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The Effect of Bentonite Utilization as a Chemical Coagulant on the Performance of a Water Treatment Plant

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ABSTRACT
In order to use alum in large numbers for the treatment of low turbidity water, a novel method has been used to treat low turbidity water using bentonite with a reduced amount of alum. Given that bentonite has a negative charge, it is added to the raw water to give the blocks weight. The weight is then added by joining the blocks together to create massive blocks that settle more quickly. In addition to providing a large surface for organic compound adsorption, it increases the suspension's weight and particle density. There are between 10 and 50 mg/l of bentonite clay utilized.In the Karbala water treatment plant, the effectiveness of the water quality index (WQI) at turbidity 20NTU (national turbidity unit) using alum alone was subpar (71.16%). Under the same circumstances, the pilot plant's WQI efficiency was equally low (72%). The turbidity of the water was increased to 120 NTUwhen bentonite was used in the pilot plant, increasing the efficiency of WQI to 97.2%. When bentonite was added to the water, the turbidity was increased to 200 NTU and the WQI efficiency was increased to 98.9%. The usage of bentonite produced a high level of WQI efficiency and a cheap substance free from infections or negative effects.

Keywords: coagulant, bentonite, turbidity, water quality index.

INTRODUCTION

The majority of the water's suspended particles, which are too small to be removed in a sedimentation basin, are made up of colloids. Because of their small size, colloidal particles have a high surface area to volume ratio. The bulk of colloidal particles in water are negatively charged, stable, and unable to settle or become clear (Murry, 2000; Pan et al., 1999; Cohen et al., 1971). The rate of contact and attraction of these particles limits the overall coagulation process when water turbidity is low (nanoparticle concentration is low) (Weber, 1972). Sweeping coagulation, which uses alum (aluminum sulphate) to enhance effective coagulation, can be used to treat low water turbidity (Weber, 1972; Amirtharajah and Mills, 1982). Aluminum hydroxide precipitates due to the high alum dose used in this type of coagulation, resulting in collisions between suspended particles that are then eliminated by sedimentation. When a significant amount of alum is employed in this thorough coagulation process, a large volume of waste sludge is produced, and the treated water has high levels of aluminum both at alkalinity and acidity. Issues with public health will be made worse by all of these increases (Drisocoll and Letterman, 1995). In order for those colloids to interact and merge, they must first be destabilized. Inorganic clay particles called mud metals, including bentonite, are strikingly similar to the metal Montmorillonite. Bentonite is commonly used in water treatment due to its superior absorption and ion exchange capabilities. Physical absorption and exchange adsorption are two categories into which this absorption can be subdivided (Yi and Yong, 1999). Numerous researchers have conducted in-depth studies on the removal of organic, inorganic, and biological pollutants from drinking water using natural mud minerals such bentonite clay (Zeng and Liu, 2001; Peng et al., 2005; Cao et al., 2013; Sabbar et al., 2020). Bentonite possesses a variety of qualities, including as superior adsorption, nontoxicity, and ion exchange capacity. There are many benefits to using these mineral resources as flocculants, including their high availability, low cost, and minimal secondary contamination. The raw water entering the Kerbala water treatment facility was found to have low turbidity because of particles of infinite size, and it must be removed. The velocity of attraction and contact between nanoparticles is constrained by the low concentration of nanoparticles in water, which also limits the overall coagulation process (Weber, 1972). Sweeping coagulation, which employs alum (aluminum sulphate) to encourage effective coagulation, is used to treat water with low turbidity (Amirtharajah and Mills, 1981). Due to the high alum concentration used in this method of coagulation, aluminum hydroxide precipitates as an amorphous form, which increases the frequency of particle collisions, causes collisions with suspended particles, and is ultimately eliminated by sedimentation. The public health is at danger because the sweeping coagulation process, which uses alum, produces a lot of waste sludge and maintains a high level of aluminum in the treated water at both alkalinity and acidity. Aluminum hydroxide, an amorphous precipitate, formed when a high alum dose is used in the sweeping coagulation process, enhancing particle collisions and collisions with suspended particles to produce a large floc, which is subsequently removed by sedimentation (Driscoll and Letterman, 1995). The creation of a revolutionary sweeping coagulation method was necessary for the treatment of low-turbid water. This approach uses flocculants materials that involve the flocculation of bentonite mixed with alum during the coagulation process (McLachlan, 1995). The use of bentonite in this study and an additional objective of raising the turbidity of the raw water were the main points of attention. As a result, the best removal effectiveness for low water turbidity is attained when using bentonite as a coagulant ingredient. This study's main objective is to examine the use of bentonite and compare its removal effectiveness to that of using only alum material.

MATERIALS AND METHOD

Clariflocculator

The original model created and recreated the entire model of the water treatment facility, which

Figure 1. Flash mixing tank

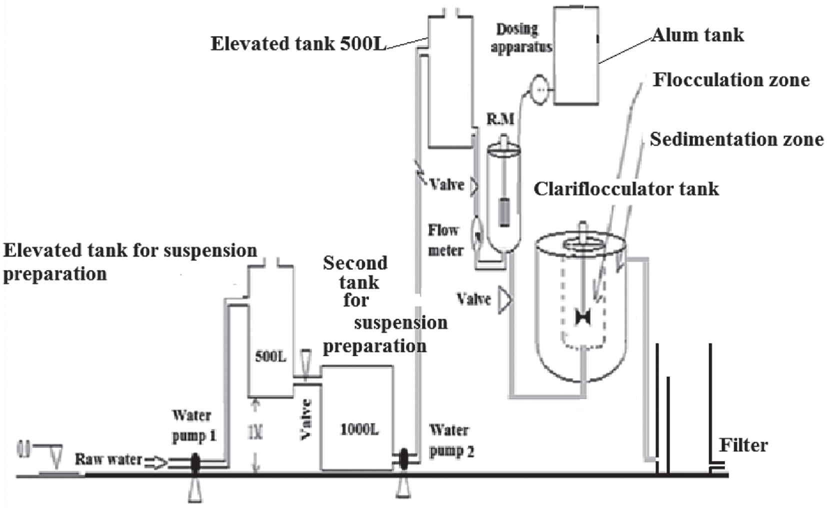

Figure 2. Schematic diagram of conventional clariflocculator

comprises of the following elements: (a rapid mix unit, clariflocculator and clarifier and filtration tanks). One dosing tank (20 liter capacity) was provided for injecting coagulant into the system. Another 1000-liter-capacity dosing tank with a 0.3 kW motor and speed control for the turbidity dosing tank to establish turbidity values was installed. The station's equivalent flow rate was 1050 m^3/h, whereas the model's flow rate was 0.475 m^3/h. The mechanical mixing unit (mixing basin), which was constructed for a 78-second detention period for mixing raw water with coagulants for evenly distributed coagulation, was composed of galvanized plate. It was determined that the tank had a diameter of 24.5 cm and a height of 21 cm. One can see the flash mixing tank in Figure 1.

Two concentric reservoirs make up the Clari-flocculator; one serves as a flocculation basin and the other as a clarifier. A 2.54 cm diameter input tube has been connected to transfer water from the flash mixer tank to the flocculation tank. It was intended for the clarifier to operate in an upflow mode. The diameters of the clarifier and clariflocculator were 31.0 cm and 91.0 cm, respectively. A sludge drain pipe with a valve was attached at the bottom of the tank to take the sludge out at regular intervals. The Peripheral channel, a conduit at the top of the clarifier basin, was used to collect the cleaned water. Figure 2 depicts a typical clari-flocculator in schematic form.

Filters unit

After the sedimentation process, the settled water is sent via a 20 mm hose-tube to the filtering unit (single-media filter). The filter used in this study had the following dimensions: 0.34 m length, 0.17 m broad, and 2.2 m tall. It was made of 1.5 mm thick galvanized plate. With a total depth of 500 mm for the support gravel layer, the filter's bottom was covered with four graded layers of gravel. As illustrated in Figure 3, the single media used in this filter is silica sand with a bed depth of 700 mm, which is placed above the support gravel.

Samples of raw water

After being pumped into the receiving well of the Kerbala Water treatment plant, raw water samples from the Euphrates river were taken. By using bentonite clay, the turbidity was adjusted to reach the desired levels of 120 and 200 NTU. To create the necessary index, Table 1 was used (JICA, 2014).

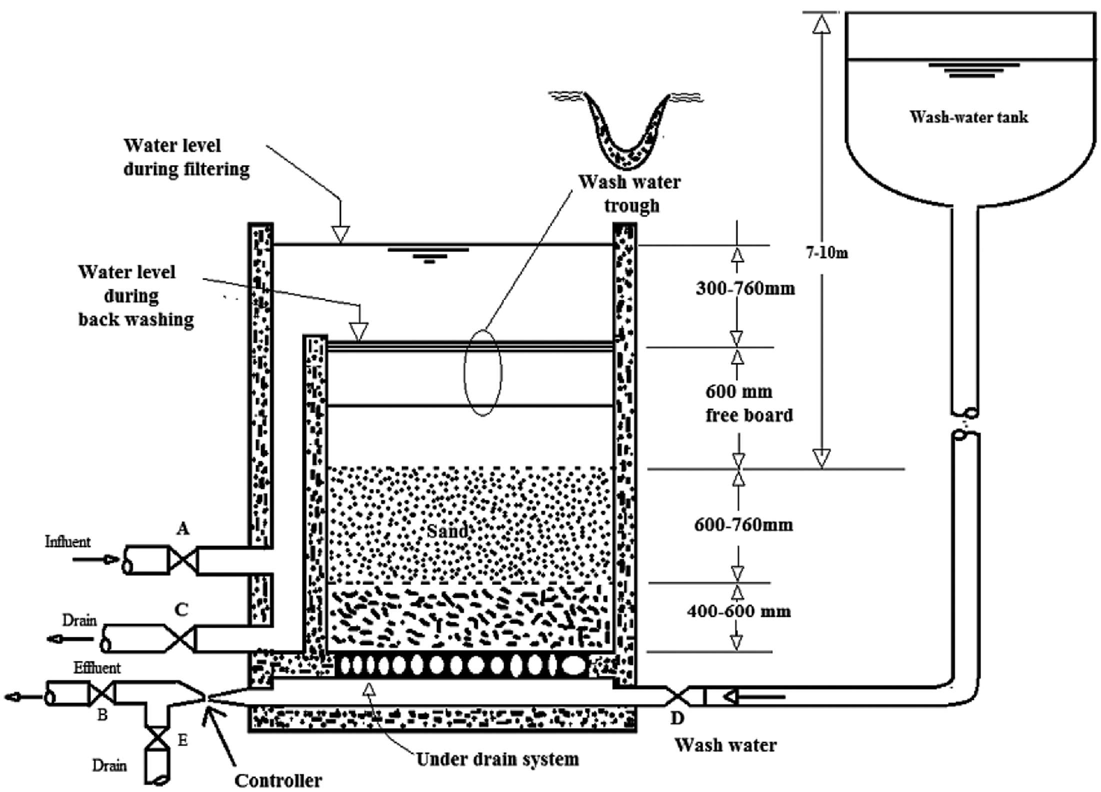

Figure 3. Typical gravity flow filter operation

Table 1. Parameters of water treatment plant in Karbala

Parameter	Tur. NTU	pH	E.C μS/cm	Alk. mg/L	T.H mg/L	Ca mg/L	Mg mg/L	Cl mg/L	SO_4 mg/L	TDS mg/L
Standard value	5	8.5	2000	125	500	75	50	250	250	1000

Experimental procedure

Four alternative turbidities were tested using this model, each with a different coagulant dose. As previously mentioned, the receiving well that feeds raw water to the station provided the raw water that was utilized to run the models. Exogenous turbidity, like bentonite clay, was used in the experiment because the raw water supply's turbidity was so low. A 1 gram per liter bentonite solution was added to the model's dosing tank. The bentonite particles were kept in suspension using a motorized stirrer to prevent settling and ensure even mixing. In this study, alum, which is available in both liquid and powder form, was used as the coagulant. The station's standard coagulation dosage is 25 ppm when the turbidity is less than 30 NTU. The bentonite clay was bought from a number of regional and industrial suppliers. To make turbid water, one litre of river water was used, and after measuring the turbidity, bentonite was gradually added at a rate of 1 g per litre until the desired level of turbidity was achieved, at which point the amount of bentonite used was counted. In Kerbala Governorate, the Euphrates River serves as the only source of water for water treatment facilities. The turbidity of the river water is low and stable throughout the year, according to data from tests done in the Kerbala governorate's water treatment facility from 2014 to 2016. The monthly turbidity levels are shown in Table (2) for the period of 2014 to 2016.

The first approach used a conventional clari-flocculator that was operated at an equivalent flow of 0.475 m^3/h while employing bentonite, and the second approach was based on data from a water treatment facility in order to compare the two approaches (2014–2016).

Chemical analysis

The drinking water treatment facility in Imam Aun district, Kerbala governorate, was picked with the intention of evaluating the quality of produced water using a mathematical index and contrasting it with the experiment work of removal efficiency while utilizing bentonite soil, which will take place between 2014 and 2019. The factory has a 10,500 m^3/h production capacity. The physiochemical parameters used in this investigation included turbidity (Turb.), pH, electrical conductivity (EC), sulphate (SO_4^{-2}), alkalinity (Alk.), total hardness (T.H.), chloride (Cl), calcium (Ca^{+2}), magnesium (Mg^{+2}), and total dissolved solids (TDS). A Nephelometric Turbid Meter (HANNA-HI88703) is used to measure the turbidity. The transportable pH-TDS meter was made in China. Prior to each pH value test, the pH meter was calibrated using a reference buffer solution. Among the types of electrical conductivity meters (HANNA - EC215).

Water quality index

One tool for determining the quality of water for many uses, including potable, agricultural, recreational, and industrial, is the water quality index (WQI). Since they are based on a set of quantifiable criteria and are organized into a numerical categorization to evaluate water quality and compare it to standards advised by human health agencies, they are believed to be very useful and advantageous (Alhayaniet al., 2021; Hasan et.al., 2021). The Kerbala water purification plant project in the Imam Aun region was evaluated in this study utilizing a weighted arithmetic index to create the water quality scale index. As was already said, three equations are utilized in this method to calculate water quality and are crucial

Table 2. The annual mean turbidity values during years (2014-2016)

Year	Raw turb.	Clear turb.	Raw TDS	Clear TDS	Raw EC	Clear TDS	Raw pH	Clear pH
2014	20.19	1.3	536.7	548.5	1147.2	1150.9	7.8	7.7
2015	18	1.3	663	634	1390	1397	7.43	7.51
2016	19	1	534.7	552.9	1122.5	1127.4	7.5	7.5

in determining the indicator. These are shown in thefollowing steps (Joshi et al., 2009).

Step 1. To obtained the value of ‘qn’ ,which is the quality rating or sub-index, using the following equation:

$$qn = [(Vn - V0.)(Sn. - V0.)] * 100 \quad (1)$$

where: Vn – Estimated value of each parameter from the water analysis;
$V\ ior\ V0$ – The ideal value of each parameter counted as zero, except the value of pH parameter = 7 and Do =14.6 mg/l;
Sn – The standard parameter recommended for the water quality.

Step 2. In this step, the relative unit weight of the parameter (Wn) can be calculated by using the formula:

$$Wn = K/Sn \quad (2)$$

where: K is the proportionality constant, found by the formula(3):

$$K = \frac{1}{\sum(\frac{1}{V_n.})} \quad (3)$$

Step 3. In this step it can be found the total Arithmetic Water Quality Index WQI using formula:

$$WQI = \frac{\sum q_n * W_n}{\sum W_n} \quad (4)$$

The improvement ratio in water quality (Removal efficiency) is calculated according to the following equation (Chaturvedi and Bassin, 2009):

$$\text{Improvement ratio (E \%)} = \frac{(\text{WQI of raw water} - -\text{WQI of treated water})}{\text{WQI of raw water}} * 100 \quad (5)$$

Table 3 shows the categories of water quality classification based on the Weighted Arithmetic Index value (Chaturvedi and Bassin, 2009; Mishra and Patal, 2001).

RESULTS AND DISCUSSION

WQI for real turbidity in WTP

For the years (2014-2016) under the following conditions: T = 20 NTU, Qp = 0.475 m^3/h, and Qe = 1050 m^3/h, the results of the water quality indicator for the water treatment facility at Kerbala are shown in tables 4 to 10. Table 4 displays the WQI for raw water in 2014 at T = 20 NTU and Qp = 0.475 m^3/h. As shown in Table 3, the WQI readings at T = 20 NTU, Qp = 0.475 m^3/h are 271.21 and are therefore unfit for ingestion [20]. In 2014, Table 5 displays the WQI for clear water at T = 20 NTU and Qp = 0.475 m^3/h.

The WQI for clear water at T = 20 NTU and Qp = 0.475 m^3/h in 2014 was 33.51, which is

Table 3. Classification of water quality based on weight arithmetic index

The value of water quality index	Category of water quality	Grading
0-25	Excellent	A
26-50	Good	B
51-75	Poor	C
76-100	Very poor	D
>100	Unsuitable for drinking	E

Table 4. WQI for raw water at T = 20 NTU and Qp = 0.475 m^3/h

WQI at raw water = 20 NTU and flow rate = 0.475 m^3/h in 2014										
Parameter	BIS standard (Sn)	I/Sn	ΣI/Sn	K = I/ΣI/Sn	WI = Wn = K/Sn	Ideal value (V_0)	Mean conc. value (V_n)	Vn/Sn	Qn = (Vn·Sn)·100	Wn·Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	20.19	4.038	403.8	251.2
pH	8.5	0.32	0.3215	3.11	0.366	7	7.81	0.54	54	19.76
EC	2000	0.0005	0.3215	3.11	0.002	0	1147.2	0.57	57	0.09
IDS	1000	0.001	0.3215	3.11	0.003	0	536.7	0.54	54	0.17
Sum		0.3215								271.21
WQI = 271.21 unfit for consumption										

excellent for consumption, as shown in Table 3. The WQI for raw water at T = 20 NTU and Qp = 0.475 m^3/h in 2015 is displayed in Table 6.

As shown in Table 3, the 2015 WQI findings for raw water at T = 20 NTU, Qp = 0.475 m^3/h are 234.76 and are therefore unfit for human

Table 5. WQI for clear water at T = 20 NTU and Qp = 0.475 m^3/h

WQI at raw water = 20 NTU and flow rate = 0.475 m³/h in 2014										
Parameter	BIS standard (Sn)	I/Sn	ΣI/Sn	K = I/ΣI/Sn	WI = Wn = K/Sn	Ideal value (V_0)	Mean conc. value (V_n)	Vn/Sn	Qn = (Vn·Sn)·100	Wn·Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	1.3	0.26	26	16.17
pH	8.5	0.32	0.3215	3.11	0.366	7	7.7	0.47	67	17.08
EC	2000	0.0005	0.3215	3.11	0.002	0	1151.9	0.58	57	0.09
TDS	1000	0.001	0.3215	3.11	0.003	0	548.5	0.55	55	0.17
Sum		0.3215								33.51
WQI = 33.51 good for consumption										

Table 6. WQI for raw water at T = 20 NTU, and Qp = 0.475 m^3/h in 2015

WQI at raw water = 20 NTU and flow rate = 0.475 m³/h										
Parameter	BIS standard (Sn)	I/Sn	ΣI/Sn	K = I/ΣI/Sn	WI = Wn = K/Sn	Ideal value (V_0)	Mean conc. value (V_n)	Vn/Sn	Qn = (Vn·Sn)·100	Wn·Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	18	3.6	360	223.95
pH	8.5	0.32	0.3215	3.11	0.366	7	7.43	0.29	28.67	10.49
EC	2000	0.0005	0.3215	3.11	0.002	0	1390	0.70	69.5	0.11
TDS	1000	0.001	0.3215	3.11	0.003	0	663	0.66	66.3	0.21
Sum		0.3215								234.76
WQI = 234.76 unfit for consumption										

Table 7. WQI for clear water at T = 20 NTU and Qp = 0.475 m^3/h in 2015

WQI at raw water = 20 NTU and flow rate = 0.475 m³/h in 2015										
Parameter	BIS standard (Sn)	I/Sn	ΣI/Sn	K = I/ΣI/Sn	WI = Wn = K/Sn	Ideal value (V_0)	Mean conc. value (V_n)	Vn/Sn	Qn = (Vn·Sn)·100	Wn·Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	1.3	0.26	26	16.17
pH	8.5	0.32	0.3215	3.11	0.366	7	7.51	0.34	34	12.44
EC	2000	0.0005	0.3215	3.11	0.002	0	13972	0.70	69.85	0.11
TDS	1000	0.001	0.3215	3.11	0.003	0	634	0.63	63.4	0.10
Sum		0.3215								28.92
WQI = 28.92 good for consumption										

Table 8. WQI for raw water at T = 20 NTU, and Qp = 0.475 m^3/h in 2016

WQI at raw water = 20 NTU and flow rate = 0.475 m³/h in 2016										
Parameter	BIS standard (Sn)	I/Sn	ΣI/Sn	K = I/ΣI/Sn	WI = Wn = K/Sn	Ideal value (V_0)	Mean conc. value (V_n)	Vn/Sn	Qn = (Vn·Sn)·100	Wn·Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	19	3.8	380	236.39
pH	8.5	0.32	0.3215	3.11	0.366	7	7.5	0.33	33.33	12.2
EC	2000	0.0005	0.3215	3.11	0.002	0	1122.5	0.56	56.125	0.09
TDS	1000	0.001	0.3215	3.11	0.003	0	534.7	0.53	53.47	0.17
Sum		0.3215								248.85
WQI = 248.85 unfit for consumption										

Table 9. WQI for clear water at T = 20 NTU and Qp = 0.475 m³/h in 2016

WQI at raw water = 20 NTU and flow rate = 0.475 m³/h in 2016										
Parameter	BIS standard (Sn)	I/Sn	ΣI/Sn	K = I/ΣI/Sn	WI = Wn = K/Sn	Ideal value (V_0)	Mean conc. value (V_n)	Vn/Sn	Qn = (Vn·Sn)·100	Wn·Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	1	0.2	20	12.44
pH	8.5	0.32	0.3215	3.11	0.366	7	7.5	33.33	33.33	12.20
EC	2000	0.0005	0.3215	3.11	0.002	0	1127.4	56.37	56.37	0.19
IDS	1000	0.001	0.3215	3.11	0.003	0	55.29	55.19	55.19	0.17
Sum		0.3215								24.90
WQI = 24.90 excellent for consumption										

Table 10. Total WQI at T = 20 NTU and Qp = 0.475 m³/h from (2014-2016)

Type of water \ Year	2014	2015	2016
Raw water	271.21	234.7	248.85
Treated water	33.51	28.92	24.90
Grade	Good	Good	Excellent

consumption. The WQI for clear water at T = 20 NTU and Qp = 0.475 m³/h in 2015 (Chaturvedi and Bassin, 2009) is shown in Table 7.

As mentioned in Table 3, the results of WQI for clear water at T = 20 NTU and Qp = 0.475 m³/h in 2015 is 28.92 which its good for consumption. Table 8 shows the WQI for raw water at T = 20 NTU, and Qp = 0.475 m³/h in 2016 for raw water (Mishra and Patal, 2001).

As mentioned in Table 3, the results of WQI for raw water at T = 20 NTU and Qp = 0.475 m³/h in 2016 is 248.85 which its unfit for consumption (Sharma and Kansal, 2011).

Table 9 shows the WQI for clear water at T = 20 NTU and Qp = 0.475 m³/h in 2016. As mentioned in Table 3, the results of WQI for clear water in 2016 is 24.90 which its good for consumption (Sharma and Kansal, 2011).

Table 10 illustrates the overall results of the water quality indicator extracted for the years 2014–2016.

WQI in pilot plant using bentonite

Table 11 is listed the characteristics of raw and treated water using bentonite matter. Table 12 illustrates the quality index calculation for raw water at flow rate 0.475m³/h utilizing bentonite.

As mentioned in Table 3, the results of WQI for raw water utilizing bentonite = 1525 is unfit for consumption at T = 120 NTU and Qe = 0.475 m³/h in pilot plant. The WQI is enhanced when

Table 11. Characteristics of raw water and treated water using bentonite

Test type	Raw water	Treated water (filtered water)
Turbidity	120	1.3
EC	1215	1195
TDS	692	682
pH	8.3	8.1
Temp.	17	17

Table 12. WQI for raw water at conditions T = 120 NTU and = 0.475 m³/h

Parameter	Standard (Sn)	I/Sn	ΣI/Sn	K = I/ΣI/Sn	WI = Wn = K/Sn	Ideal value (V_0)	Mean conc. value (V_n)	Vn/Sn	Qn = (Vn·Sn)·100	Wn·Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	120	24	2400	1493
pH	8.5	0.12	0.3215	3.11	0.366	7	8.3	0.86	86	31.47
EC	2000	0.0005	0.3215	3.11	0.002	0	1215	0.61	61	0.12
TDS	1000	0.001	0.3215	3.11	0.003	0	692	0.69	69	0.21
Sum		0.3215			I					1525
WQI of raw water = 1525 (unfit for consurnption)										

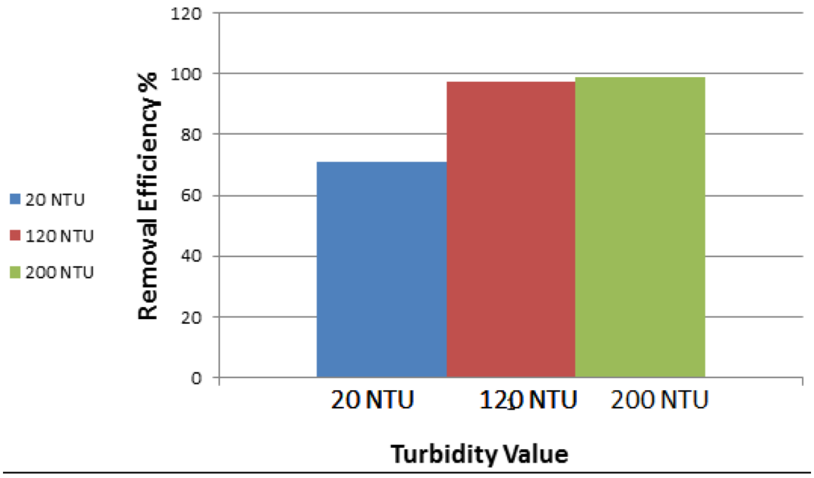

Figure 4. Enhancing of water quality (E%) at 20, 120 and 200 NTU in Pilot plant

turbidity is increased from 20 to 200 NTU as shown in Figure 4.

When using river raw water in the pilot plant at 20 NTU, the improvement ratio for the water quality was 71.16%. The improvement ratio in water quality was 97.2 and 98.9% when employing turbidity values at 120 and 200 NTU with bentonite, respectively. There is evidence for this bentonite mechanism (Sharma and Kansal, 2011; Mohammed et al.,2020; Abbas and Abbas, 2022; Abd-almohi et al., 2022; Fadhil et al., 2021; Idan and Obyed, 2019).

CONCLUSIONS

The best outcomes were obtained by adding bentonite to low-turbid raw water in order to raise turbidity since the supernatant got clearer as the amount of bentonite increased. The inclusion of bentonite will lower the electrostatic forces and increase the production of flocs, which will lower the turbidity. This suggests that low turbidity raw water shouldn't be treated directly. To increase turbidity, bentonite should be added; after that, the water needs to be treated. Bentonite is used in therapy for a number of reasons, including: Low turbidity raw water needs a greater coagulant dose, like aluminum sulphate, to clear it, but too much alum can lead to Alzheimer's disease. Bentonite is a natural substance that has no negative effects when added to water. Many treatment facilities in the region don't treat low-turbid water with alum; instead, water is passed straight from sedimentation basins to filters without any additional treatment. This process puts pressure on the filters, which are the only ones that reduce turbidity, necessitating frequent washings.

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