stream has extremely good water quality features, and that the amounts of trace elements were not dangerous for the health of the general people. Under various operating conditions, (Bote & Desta, 2022) found that the electrocoagulation process was a successful way to remove turbidity from household wastewater. The experimental investigation was optimally optimized using response surface methodology after the numerical and statistical data were analyzed. This resulted in an Al–Fe electrode combination of 91.053% and an Fe–Al electrode combination of 96.68%.

Four mathematical models—ANN (artificial neural networks), SVM (support vector machine), ANFIS (adaptive neuro-fuzzy inference system), and RSM (response surface methodology)—were developed by (Tahraoui et al., 2021) and used to create models that could forecast the amount of coagulant needed to remove organic materials and turbidity. (Alenazi et al., 2020) found that turbidity remediation using coagulation agents derived from *Strychnos potatorum* seeds could be replicated using the central composite design (CCD) technique, a component of RSM. The Box-Behnken design (BBD) was utilized in the statistical experimental planned by (Ezemagu et al., 2021), and the RSM was employed to describe the findings. The ANN outperformed the RSM model in describing the parametric impact, with lesser absolute average deviation (AAD) and percentage relative error (PRE) of $\pm 0.0241\%$ and $\pm 0.0139\%$, respectively.

RSM and ANNs coupled with genetic algorithms (ANN-GA) were employed by (Kusuma et al., 2021) to assess the flocculation process. An initial turbidity and a maximum turbidity removal of 96% were determined using the ANN model. With confidence intervals set at 95% ($\alpha = 0.05$) and $p < 0.05$, (Ahmad et al., 2022) used the SPSS version 21 (IBM, USA) to find significant differences from experiment findings. The Kolmogorov–Smirnov method was used to test the acquired results for homogeneity and normal distribution. (Dayarathne et al., 2022) used SPSS to investigate how temperature affected the coagulation process' ability to remove turbidity. After 10 min of sedimentation at pH 7, the effectiveness of removing turbidity was calculated to be 83% at 2 °C and 78% at 40 °C.

This research aims to:

1. Use horizontal and vertical baffles instead of mechanical flocculation in Benha water treatment and compare them.
2. Evaluate the water quality by using statistical analysis for samples taken from the water treatment plant using SPSS V26.

2 Materials and Method

2.1 Study Area

Benha water treatment is a traditional water treatment plant that has a design capacity of 800 L/s (Table 1). Its intake takes from El-Riah El-Tawfeeqi. It is located at El-mawqaf El-gdeed in Benha City as in Fig. 2. The layout of Benha water treatment is shown in Fig. 3.

Table 1 Description of the components of Benha water treatment

Component of Benha water treatment	Descriptions
Pipe intake	3 pipes of 600 mm diameter with 150 m length
Raw water pipe diameter	800 mm
Pump of raw water	6 pumps with 220 L/s
Distribution tank	6*6*17 m
Rapid flash mixing	4 (2.5*2.5) m
Detention time of rapid flash mixing	30–60 s
Mechanical flocculation tank	4 (21*12) m
Detention time of flocculation tank	20–30 min
Sedimentation tank	4 (57*12) m
Filtration tank	10 (10*6) m

2.2 Experimental Work and Pilot Plant

The pilot plant depends on design requirements (McConnachie & Liu, 2000). This pilot project simulates a traditional water treatment facility located in Benha, Qalyubia Governorate. Table 2 shows that the pilot's dimensions are all dependent on the Benha water treatment plant's G-value as well as additional design requirements (G =30 S-1) (Joodi, 2013). In order to verify the velocity gradient, the dynamic similarity is utilized to account for the velocity, viscosity, and gravitational force (fraud number, Reynolds number) (Visconti & Ruggieri, 2020); (Lohse, 2022); (Çengel & Cimbala, 2010). The measurements

Fig. 2 The location of Benha water treatment plants

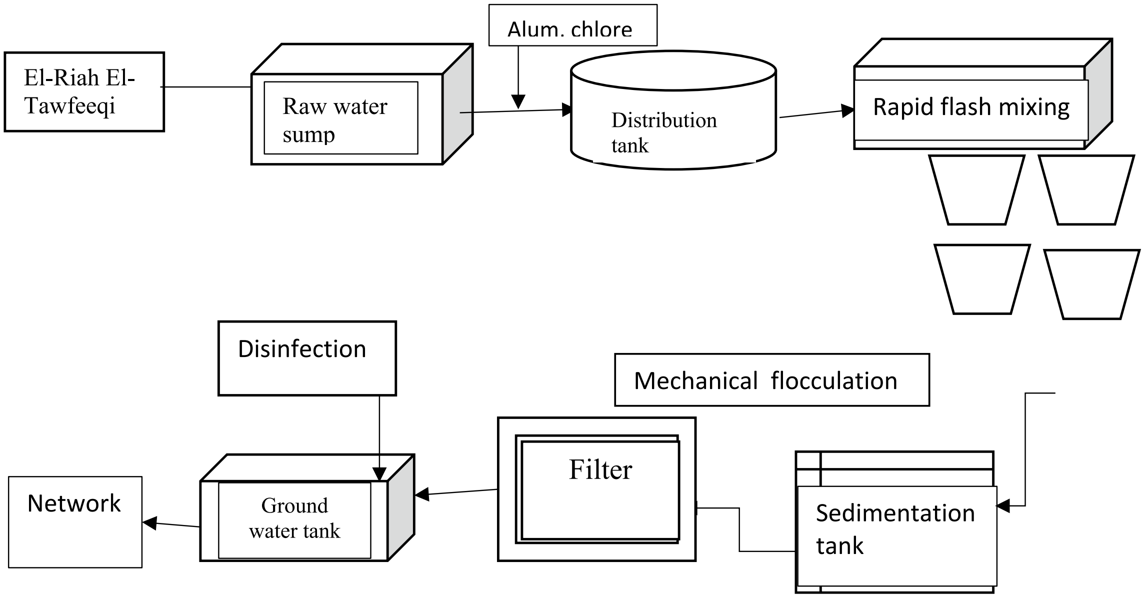


Fig. 3 The layout of Benha water treatment

Table 2 The dimensions and details of the pilot plant

Component of pilot plant	Dimension
Hydraulic rapid flash mixing	15*15 *40 cm square shape with V-notch
Pump flow	5–26 L/min at head 15–26 m with hp 0.35
Hydraulic flocculation	75*40*62 cm
Inlet pipe diameter	2.54 cm plastic pipe

were made in the Benha water treatment facility prior to the fast flash mixing and flocculator, and the outcomes were simulated in our prototype. The average velocity of the flocculator in Benha water treatment is 1.1 m/sec in the inner pipe to the flocculator. This value is the basis for the pilot's design as shown in Fig. 4.

The pilot consists of Inlet pipe intake, pump, flowmeter, pipe connection, rapid flash mixing tank, injection regulator, v- notch weir, flocculation tank, baffles. Figure 5 shows the two rectangular acrylic tanks that the pilot is using. The quick flash mixing in Fig. 5A uses a 15 by 15 cm square form with a V-notch. Using the pump, remove the water from the raw water sump at the Benha water treatment plant, as indicated in Fig. 2. The hydraulic flocculation shape is found in Part B. There are both horizontal and vertical baffles. As seen in Figs. 6 and 7, the baffles flocculator tank has nine baffles spaced 7.5 cm apart. The flow enters through a 1-inch plastic pipe diameter at the top of the fast flash mixing system. Alum is used in a flash mixing machine to create the coagulation, which is then injected in minute doses using tiny tools. After that, proceed via the channel and V-notch to get to the hydraulic mild mixing (Lin et al., 2013). The experiments will be done through five stages. First Stage measuring the pipe enter to the rapid flash mixing. The used device is ultrasonic flow meter. The data enter to the device for the rapid flash mixing and has outer diameter 541 mm and

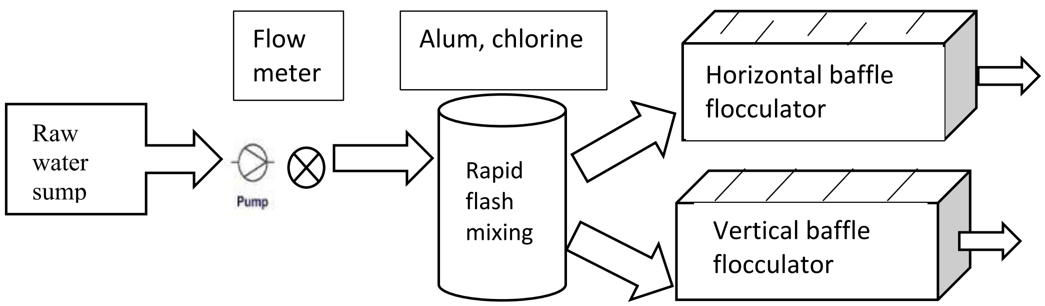


Fig. 4 Schematic diagram of the pilot plant in Benha water treatment

Fig. 5 The pilot used in the test

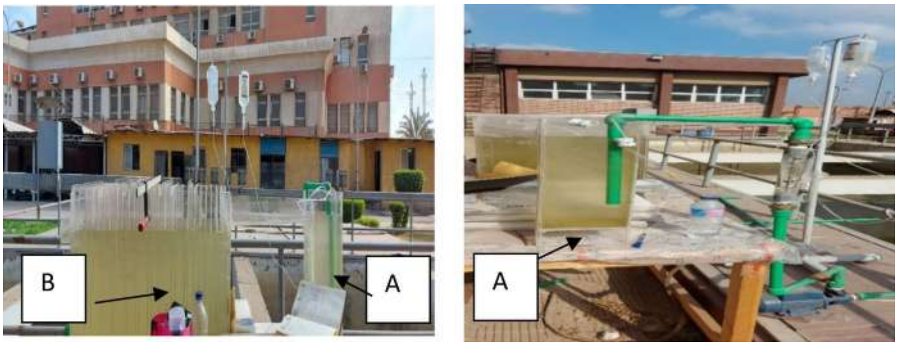


Fig. 6 The horizontal baffles

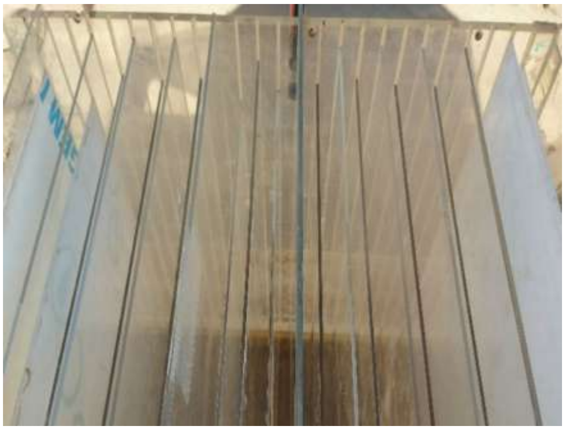


Fig. 7 The vertical baffles

inner diameter is 527mm. The pipe type is stainless steel with cross section area is 0.218 m^2. The minimum velocity and maximum velocities are 0.889 m/s and 1.44 m/s. based of this velocity we adjust the flow simulate to the Benha water treatment plant. Second Stage put the horizontal baffles in the pilot. This test is taking time from January 2021 to January 2022. In the same interval of time, we used vertical pipe. In this stage used the same flow 0.28 l/s. Detention time of rapid flash mixing is 1 min. the detention time for flocculation is different 18,27,28,29,30 min with constant alum dose 28 P.P.M from jar test.Third Stage change the alum dose (24,26,28,30,33) P.P.M with detention time 18 min for flocculation tank and 1 min for rapid flash mixing. This test is taking time from January 2021 to January 2022. In the same interval of time, we used vertical pipe. Forth Stage using vertical baffles with alum dose 26 P.P.M with detention time 18 min with different media type (gravel, plastic and foam). The flow is constant 0.28 l/s. The duration of this test from December 2022 to May 2023. The percentage of NTU results removed at various detention times, as determined by the relation below, shows the effectiveness of turbidity removal: According to (Muthuraman & Sasikala, 2014) and (Montgomery, 2009), %Removal =(N_1-N_2) *100/N_1, where N_1 is the initial turbidity (NTU) and N_2 is the final turbidity (NTU).

2.3 Sample Collection

Water samples were collected from the Nile River from El-Riah El-Tawfeeqi. (Ali & El Shehawy, 2017) collected samples from Damietta branch and made stastical analysis on the result of physical and biological analysis. From January 2021 to May 2023, samples were collected from the raw water sump located at the Benha water treatment plant. Water samples were taken in a plastic beaker and examined at the plant's laboratory.

2.4 Laboratory Analysis

Seven parameters were measured in the Benha lab of the water treatment (NTU for Nile River N_1, NTU after using Alum for horizontal (hl) baffles N_2 and vertical (vl) baffles N_3, conductivity, pH, alkalinity, and temperature (TMP)) (APHA, 2017).

All laboratory analyses followed the conventional procedures. The jar test determined the optimal concentration of aluminum sulfate for suspended matter removal. All laboratory analyses followed the conventional procedure (Rice et al., 2012b); (Alsaeed et al., 2022; Pivokonský et al., 2022). Alum and chlorine were used in the prototype to make coagulation and flocculation. The jar test was made in the Benha lab of Benha water treatment by simulating the treatment process of the Benha water treatment plant. The number of revolutions in rapid flash mixing was 120 for 60 s. The number of revolutions for gentle flash mixing was 60 for 20 min, followed by a sedimentation phase for 10 min. The optimum dose ranged from 24 to 30 P.P.M.

2.5 Statistical Models

Multiple regression analysis was used to build statistical models to modify the results. The theoretical details of the analysis can be found in various statistics textbooks, including (Watkins, 2021) and (Denis, 2021). Stepwise multiple regression analysis was carried out in this study using SPSS V26 software. $Y = a0 + b1X1 + b2X2 + b3X3 + b4X4 + e$ (5) was the generic multiple regression equation that was modified. In this equation, Y represents the dependent variable, $a0$ = intercept, $b1$, $b2$, $j3$, $j4$ = partial regression coefficients, $X1$, $X2$, $X3$, $X4$ = independent variables, and e = error term (residuals). The residual turbidity ($N2$, N3), the dependent variable in this study, will be predicted for both horizontal and vertical baffles with various parameters:

1. Optimum-Coagulant-Dose (CO)

Here, the independent variables for coagulants are

$$X1 = \text{pH}, X2 = N1, X3 = \text{TMP}, \text{ and } X4 = \text{CO}.$$

2. Optimum-Flocculation-Period (TO)

Here, the independent variables for both coagulants are

$$X1 = \text{pH}, X2 = N1, X3 = \text{TMP}, \text{ and } X4 = \text{TO}.$$

3 Results and Discussion

3.1 Descriptive Statistics of Raw and Production Water Parameter

Table 3 lists the descriptive statistics that were derived from the water supplied to the Benha water treatment plant. In contrast to the peak of the normal distribution, the parameters with a negative Kurtosis value—temperature, alkalinity, pH, turbidity for the Nile River N1, turbidity after hl N2, and vl baffles N3—have a flat peak (Saravanan et al., 2023). The arithmetic mean is less than the median when the skewness coefficient for all parameters is negative (excluding conductivity). This means that the frequency distribution curve is skewed to the left, and these factors contribute to reduce the value of the data set (Issa & Abdulrazzaq, 2024).

In order to select the best test for this data, the Shapiro–Wilk and Kolmogorov–Smirnov tests were used to ascertain if the water quality parameter data were normally distributed or not. The following methods were followed in order to execute the test's null hypothesis:

- If the data distribution is normal (F0), it is not normal (FA).
- Reject F0 and accept FA if P (Sig.) < (0.05), indicating that the data distribution is non-normal.
- If P (Sig.) > (0.05), the data distribution is considered normal; accept F0 and reject FA.

The turbidity NTU of the Nile River has significant values (Sig.) larger than 0.05, according to the normality tests mentioned in Table 4, suggesting

Table 3 Descriptive statistics of raw and production water parameters

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
TMP (°C)	54	15.0	30.0	23.777	4.5724	−0.498	0.325	−1.389	0.639
Conductivity (EC)	54	318.0	512.0	381.03	53.18	1.061	0.325	0.302	0.639
pH	54	7.100	8.100	7.71574	0.303	−0.892	0.325	−0.740	0.639
Alkalinity	54	130.0	160.0	145.98	8.21	−0.043	0.325	−1.172	0.639
N_1 (NTU)	54	11.0	15.0	13.244	0.945	−0.203	0.325	−0.135	0.639
N_2 after hl baffles (NTU)	54	7.0	12.5	10.127	1.624	−0.352	0.325	−1.239	0.639
N_3 after vl baffles (NTU)	54	5.90	11.5	8.642	1.715	−0.035	0.325	−1.421	0.639
Valid N (list-wise)	54								

Table 4 Tests of normality

	Kolmogorov-Smirnov[a]			Shapiro–Wilk		
	Statistic	df	Sig	Statistic	df	Sig
TMP (°C)	0.224	54	0.000	0.853	54	0.000
Conductivity (EC)	0.201	54	0.000	0.866	54	0.000
pH	0.313	54	0.000	0.783	54	0.000
Alkalinity	0.156	54	0.002	0.944	54	0.013
N_1 (NTU)	0.120	54	0.050	0.967	54	0.137
N_2 after hl baffles (NTU)	0.201	54	0.000	0.920	54	0.002
N3 after vl baffles (NTU)	0.156	54	0.002	0.923	54	0.002

[a]Lilliefors Significance Correction

that their normalcy has been disrupted. The remaining parameters, on the other hand, show disturbed non-normality with Sig. values smaller than 0.05. Shapiro–Wilk and Kolmogorov–Smirnov tests were employed (Rafique et al., 2022). The t and ANOVA tests, for example, can be used to test the data set with disrupted normality, whereas the chi-square test can be used to evaluate other data (Nasir et al., 2022). ANOVA was utilized by (Hassan et al., 2024) to analyze water quality in the drain.

As can be seen in Table 3, the results of the pH measurement showed that there were no discernible annual fluctuations in the pH of the water in the study area, with recorded pH values falling between 7.1 and 8.1. According to (Othman et al., 2011), the optimal pH range for effective coagulants is between 6 and 8.5. pH has an impact on the proportion of turbidity removed. The percentage of turbidity reduction falls as pH rises (Ernest et al., 2017). According to (Xiao et al., 2009), temperature plays a significant role in the coagulation of water treatment, with a temperature range of 15–30 °C. The viscosity of water increases and the flocculation process decreases at low temperatures (0–24 °C). The viscosity of water increases and the flocculation process decreases at low temperatures (0–24 °C). The floc size reduction is larger at temperatures above thirty degrees (Bratby, 2016). The TDS in this investigation varied from 205 to 240 mg/l. The TDS and EC are connected. High total dissolved solids are indicated by a high EC (Rusydi, 2018). The value of it varied between 318 µS/cm and 495 µS/cm. The Nile River's turbidity varied from 11 to 22 NTU. Numerous elements influence it, including geography, vegetation, precipitation, farming, urban development operations, and geology (Rice et al., 2012a; Siliem, 1995).

3.2 Results of Turbidity Removal for Horizontal and Vertical Baffles at Different Detention Times

Alum coagulant dose, pH, turbidity of the Nile River (N1), and TMP are some of the variables that affect the percentage of removal values (Brown et al., 2012; Manseau et al., 2022). After hl baffles flocculation, the turbidity levels vary from 7 to 16 NTU. In any other case, the readings following the vl baffles flocculator fall between 5.5 and 15.5 NTU. According to (Ghawi, 2018) and (Marques & Ferreira Filho, 2017), the hydraulic flocculation is dependent on the hydraulic gradient and the intensity of energy distribution in the system, which is often related to guaranteeing the product of velocity gradient and retention time, GT. Figure 8 illustrates the contrast between horizontal and vertical baffles. According to test results, vl baffles remove more turbidity in percentage terms than hl baffles do. To improve the mixing, the water flows vertically in order to produce turbulence. In the vertical baffles, turbidity removal varied from 15 to 65%. The horizontal baffles, on the other hand, registered 9% to 53%. According to (Obianyo & Agunwamba, 2019), in a sedimentation tank, vertical baffles perform better at low flow than horizontal baffles. Here, the G-value is simulated to the flow of the Benha water treatment facility, and the flow is constant.

According to (Pennock et al., 2023), residual turbidity is better when increasing the detention time. The detention time study is at 18 min, 27 min, 28 min, 29 min, and 30 min. This is because of the settling behavior of suspended particles and floc particles which are collected during their movement in the big part of the solution forming settled particles. (Sartori et al., 2015) stated that the baffles flocculator has a hydraulic detention time lower than mechanical flocculation.

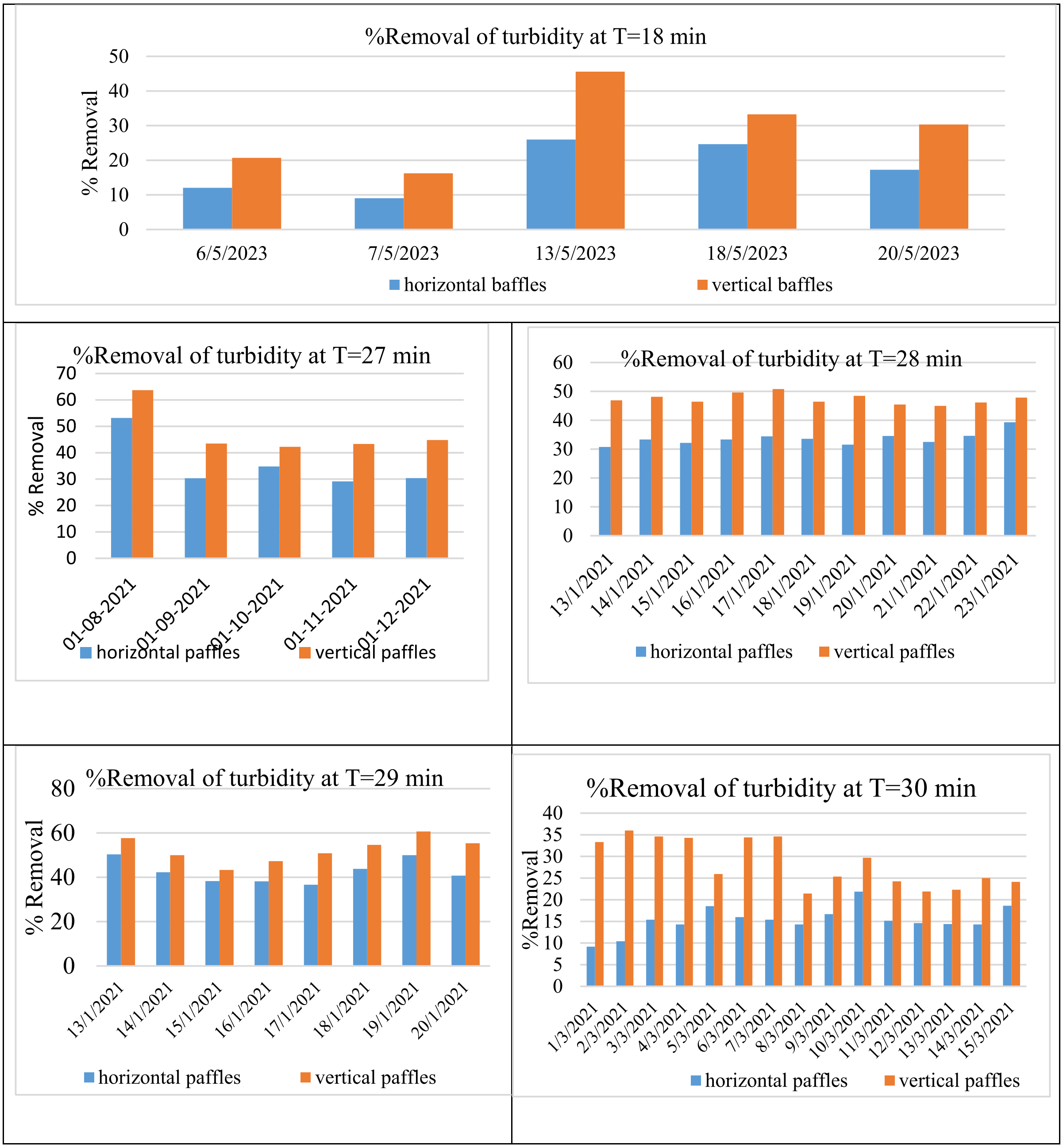


Fig. 8 The recorded values of %removal of turbidity in horizontal and vertical baffles

3.2.1 Studying the Normality Distribution and Homogeneity of Variance of Data

Using SPSS V26 software, data were examined for all parameters, such as Nile turbidity, vertical baffles, and horizontal baffles. All parameters, with the exception of T = 27 min, follow the normal distribution, according to the results of the Kolmogorov–Smirnov and Shapiro–Wilk tests for normal distribution (Nasir et al., 2022). According to the Kolmogorov–Smirnov and Shapiro–Wilk tests, the P value is bigger than the significance level (0.05), which does not rule out the

Table 5 Tests of normality for horizontal and vertical baffles

	Detention time (min)	Kolmogorov-Smirnov[a]			Shapiro–Wilk		
		Statistic	df	Sig	Statistic	df	Sig
N_1 (NTU)	18.00000	0.125	27	0.200*	0.970	27	0.612
	27.00000	0.346	5	0.050	0.713	5	0.013
	28.00000	0.220	11	0.144	0.893	11	0.152
	29.00000	0.205	8	0.200*	0.959	8	0.803
	30.00000	0.087	31	0.200*	0.969	31	0.495
N_2 after hl baffles (NTU)	18.00000	0.170	27	0.045	0.880	27	0.005
	27.00000	0.243	5	0.200*	0.894	5	0.377
	28.00000	0.171	11	0.200*	0.962	11	0.790
	29.00000	0.207	8	0.200*	0.927	8	0.486
	30.00000	0.129	31	0.200*	0.946	31	0.121
N_3 after vl baffles (NTU)	18.00000	0.130	27	0.200*	0.940	27	0.123
	27.00000	0.450	5	0.001	0.638	5	0.002
	28.00000	0.218	11	0.151	0.929	11	0.405
	29.00000	0.272	8	0.083	0.924	8	0.464
	30.00000	0.180	31	0.012	0.938	31	0.071

*This is a lower bound of the true significance

[a]Lilliefors Significance Correction

Table 6 Test of homogeneity of variance for horizontal and vertical baffles

		Levene Statistic	df1	df2	Sig
N_1 (NTU)	Based on mean	4.771	4	77	0.002
	Based on median	3.045	4	77	0.022
	Based on median and with adjusted df	3.045	4	28.307	0.033
	Based on trimmed mean	4.269	4	77	0.004
N_2 after hl baffles (NTU)	Based on mean	24.963	4	77	0.000
	Based on median	21.087	4	77	0.000
	Based on median and with adjusted df	21.087	4	53.358	0.000
	Based on trimmed mean	25.012	4	77	0.000
N3 after vl baffles (NTU)	Based on mean	16.449	4	77	0.000
	Based on median	12.093	4	77	0.000
	Based on median and with adjusted df	12.093	4	38.444	0.000
	Based on trimmed mean	16.664	4	77	0.000

null hypothesis because the results of Table 5 indicate that the differences are not significant.

Additionally, the data were subjected to the Levene test, which revealed that, as indicated in Table 6, the P value was less than the significance level (0.05), indicating that the homogeneity of variance did not follow the data, with the exception of the median for the turbidity of the Nile River. Table 7 displays the results of the reliability test of the data based on Cronbach's Alpha Reliability (Saravanan et al., 2023).

Table 7 Reliability statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.874	0.882	3

The model's overall Cronbach's Alpha score is 0.874, or 88% reliability, which is a high indicator of reliability.

3.3 Statistical Modeling for Horizontal and Vertical Baffles

Using a multiple regression model, this study used data on the elimination of turbidity in the Nile River after hl and vl flocculation with varying detention times at the optimal Alum dose of 28 P.P.M. using SPSS V26. According to (Muniz & Oliveira-Filho, 2023), 121 papers on water quality employed multiple regression models, with the following outcomes:

$N_2 = 1.712 + 0.8551N_1 - 0.063TO$	(after horizontal baffles)
$N3 = -4.682 + 1.131N1\text{-}0.022TO$	(after vertical baffles)

This indicates that pH and TMP, the independent variables, were not statistically significant. According to (Dayarathne et al., 2022), there was no discernible change in turbidity reductions when reuse sludge was increased between 10 °C and 30 °C. Viscosity declines with temperature, and settling occurs more quickly between 2 °C and 30 °C. The result at 40 °C is intriguing, yet it is consistent across all pH values, indicating the presence of more particles or distinct floc structures. The average floc is larger and more buoyant at 40 °C, an effect that has previously been seen. According to (Niu et al., 2022), there is a reasonably substantial root mean square error of 0.794 and a mean absolute error of 0.872 between the theoretical settlement temperature model velocity and the actual velocity.

The above regression in Tables 8 and 9 gave F-ratio = 124.969,81.85 compared to the theoretical F (0.05, 2, 31) = 3.32 (which resulted from the tables); this means that regression was highly significant. R^2 = 0.89,0.841 indicates that the regression contribution ratio was very acceptable and had strong relationships (Issa & Abdulrazzaq, 2024). The Durbin-Watson ratio was d = 1.471, 1.197 indicating that *e* was serially uncorrelated (independently distributed).

3.3.1 Effect of Alum dose

The study used data from turbidity removal in the Nile River and after hl flocculation and vl flocculation with varying Alum doses with a detention time of 18 P.P.M using SPSS V26 and a multiple regression model. (Schreiber et al., 2022) discovered that linear regression and correlation are the most commonly utilized statistical methods, with the following outcome:

$N_2 = 18.499 + 0.212N_1 - 0.334CO$	(after horizontal baffles)
$N3 = 12.486 + 0.279N1\text{-}0.237CO$	(after vertical baffles)

In comparison to the theoretical F (0.05, 2, 28) = 3.49 (which came from the tables), the above

Table 8 ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig
1	Regression	52.326	2	26.163	124.969	0.000[b]
	Residual	6.490	31	0.209		
	Total	58.816	33			

[a]Dependent Variable: Turbidity after hl flocculation (NTU)

[b]Predictors: (Constant), detention time (min), turbidity NTU of the Nile River

Table 9 ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig
1	Regression	73.408	2	36.704	81.850	0.000[b]
	Residual	13.901	31	0.448		
	Total	87.310	33			

[a]Dependent Variable: Turbidity after vertical flocculation (NTU)

[b]Predictors: (Constant), detention time (min), turbidity NTU of the Nile River

Table 10 ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig
1	Regression	29.228	2	14.614	4.268	0.024[b]
	Residual	95.876	28	3.424		
	Total	125.104	30			

[a]Dependent Variable: Turbidity after hl flocculation (NTU)

[b]Predictors: (Constant), Alum dose (P.P.M), turbidity NTU of the Nile River

Table 11 ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig
1	Regression	28.491	2	14.245	1.796	0.185[b]
	Residual	222.063	28	7.931		
	Total	250.553	30			

[a]Dependent Variable: Turbidity after vl flocculation

[b]Predictors: (Constant), Alum dose (P.P.M), turbidity NTU of the Nile River

regression in Tables 10 and 11 produced an F-ratio of =4.268,1.796. This indicates that the regression was only highly significant for horizontal baffles when the Alum dose was changed. According to (Issa & Abdulrazzaq, 2024), the regression contribution ratio shows mild connections between turbidity and Alum (R2 =0.234,0.114). d= 1.931, 1.52 for the Durbin-Watson ratio showed that *e* was serially uncorrelated, or independently distributed. The optimal turbidity removal efficiency of 83% was predicted by (Ezemagu et al., 2021) using the RSM model at conditions of ×1 (1 g/L), ×2 (16.5 min), and ×3 (45◦C). This prediction was validated experimentally at 82.73% with a low model lack of fit F value of 0.6 and CV value of 8.22%.

4 Conclusion

This prototype used coagulation and flocculation in one unit using hydraulic mixing instead of mechanical mixing. From the prototype, it is clear that the result of the vertical baffles flocculator is better than that of the horizontal baffles flocculator. The percentage of removal in horizontal baffles is 33%. The percentage of turbidity removal in vertical baffles is 50%. The efficiency of the proposed system is increased with the increase in the initial turbidity of raw water. The results show that vertical baffles' efficiency is better than horizontal baffles' in hydraulic mixing by 17% of turbidity removal.

Acknowledgements We thank everyone who helped and supported us to complete and acheive this research.

Author Contributions Authors contributed to the study conception and design, material preparation, data collection, analysis, writing, and review. All authors read and approved the final manuscript.

Funding There is no funding regarding this work.

Data Availability Data will be made available on request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Ahmad, A., Abdullah, S. R. S., Hasan, H. A., Othman, A. R., & Ismail, N. I. (2022). Potential of local plant leaves as natural coagulant for turbidity removal. *Environmental Science and Pollution Research, 29*(2), 2579–2587.

Alenazi, M., Hashim, K.S., Hassan, A.A., Muradov, M., Kot, P., & Abdulhadi, B. (2020). *Turbidity removal using natural coagulants derived from the seeds of strychnos potatorum: statistical and experimental approach* (p. 012064). IOP Publishing.

Ali, E. M., & El Shehawy, A. (2017). Environmental indices and phytoplankton community structure as biological indicators for water quality of the River Nile, Egypt. *Egyptian Journal of Aquatic Biology and Fisheries, 21*(1), 87–104.

Alsaeed, R. D., Alaji, B., & Ibrahim, M. (2022). Modeling jar test results using gene expression to determine the optimal alum dose in drinking water treatment plants. *Baghdad Science Journal, 19*(5), 0951–0951.

Bilde, K. G., Hærvig, J., & Sørensen, K. (2023). On the design of compact hydraulic pipe flocculators using CFD-PBE. *Chemical Engineering Research and Design, 194*, 151–162.

Bote, M. E., & Desta, W. M. (2022). Removal of turbidity from domestic wastewater using electrocoagulation: Optimization with response surface methodology. *Chemistry Africa, 5*(1), 123–134.

Bratby, J. (2016). *Coagulation and flocculation in water and wastewater treatment*. IWA publishing.

Brown, R., Lemay, M., Allard, M., Barrand, N., Barrette, C., Bégin, Y., Bell, T., Bernier, M., Bleau, S., & Chaumont, D. (2012). Climate variability and change in the Canadian Eastern Subarctic IRIS region (Nunavik and Nunatsiavut). Nunavik and Nunatsiavut: From science to policy. An Integrated Regional Impact Study (IRIS) of climate change and modernization, 57–93.

Cahyana, G. H., Suwandhi, P., Mulyani, T. (2021). *Novel helical or coiled flocculator for turbidity reduction in drinking water treatment: a performance study* (p. 012009), IOP Publishing.

Çengel, Y.A., & Cimbala, J.M. (2010). *Fluid Mechanics: Fundamentals and Applications*. McGraw-Hill Higher Education.

Dayarathne, H., Angove, M. J., Jeong, S., Aryal, R., Paudel, S. R., & Mainali, B. (2022). Effect of temperature on turbidity removal by coagulation: Sludge recirculation for rapid settling. *Journal of Water Process Engineering, 46*, 102559.

de Oliveira, D. S., & Costa Teixeira, E. (2017). Experimental evaluation of helically coiled tube flocculators for turbidity removal in drinking water treatment units. *Water SA, 43*(3), 378–386.

Denis, D. J. (2021). *Applied univariate, bivariate, and multivariate statistics: Understanding statistics for social and natural scientists, with applications in SPSS and R*. John Wiley & Sons.

Desye, B., Belete, B., AsfawGebrezgi, Z., & Terefe Reda, T. (2021). Efficiency of treatment plant and drinking water quality assessment from source to household, gondar city, Northwest Ethiopia. *Journal of Environmental and Public Health, 2021*, 1–8.

Ernest, E., Onyeka, O., David, N., & Blessing, O. (2017). Effects of pH, dosage, temperature and mixing speed on the efficiency of water melon seed in removing the turbidity and colour of Atabong River, Awka-Ibom State, Nigeria. *International Journal of Advanced Engineering, Management and Science, 3*(5), 239833.

Ezemagu, I., Ejimofor, M., Menkiti, M., & Nwobi-Okoye, C. (2021). Modeling and optimization of turbidity removal from produced water using response surface methodology and artificial neural network. *South African Journal of Chemical Engineering, 35*, 78–88.

García-Ávila, F., Méndez-Heredia, A., Trelles-Agurto, A., Sánchez-Cordero, E., Alfaro-Paredes, E. A., Criollo-Illescas, F., Tonon-Ordoñez, M. D., & Heredia-Cabrera, G. (2023a). Experimental evaluation of tubular flocculator implemented in the field for drinking water supply: Application in the developing world. *Water, 15*(5), 833.

García-Ávila, F., Tenesaca-Pintado, D., Novoa-Zamora, F., Alfaro-Paredes, E. A., Avilés-Añazco, A., Guanuchi-Quito, A., Tonon-Ordoñez, M. D., & Zhindón-Arévalo, C. (2023b). Vertical tubular flocculator: Alternative technology for the improvement of drinking water treatment processes in rural areas. *Journal of Environmental Management, 331*, 117342.

Ghawi, A.H. (2018). *Optimal design parameters for hydraulic vertical flocculation in the package surface water treatment plant* (p. 28). Przegląd Naukowy Inżynieria i Kształtowanie Środowiska.

Ghawi, A.H., Tisti, H.J.M., & Shallal, M.A. (2023). *Study the hydraulic mixing tank to improve the performance of water treatment plants*. AIP Publishing.

Hassan, A., Samy, G., Hegazy, M., Balah, A., & Fathy, S. (2024). Statistical analysis for water quality data using ANOVA (Case study–Lake Burullus influent drains). *Ain Shams Engineering Journal, 15*(4)

Howe, K. J., Hand, D. W., Crittenden, J. C., Trussell, R. R., & Tchobanoglous, G. (2012). *Principles of water treatment*. John Wiley & Sons.

Issa, M.S., & Abdulrazzaq, K.A. (2024). *Statistical analysis of Al-Qadisiyah water treatment plant*. AIP Publishing.

Joodi, A. S. (2013). Effect of baffles geometry of the flocculation basin on the turbulence behavior using Comsol multiphysics technique. *Journal of Environmental Studies, 10*(1), 71–77.

Kambuyi, T. N., Bejjany, B., Lekhlif, B., Mellouk, H., Digua, K., & Dani, A. (2021). Design of a continuous-flow single-channel reactor using optimal experimental data from batch reactor for turbidity removal by electrocoagulation. *Journal of Environmental Chemical Engineering, 9*(1), 104651.

Kusuma, H. S., Amenaghawon, A. N., Darmokoesoemo, H., Neolaka, Y. A., Widyaningrum, B. A., Anyalewechi, C. L., & Orukpe, P. I. (2021). Evaluation of extract of Ipomoea batatas leaves as a green coagulant–flocculant for turbid water treatment: Parametric modelling and optimization using response surface methodology and artificial neural networks. *Environmental Technology & Innovation, 24*, 102005.

Lin, J.-L., Pan, J. R., & Huang, C. (2013). Enhanced particle destabilization and aggregation by flash-mixing coagulation for drinking water treatment. *Separation and Purification Technology, 115*, 145–151.

Liu, J., Crapper, M., & McConnachie, G. (2004). An accurate approach to the design of channel hydraulic flocculators. *Water Research, 38*(4), 875–886.

Lohse, D. (2022). Fundamental fluid dynamics challenges in inkjet printing. *Annual Review of Fluid Mechanics, 54*, 349–382.

Manseau, F., Bhiry, N., Molson, J., & Cloutier, D. (2022). Factors affecting River Turbidity in a degrading Permafrost

environment: The Tasiapik River, Umiujaq (Nunavik)". *Arctic Science (ja)*.
Marques, Rd. O., & Ferreira Filho, S. S. (2017). Flocculation kinetics of low-turbidity raw water and the irreversible floc breakup process. *Environmental Technology, 38*(7), 901–910.
McConnachie, G., & Liu, J. (2000). Design of baffled hydraulic channels for turbulence-induced flocculation. *Water Research, 34*(6), 1886–1896.
Montgomery, D. C. (2009). *Statistical quality control*. Wiley.
Muniz, D. H., & Oliveira-Filho, E. C. (2023). Multivariate statistical analysis for water quality assessment: A review of research published between 2001 and 2020. *Hydrology, 10*(10), 196.
Muthuraman, G., & Sasikala, S. (2014). Removal of turbidity from drinking water using natural coagulants. *Journal of Industrial and Engineering Chemistry, 20*(4), 1727–1731.
Nasir, M. J., Abdulhasan, M. J., Ridha, Sz. A., Hashim, K. S., & Jasim, H. M. (2022). Statistical assessment for performance of Al-Mussaib drinking water treatment plant at the year 2020. *Water Practice & Technology, 17*(3), 808–816.
Niu, F., Zhang, H., Zhang, J., & Yu, X. (2022). Temperature variation characteristics and model optimization of flocculation sedimentation of overflow ultra-fine iron tailings. *Minerals, 12*(5), 643.
Obianyo, J. I., & Agunwamba, J. (2019). Efficiencies of horizontal and vertical baffle mixers. *Emerging Science Journal, 3*(3), 130–145.
Oliveira, D. S., & Donadel, C. B. (2024). Helically coiled tube flocculators in water clarification systems: Optimal length evaluation and process efficiency probabilistic analysis. *Sustainability, 16*(5), 2172.
Othman, Z., Bhatia, S., & Ahmad, A. L. (2011). Influence of the settleability parameters for Palm Oil Mill Effluent(POME) pretreatment by using Moringa Oleifera seeds as an environmental friendly Coagulant. *Journal of Materials Science and Engineering, 5*(3), 332–340.
Pennock, W. H., Lion, L. W., & Weber-Shirk, M. L. (2021). Design algorithm for vertically-baffled flocculators. *Environmental Engineering Science, 38*(7), 592–606.
Pennock, W. H., Lion, L. W., & Weber-Shirk, M. L. (2023). Simple model for coupled hydraulic flocculation-sedimentation performance. *Journal of Environmental Engineering, 149*(12), 04023089.
Pivokonský, M., Novotná, K., Čermáková, L., & Petříček, R. (2022). *Jar tests for water treatment optimization: How to perform jar tests–a handbook*. IWA Publishing.
Pyakurel, H. R., Khatri, N. R., & Lekhak, B. (2024). Field approach on the effectiveness of Hydraulic Flocculator followed by sedimentation and rapid sand filter. *Himalayan Journal of Applied Science and Engineering, 4*(2), 54–62.
Rafique, A., Saud, N., Amjad, N., Ijaz, M., Chipepa, F., & El-Morshedy, M. (2022). Statistical Analysis of Water Purification (Using Vinyl Chloride) Data. *Mathematical Problems in Engineering, 2022*(1), 4410615.
Rice, E. W., Baird, R. B., Eaton, A. D., & Clesceri, L. S. (2012a). *Standard methods for the examination of water and wastewater*. American public health association Washington.
Rice, E. W., Bridgewater, L., & Association, A. P. H. (2012b). *Standard methods for the examination of water and wastewater*. American public health association Washington.
Rusydi, A.F. (2018). *Correlation between conductivity and total dissolved solid in various type of water: A review* (p. 012019), IOP Publishing.
Saravanan, V., Raja, C., Ramachandran, M., & Selvam, M. Forecasting and Quality Control of Confectionery Products with the use of "Water Activity Using the SPSS Method.
Sartori, M., Oliveira, D., Teixeira, E., Rauen, W., & Reis, N., Jr. (2015). CFD modelling of helically coiled tube flocculators for velocity gradient assessment. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 37*(1), 187–198.
Schreiber, S. G., Schreiber, S., Tanna, R. N., Roberts, D. R., & Arciszewski, T. J. (2022). Statistical tools for water quality assessment and monitoring in river ecosystems–a scoping review and recommendations for data analysis. *Water Quality Research Journal, 57*(1), 40–57.
Siliem, T. (1995). Primary productivity of the Nile in barrage area. *Menofiya Journal of Agricultural Research*.
Tahraoui, H., Belhadj, A.-E., Moula, N., Bouranene, S., & Amrane, A. (2021). Optimisation and prediction of the coagulant dose for the elimination of organic micropollutants based on turbidity. *Kemija u Industriji, 70*(11–12), 675–691.
Ustaoğlu, F., Tepe, Y., & Taş, B. (2020). Assessment of stream quality and health risk in a subtropical Turkey river system: A combined approach using statistical analysis and water quality index. *Ecological Indicators, 113*, 105815.
Visconti, G., spsampsps Ruggieri, P. (2020). *Fluid dynamics: Fundamentals and applications*. Springer Nature.
Wang, L. K., Hung, Y.-T., & Shammas, N. K. (2005). *Physicochemical treatment processes*. Springer.
Wang, Z., Wu, M., Liang, X., Huang, N., & Li, X. (2023). A novel vortex flocculation reactor for efficient water treatment: Kinetic modeling and experimental verification. *Chemical Engineering and Processing-Process Intensification, 183*, 109245.
Watkins, M. W. (2021). *A step-by-step guide to exploratory factor analysis with SPSS*. Routledge.
Xiao, F., Huang, J.-C.H., Zhang, B.-J., & Cui, C.-W. (2009). Effects of low temperature on coagulation kinetics and floc surface morphology using alum. *Desalination, 237*(1–3), 201–213.