Polytechnic Journal. 2022. 12(1): 21-29
ISSN: 2313-5727
http://journals.epu.edu.iq/index.php/polytechnic

RESEARCH ARTICLE

Performance Evaluation and Water Quality Index Analysis for Qandil Water Treatment Plant

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Received: 07 June 2021
Accepted: 03 April 2022
Published: 14 August 2022

DOI
10.25156/ptj.v12n1y2022.pp21-29

ABSTRACT

Water treatment plant (WTP) can be described as water processing to attain water quality that meets specific end-user or community objectives. A WTP's performance assessment is a method for measuring functioning efficiencies based on certain performance indices such as degree of removal of pollutants such as turbidity, color, suspended impurities, etc. The present study aimed to evaluate the performance of Qandil WTP units, Erbil City, Iraq. For assessment of the WTP units by turbidity removal efficiency, water samples were collected from raw water, after clarification, after filtration, and storage tank. Obtained removal efficiencies for the sedimentation unit, filtration unit, after disinfection, and the entire Qandil WTP were 86.83 %, 91.28 %, 31.26%, and 99.29 %, respectively. Also, water quality index (WQI) for the WTP was studied. WQI assessment was made by testing 14 physicochemical and bacteriological drinking water quality parameters such as turbidity, pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity, total hardness, calcium (Ca), chloride (Cl), Sulfate (SO_4), magnesium (Mg), sodium (Na), potassium (K), Nitrate (NO_3), and total Coliform. It has been found that turbidity, EC, total alkalinity, and total hardness had more effect on drinking water quality. WQI for Qandil WTP was 43.29 and it regarded as excellent level.

Keywords: Water treatment plant, water quality index, evaluation, drinking water, Greater-Zab River.

1. INTRODUCTION

Water is an important natural resource in the world, and it is the most essential element on the earth to maintain human life (Issa, 2017). It is availability with appropriate quality and sufficient quantity is essential for human life and other purposes (Khwakaram et al., 2012). Water treatment plant (WTP) can be defined as the processing of water to achieve a water quality that meets specified goals or standards set by the end user or a community through its regulatory agencies. The development of WTP practice has a rich history of empirical and scientific developments and challenges met and overcome (Crittenden et al., 2012). During the last decade, general corruption in water quality of inland aquatic systems has been reported due to the speedy enlargement of industries, agriculture, and urban sprawl (Puri et al., 2015). Most current drinking WTPs use conventional treatment methods like coagulation-flocculation, sedimentation, sand filtration, and disinfection to produce fresh portable water (Spellman, 2003; Doosti et al., 2012; Issa, 2017; Aziz and Mustafa, 2019). The performance evaluation of a WTP is a process to measure the functioning efficiencies based on some established performance indicators such as a degree of removal of pollutants such as turbidity, color, suspended impurities etc. (Vieira et al., 2008). Many attempts have been made to reduce the timescale for making decisions on the quality of drinking water and to have more general assessment processes which involve all concerned parameters (Issa and Alrawi, 2018). Water quality index (WQI) was developed to contain whole comparisons and evaluation procedures for a specific drinking water in one standard that represents the accurate status of the drinking water that is under investigation (Berisha and Goessler, 2013). It is also a very useful and efficient tool for assessing the suitability of water quality to the concerned citizens and decision makers (Asadi et al., 2007). The WQI is a mathematical equation used to transform large numbers of water quality parameters into a single number (Batabyal and Chakraborty, 2015). Hazzaa (2017) conducted a study to evaluate the quality of raw and treated water for number of WTPs in Baghdad from 2005 to 2013, by using Canadian Model for a WQI for some parameters such as the temperature of the water, turbidity, pH, total hardness, magnesium, calcium, sulfate, iron, fluoride, nitrate, chloride, color, and conductivity.

Commonly, river water after treatment and groundwater are sources of water supply in Erbil City-Iraq. Greater-Zab River is the main surface water source for supplying water to Erbil City and some districts. Qandil WTP constructed on Greater-Zab River supplies drinking water to Shaqlawa District and Salahaddin Sub-District. Various studies were performed to investigate the drinking water quality of Erbil City. Bapeer et al. (2006) Are done a study for the first time for some physicochemical variables and trace metal concentrations in treated water samples from two water treatment plants Ifraz 1 and Ifraz 2, and they found that water samples were fluctuated from safe and unsafe for drinking purposes. Shareef and Kafia (2008) were conducted several studies on monitoring the physical, chemical and biological quality of natural and drinking water in Erbil. The quality of water samples was generally fluctuated from safe to unsafe for drinking due to the variation of the studied properties with time and sample sites.

The main objectives of this study are to evaluate the efficiency of Qandil WTP units, and to evaluate treated water quality of Greater-Zab River at Qandil WTP by WQI analysis. To date, analyzing of Qandil WTP units, performance evaluation of the units and WQI of Qandil WTP have not been published yet.

2. Materials and Methods

2.1 Site Description

Greater-Zab River, which is shared by Iraq and Turkey, stems from the Ararat Mountains in Turkey, runs through the central northern part of Iraq, and then, links with Tigris River south of Mosul City traversing a distance of 372 km (Abbas et al., 2016). Four water treatment plants (WTPs) have been constructed with intake of raw water from this river at Greater-Zab River (DOW, 2019).

Qandil WTP project is considered to be a vital project for the areas falling between the Greater-Zab River and the Shaqlawa District in Erbil City-Iraq. The Project supplies water to the towns of Shaqlawa and Salahaddin as well as 20 villages in the region. Qandil WTP is design to supply 120000 cubic meter per day, but now it produced about 60,000 m^3/day (DOE, 2019). It is Longitude and Latitude values are 44° 06′ 56″ East (E) and 36° 36′ 05″ North (N). The plant was built in 2013 as shown in Figure 1.

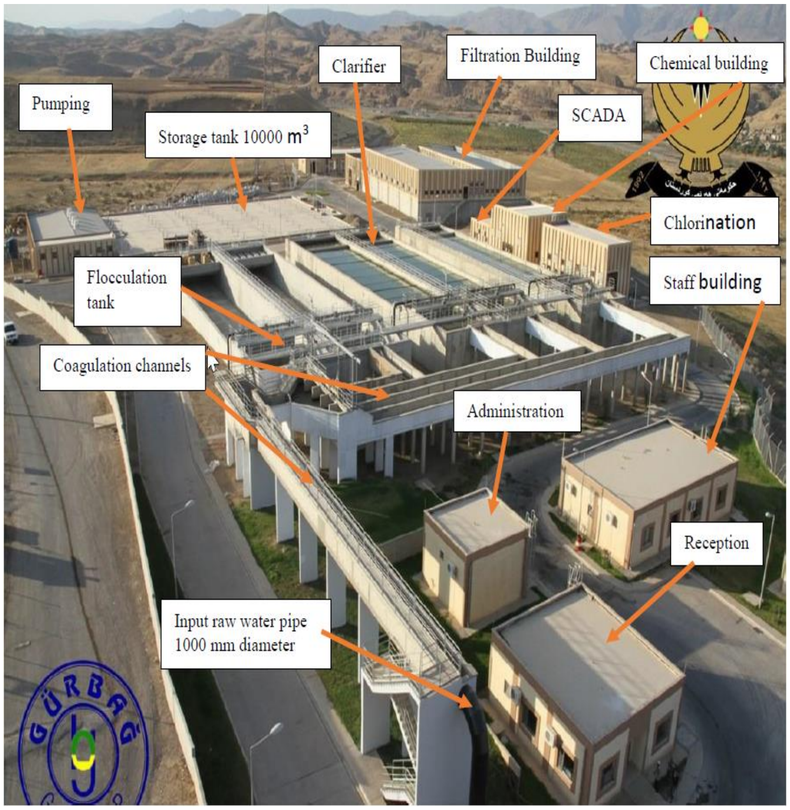

Figure 1: Qandil WTP site

2.1 Turbidity Removal efficiency

The samples were collected and analyzed according to American Public Health Association (APHA) (2005). Removal efficiencies for the WTP units were calculated according to the equation:

$$\text{Removal efficiency} = (C_o - C_f)/C_o * 100 \quad \dots (1)$$

Where:

C_o = Turbidity of the water sample before treatment, NTU.

C_f = Turbidity of the water sample after treatment, NTU

2.3 Water Quality Index

An average of two set of samples per month were collected from November 2018 to April 2019, for Qandil WTP. The samples of treated water were collected in plastic containers and immediately transported to the Laboratory. The samples were stored in the refrigerator at 4°C before experimental use to prevent biological activities and changes in their characteristics (APHA, 2005). The collected samples were analysed for 14 water-quality parameters. These parameters are as follows: Turbidity (NTU), pH, electrical conductivity (EC) (μs/cm), total dissolved solids (TDS) (mg/L), total alkalinity (mg/L), total hardness (mg/L), calcium (Ca) (mg/L), chloride (Cl) (mg/L), sulphate (SO_4) (mg/L), sodium (Na) (mg/L), magnesium (mg/L), potassium (K) (mg/L), nitrate (NO_3) (mg/L), and total Coliform (MPN/100 ml). The experiments were conducted in the Erbil Water Directorate Laboratory, Erbil, Iraq.

WQI is one of the most effective tools to monitor the surface as well as ground water pollution and can be used efficiently in the implementation of water quality upgrading programs. WQI provide information on a rating scale from zero to hundred. Thirteen parameters have been selected for developing the water quality index (Singh and Hussian, 2016).

For computing WQI three steps are followed. Firstly, each of the 14 parameters has been assigned a weight (wi) according to its relative importance in the overall quality of water for drinking purposes. The maximum weight of 5 has been assigned to parameters such as turbidity, chloride, nitrate, and total Coliform due to their major importance in water quality assessment. The parameters such as pH, EC, TDS, total alkalinity, total hardness, Ca, Mg, Na, K, and SO_4 were assigned a weight between 1 and 5 based on their relative significance in the water quality evaluation (Batabyal and Chakraborty, 2015; Singh and Hussian, 2016).

Secondly, the relative weight (Wi) is computed from the following equation:

$$Wi = \frac{wi}{\sum wi} \quad \dots (2)$$

Finally, a quality rating scale (Qi) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down by World health organization (WHO) and the result for the same is multiplied by 100 (Equation 3).

$$Qi = (Ci/Si) \times 100 \quad \dots (3)$$

Where, Qi = the quality rating, Ci = value of the water quality parameter obtained from the laboratory analysis, Si = value of the water quality parameter obtained from recommended WHO or Iraqi standard of corresponding parameter.

While the sub-index water quality for pH (Q_{pH}) was calculated on the basis of the following relation.

$$Qi = [(V\ actual - V\ ideal) / (V\ standard - V\ ideal)] * 100 \quad \dots (4)$$

Where, Qi = Quality rating of ith parameter for a total of n water quality parameters V actual = Actual value of the water quality parameter obtained from laboratory analysis.

V ideal = Ideal value of that water quality parameter can be obtained from the standard Tables.

V ideal for pH = 7 and for other parameters it is equaling to zero (WHO, 2011).

Equations 3 and 4 ensures that Qi = 0 when a pollutant is totally absent in the water sample and Qi = 100 when the value of this parameter is just equal to its permissible value. Thus the higher the value of Qi is, the more polluted is the water (Toma, 2013).

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following Equations (5 and 6).

$$SI_i = W_i \times Q_i \quad \dots (5)$$

$$WQI = \Sigma\ SI\ i \quad \dots (6)$$

3. Results and Discussions

3.1 Qandil WTP Units/Processes Description

3.1.1 Intake

Firstly, the suspended debris, floating body, and living organism should be removed, possibly including fish (Aziz, 2009). The design of Qandil intake is based on the screening, primary sedimentation. It locates at Makirdan village, it is E and N values are 44º 07' 28" and 36º 35' 38", Figure 2. Raw water from Greater-Zab River intake pumped to Qandil WTP by 4 submersible pumps each with 1080 m^3/h capacity. The raw water transferred to Qandil WTP by 1000 mm steel pipe diameter with length of 800 m.

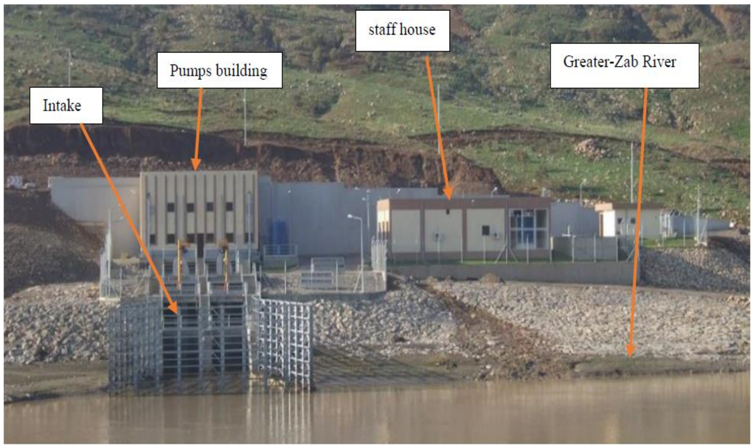

Figure 2: Water intake of Qandil WTP on Greater-Zab River

3.1.2 Coagulation Process

Chemical coagulation usually is applied in advance to sedimentation and filtration to improve the particles removal process (Alnasrawi et al., 2018). It is the first treatment for incoming raw water. Several factors affect the type and amount of coagulating chemicals required, including the nature of suspended solids and the chemical characteristics of the influent water (Baruth, 2005). The raw water is coagulated continuously with alum and polymer which used to enhance coagulation and flocculation in open channel mixing by hydraulic power to the flow of water through (inlet channel and Parshall flume and baffle walls installed vertically in the rapid mix basin) with a specific retention time of 20 s according to Erbil Water Directorate (EWD, 2019) as shown in Figure 3.

Figure 3: Coagulation process, inlet channel and Parshall flume

3.1.3 Flocculation Process

The flocculation and sedimentation are affected in separate tanks, the flocculation zone is normally located upstream of the sedimentation tank and is separated from the sedimentation basin by a baffle wall/weir. The flocculation tank employs a turbine type flocculator in the vertical position. The flocculated particles flow from the flocculation tank into the sedimentation tank and are removed by a bottom scraper for ultimate disposal. Flocculation Tank is square with dimension of 11 m (length) x 11 m (width) x 4.5 m (depth). From the rapid mix chamber, water flows to the flocculation tank over a weir. The weir is designed to ensure enough head for the water to flow by gravity into the downstream sedimentation tanks. Slow mix in the flocculation tank is affected mechanically by means of rotating paddles. Detention Time is 30 min. in the flocculation tank (EWD, 2019).

3.1.4 Sedimentation Process

From the flocculation basin, water flows over a weir to the sedimentation tank, which has a rectangular configuration with a bottom scraper and solids collection hopper. Collected solids are removed hydraulically by means of telescopic valves and a discharge channel. Solids flow by gravity for ultimate discharge / disposal overland. Sedimentation tanks are rectangular with dimension of 11m x 46 m, depth of sedimentation tank is 4 m. and the detention time is 2 h. (EWD, 2019), for more details see Figure 5. Baruth (2005) indicated that modern designs of conventional basins with detention times of 1.5 to 2.0 h provide great treatment.

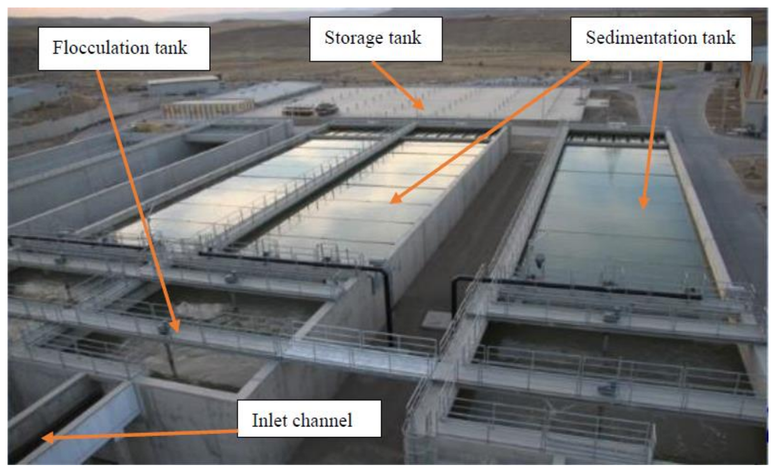

Figure 5: Sedimentation tank

3.1.5 Filtration Unit

The filtration processes for this project are rapid sand filtration. The filtration building consists from 10 sets of gravity sand filters, the dimensions of each filters are 12.75 m in length x 7.45 m in width. The total height of the filtration building is 6m. The filtration building also house clarified water supply pipe, filtered water pipes, as well as the filters backwash system. Backwash water is supplied from the treated water elevated tank. Backwash system also uses air for scouring, which shall be affected by means of filter air scouring blowers that are placed in a separate building along with the chlorination system. Silica sand is used as a filter medium with a depth of 0.8 m. Sand has an "effective size" within the range of 0.35 to 0.5 millimeter with a uniformity coefficient of 1.3 to 1.7. Figure 5.

Figure 5: Filtration unit

3.1.6 Disinfection/Chlorination

The objective of chlorination process is to disinfect the filtered water to make it suitable for potable use (Mishera, 2014). Chlorine gas is added to the process to kill and inactivate any remaining pathogens (Angreni, 2009). In Qandil WTP and after the filtration stage, the filtered water passes to the disinfection unit. Chlorine gas is added before the storage and distribution of treated water. After the disinfection step, water is ready to pump into the network to distribute to the public, Figure, 6.

3.1.7 Storage and other facilities

After the water has been purified in the treatment plant, it stored in the large underground tank with a capacity of 10,000 m^3. Then from reservoir water is directly pumped by 1,000 mm ductile pipe to Salhaddin water tank by five booster stations. The capacity of salahaddin reservoir tank is 36000 m^3. After that the clean water distribute to the Salahaddin public, and some of the water tranfer to Shaqlawa City. The three reservoirs for Shaqlawa city supplied directly by gravity from the transmission pipeline fed from Salahadin reservoir, each reservoir with capcity of 7500 m^3 (EWD, 2019).

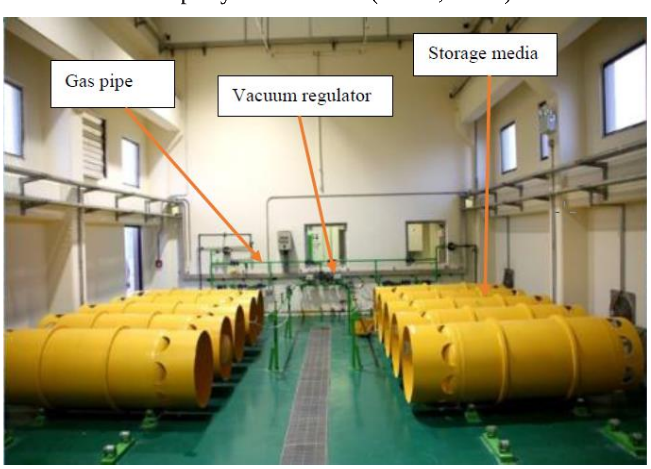

Figure 6: Disinfection unit

3.1.8 SCADA System

Supervisory control and data acquisition (SCADA) refers to virtually any data acquisition system, but usually, one which exercises monitoring and supervisory control of a number of sites from a control center. Such systems are widely used in the water industry so that a 24 h manned control center can react to any problems arising at sources or throughout a water production facility or a water distribution system (Brandt et al., 2017). In Qandil WTP there was a SCADA control room which has a number of duty such as controlling and monitoring all the parts and units of the project, input flow, pumps operation and how long it works, storge water tank level, booster stations water level and operation, input raw water turbidity, before and after filtration turbidity, and output turbidity, Figure 7. (EWD, 2019).

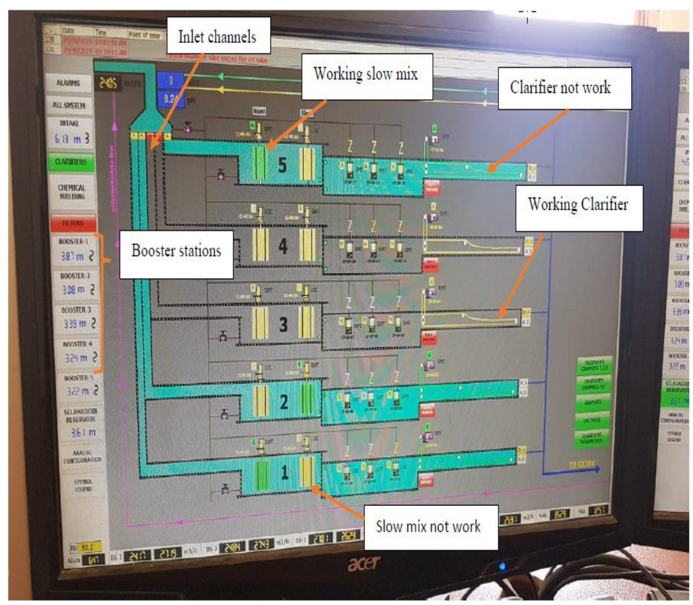

Figure 7: SCADA system

3.2 Performance of Qandil WTP

To assess the turbidity removal efficiency after each unit process and measured the efficiency of each unit and the entire WTP, 24 samples were taken from November 2018 to April 2019. The results for sedimentation basin, filtration unit, and storage units are presented in Table 1. Removal efficiency for the units and the entire WTP was determined using Eq. 1. It can be noticed from Table 1 that a wide variation of turbidity values for the raw water were reported; the fluctuation was due to rainfall and effect of surface run off to the Greater-Zab River.

Removal efficiencies for the sedimentation tank are shown in Figure 8. Maximum and minimum removal efficiencies were 98.8% and 58.79%, respectively. The overall proportion of the total basin sedimentation was 86.83%. Mohammed and Shakir (2012) observed the overall removal efficiency in the sedimentation basin 46% in Al-Wahdaa Project Drinking WTP. It is obvious to observe that effective removal of sedimentation fluctuated during the period of the study.

Table 1: Turbidity value for the collected samples in different units

No.	*Date*	*pH*	*Temperature*	*Raw water turbidity (NTU)*	*After sedimentation (NTU)*	*After filtration (NTU)*	*After disinfection (NTU)*
1	07/11/2018	7.81	18.1	452	8.9	0.80	0.4
2	11/11/2018	7.79	17.3	162	15.4	0.60	0.2
3	18/11/2018	7.79	16.6	330	7.8	0.60	0.2
4	26/11/2018	7.77	16	160	8.8	0.70	0.5
5	06/12/2018	7.83	14.6	1180	14.3	0.90	0.71
6	09/12/2018	7.56	13.7	885	10.5	0.90	0.8
7	16/12/2018	7.76	12.8	165	10.6	2.80	2.4
8	23/12/2018	7.64	12.6	108	12.8	0.50	0.29
9	05/01/2019	7.7	11.7	89	21	1.00	0.9
10	13/1/2019	7.72	10	43	7.9	2.80	1
11	20/1/2019	7.77	10.6	35	8.9	0.56	0.34
12	27/1/2019	7.74	13	33	13.6	0.96	0.81
13	04/02/2019	7.75	13.8	143	17.8	1.00	0.86
14	12/02/2019	7.65	13.6	77	13.5	1.20	0.99
15	20/2/2019	7.68	13.9	62	18.2	0.50	0.3
16	24/2/2019	7.5	14	56	16.8	1.00	0.84
17	04/03/2019	7.78	13.2	86	14.7	1.16	0.94
18	12/03/2019	7.77	12.4	51	12.3	0.90	0.48
19	16/3/2019	7.79	14	134	18.6	1.00	0.55
20	31/3/2019	7.41	14	754	16.6	0.80	0.41
21	01/04/2019	7.49	16	680	12.2	1.10	0.95
22	09/04/2019	7.78	19	327	19	1.10	0.85
23	21/4/2019	7.69	18	310	14.1	1.22	1.07
24	25/4/2019	7.68	16	185	16.1	1.60	1.2

It is obvious to observe that effective removal of the sedimentation fluctuated during the period of the study due to absent of using an optimum dosage of coagulant, especially on 5/1/2019 reached to high value of turbidity with 21 NTU.

The turbidity of water after filtration had reached its highest value on 16/12/2018 and 13/1/2019 with a total value of 2.8 NTU and lowered on 23/12/2018 and 20/2/2019 with a value of 0.5 NTU. The overall rate of turbidity passed filtration basin is 1.07 NTU. Mohammed and Shakir (2012) observed the overall rate of turbidity abroad filtration basin 3.4 NTU. However, the removal efficiency of filtration basins had peaked on 20/2/2019 with around 97.25% and it lowered on 13/1/2019 with about 64.56%. While, the removal efficiency of 60% after the filtration basin at Midc Hingna WTP in India was observed by

(Mahinge and Khedikar, 2016), which indicates good result compare with Qandil WTP. The removal efficiency fluctuated during the period of the study. It observed that the rates of removal of the basins filtration are relatively high with the average of 91.28%.

In the last stage of storage water after disinfection, it is clear to know from Table 1 that the turbidity of water after disinfection had reached its highest value on 25/4/2019 with a total value of 1.2 NTU and decreased to the lowest value on 11/11/2018 and 18/11/2108 to 0.2 NTU. The overall rate of turbidity abroad disinfection is 0.75 NTU. However, the removal efficiency of disinfection and storage basins had peaked in 11/11/2018 and 18/11/2108 with around 66.7 % and it lowered in 9/12/2018 with about 11.1%. The removal efficiency fluctuated during the period of the study. It observed that the rates of removal of the disinfection and storage basins are relatively low with an average of 31.26%. The removal efficiency fluctuated during the period of the study. The average whole removal efficiency of the WTP was 99.29%, less value for WTP in Khanaqin City-Iraq of 97.88% was reported by Issa (2017). Also, the average removal efficiency of 97.29 % was reported by Omar and Aziz (2019) in Ifraz-2 WTP in Erbil City-Iraq.

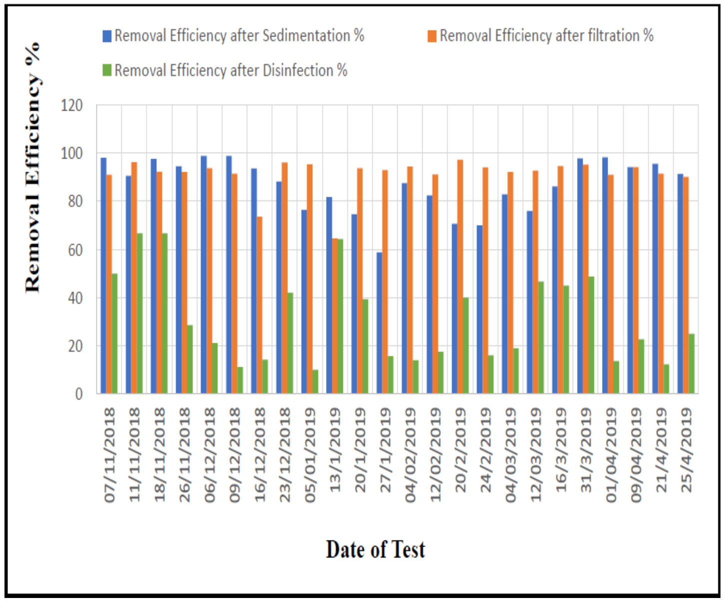

Figure 8: The removal efficiency in different units of Qandil WTP

3.3 Water quality

The descriptive statistics for the obtained dataset of drinking water quality of 14 parameters from November 2018 to April 2019 is shown in Table 2, which includes the mean, standard deviation, maximum, and minimum values for each parameter in the monitoring period from a dataset of 12 water samples. The mean values of the investigated parameters in drinking water samples have been arranged according to their quality rating.

Table 2: Descriptive statistics and assigned weights of physiochemical parameters of drinking water samples produced from Qandil WTP

Parameters	Unit	Minimum	Maximum	Mean	Water Quality Standard	Weight (wi)	Relative weight (Wi)
Turbidity	NTU	0.3	2.4	1.23	5	5	0.09
pH	_	7.3	7.9	7.72	8	3	0.06
EC	µs/cm	317	491	397.75	1000	4	0.07
TDS	mg/L	206.05	319.15	258.54	500	5	0.09
T. Alkalinity	mg/L	160	237	204.83	200	3	0.06
T. Hardness	mg/L	200	320	273.58	200	3	0.06
Ca	mg/L	50	80	68.33	100	3	0.06
CI	mg/L	10	19	14.67	250	5	0.09
SO_4	mg/L	22	42	32.75	250	4	0.07
Mg	mg/L	36	57.6	49.26	30	2	0.04
Na	mg/L	6	14	8.86	200	3	0.06
K	mg/L	0.7	1.7	1.06	10	4	0.07
NO_3	mg/L	1.5	8	4.58	50	5	0.09
Total Coliform	(MPN/100 ml)	0	0	0	0	5	0.09
						Σwi=54	ΣWi= 1.00

Mean values of turbidity, pH, EC, TDS, Ca, Cl, SO_4, Na, K, and NO_3 are remain with the standards for drinking water (WHO, 2011). Total Alkalinity has a mean value of 204.83 mg/L, and this value is slightly higher than the standard of 200 mg/L. High alkalinity (above 200 ppm) results in the water being too buffered. Thus, having significant alkalinity in water is usually beneficial, because it tends to prevent quick changes in pH that interfere with the effectiveness of common water treatment processes. Low alkalinity also contributes to water's corrosive tendencies (Spellman, 2003). A similar condition exists for total hardness mean value which is 273.58 mg/L, and this value is higher than WHO standard of 200 mg/L, but within the Iraqi standard 500 mg/L. Hardness causes soaps and detergents to be less effective and contributes to scale formation in pipes and boilers. Hardness is not considered a health hazard; however, water that contains hardness must often be softened by lime precipitation or ion exchange (Spellman, 2003). Mean values of Mg in water samples are 49.26 mg/L, which is higher than WHO standard for Mg of 30 mg/L, but within the Iraqi standard 50 mg/L. The rest of the parameters display low levels in examined drinking water samples, and they are within the standard ranges.

3.4 WQI of Qandil WTP

The computed WQI values could be classified as Excellent for WQI $\leq$ 50, Good for WQI between 50.1 and 100; Poor for WAI ranged from 100.1 to 200, Very poor for WQI varies from 200.1 to 300, and Unsuitable for WQI>300 (Ramakrishnaiah et al., 2009). The average WQI values for Qandil WTP during the period of the study have been calculated according to the section 2.3, and built a clear and general vision for the physicochemical quality of drinking water produced from this plant during the observation time. The average WQI for Qandil WTP value was 43.29 and fall in excellent quality. Issa and Alrawi (2018) conducted a long-term Drinking Water Quality Assessment Using Index for 3 WTPs of Erbil City, Iraq, results showed that drinking water quality falls within the excellent to good quality. Omar and Aziz (2019) stated that the WQI in Ifraz-2 WTP was good.

4. Conclusions

Greater-Zab River water needs treatment prior using by consumers. A great part of solids removed after coagulation-flocculation and sedimentation tanks. The removal of the sedimentation fluctuated during the period of the study due to absent of using an optimum dosage of coagulant. Commonly, overall removal efficiency for Qandil WTP was greater than 99% and the treated water is safe for drinking. Drinking water quality assessment has been performed for Qandil WTP during the study period. Fourteen physicochemical and bacteriological water parameters were analysed. Drinking WQI result showed that the drinking water quality from Qandil WTP falls within the excellent quality.

4. Acknowledgement

The authors would like to acknowledge Erbil Water Directorate Laboratory and all the staffs who participate for analyzing the samples and providing assistance for this research.

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