Applying mass balance dilution technique for wastewater disposal to Greater-Zab river in Erbil, Kurdistan Region-Iraq

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A R T I C L E   I N F O

A B S T R A C T

Treatment is essential for wastewaters prior to its disposal to the environment or water sources. Numerous wastewater treatment techniques are applied for the treatment of wastewater types. To date, dilution via mass balance approach has not been reported for treatment of various types of wastewaters in Erbil City, Kurdistan Region-Iraq. Consequently, the aim of this work was to examine the treatment of various types of wastewaters using dilution method by river water through applying mass balance approach. Characteristics of different types of wastewaters and Greater-Zab River water in Erbil City were studied. Slaughterhouse, tannery, municipal, landfill-leachate, dairy, and refinery wastewaters in Erbil City were used in the present work. Mass balance approach was applied to verify that dilution of various types of wastewaters using Greater-Zab river water. Dilution factor and required amount of river water were calculated. Temperature, biochemical oxygen demand (BOD), and Dissolved oxygen (DO) were studied using mass balance approach. Results revealed that dilution factor for Erbil wastewaters varied from 10.36 to 513.91. Mixing of wastewaters with Greater-Zab river water led to decreasing of DO in the river water by 3.525 % and increasing of BOD in the Greater-Zab River water. Dilution using various quantities of raw river water via applying mass balance approach resulted in decreasing the pollutants in the wastewaters to an acceptable level and it was regarded as a treatment process. Each type of wastewater needs a definite quantity of raw water for the treatment. Commonly, sedimentation is suggested prior dilution of wastewater with the Greater-Zab River water. Maximum discharge of 1,182 m^3/s is sufficient for treatment of all mentioned types of wastewaters in Erbil City.

1. Introduction

The surface waters that are contaminated by humans' bad use causes the main problem in supplying water for humans. The concentration of pollutants in wastewater related to any combination of surface runoff, storm water, domestic, industrial, commercial, and agricultural activities is called wastewater (Sagasta et al., 2017). The characteristics of wastewaters depend on the source of the wastewater such as domestic, industrial, dairy, municipal, slaughterhouse, refinery, landfill leachate, tannery, etc. (Aziz and Ali, 2018). Mainly, pollutants in the wastewaters exceed the standards for the disposal of wastewater. Consequently, treatment methods like

natural (dilution and land treatment), artificial (primary and secondary treatment), and combined (primary treatment and effluent disposal by natural methods) are necessary (Punmia et al., 1998; Singh and Singh, 2003). Of course, each treatment method, such as dilution method, land treatment, physical, chemical and biological treatment has advantages and disadvantages (Punmia et al., 1998; Singh and Singh, 2003; Metcalf and Eddy, 2014; Qasim, 2017; Aziz and Ali, 2018; Aziz et al., 2020). On the other hand, initial cost, maintenance and operation coasts, chemicals, and sludge disposal are other problems for the artificial treatment processes. Therefore, examining dilution process for treatment of wastewaters using river water via applying mass balance approach is another option for the treatment processes.

Mass balance approach combine quality and quantity of waters/wastewaters before and after mixing (Davis and Cornwell, 2013). In literature, several investigations and analyses were done to solve various problems that were created by wastewaters and applying the concept of mass balance. Wentze et al. (2006) investigated, both experimentally and theoretically, the conservation of mass of wastewater organic chemical oxygen demand (COD) and nitrogen compounds along the link connecting the primary settling tank and anaerobic digester. It was found that the primary sludge characteristics verses the biodegradable and un biodegradable soluble and particulate COD and nitrogen compounds needed to be calculated from mass balances around the primary settling tank. Wooley (1981) described the process to determine solids mass and location throughout a treatment plant. The researcher explained how these values could be used to determine the solids mass balance around single treatment units and the entire system. This was done by applying an analytical solution of mass balance calculations. Assis (2016) analyzed the energy and material balances of wastewater including anaerobic biological treatment process with aerobic biological treatment in a recycled board mill. The comparison of the wastewater treatment plant running before and after the start-up of the biogas plant was studied. The plant systems with the anaerobic digestion showed an increased energy use coupled to an increased flow of wastewater. Ekama et al. (2011) studied the steady state modelling of mass balance to evaluate the municipal wastewater treatment process from input and output of a stream. Nowadays, the gradual growth of continuous flow models and stoichiometry has been estimated to have a higher precedence than further progressions of simulation models. Therefore, after validation, the experimentally performances of the first stage biodegradability and waste activated sludge under anaerobic and aerobic digestion conditions was determined. Slewa et al. (2018) studied impact of Alton Kopri slaughterhouse wastewater on the quality of Lesser-Zab river water in Kirkuk City, Iraq. They found that the Alton Kopri slaughterhouse wastewater affected on the Lesser-Zab water.

In the present research, different types of wastewaters in Erbil City, Kurdistan Region-Iraq were studied. To date, there is no central wastewater treatment plant in Erbil City and produced wastewater in some areas are treated using small treatment plant in the site. Additionally, a huge amount of Greater-Zab River water is available close to Erbil City. Applying different quantities of river water for dilution of wastewaters as treatment process in Erbil City was examined. Consequently, the current study was focused on the different types of wastewaters and mixing them with Greater-Zab River water through implementing the mass balance concept for the treatment purpose.

2. Materials and Methods

### 2.1. Plan of the work and location of wastewaters

In the present research, treatment of different types of wastewaters such as slaughterhouse, tannery, municipal, landfill-leachate, dairy, and Kawergosk oil refinery wastewaters in Erbil City, Kurdistan region-Iraq were studied, Figure 1. Data for various kinds of wastewaters were obtained from published works and are given in Table 1. Additionally, site visiting was conducted as well. Greater-Zab River water was proposed for dilution of wastewaters as treatment technique. Information for Greater-Zab was achieved through literature and site visiting. Mass balance approach was planned for using different amount of Greater-Zab river water for dilution of wastewaters. Further, information about biochemical oxygen demand (BOD) were studied and dissolved oxygen (DO) were estimated as 0.01 mg/L for all types of wastewaters. Details about wastewaters, Greater-Zab River, Mass balance approach, and DO information are given in the upcoming parts. Dilution factor for mixing of wastewaters with river water was calculated. Further, impacts of wastewaters mixing with river water on BOD and DO in the river water were studied.

2.2. Greater-Zab River Water

Location of Greater-Zab River is illustrated in Figure 1. Characteristics of Greater-Zab water are given in Table 2. The plan was to use different amounts of river water for dilution of different types of wastewaters in Erbil city for the purpose of the study.

2.3. Mass Balance Approach

The solution of mass balances was necessary to perceive the implications of the DO sag curve problem, Figure 2. The mass balances may be applied to explain for initial mixing of the waste stream and the river. For this purpose, three resistant changes such as DO, five-day biochemical oxygen demand (BOD_5), and temperature were not stable and constant as the pollutant water mixed with the river. The conservation of mass balance for
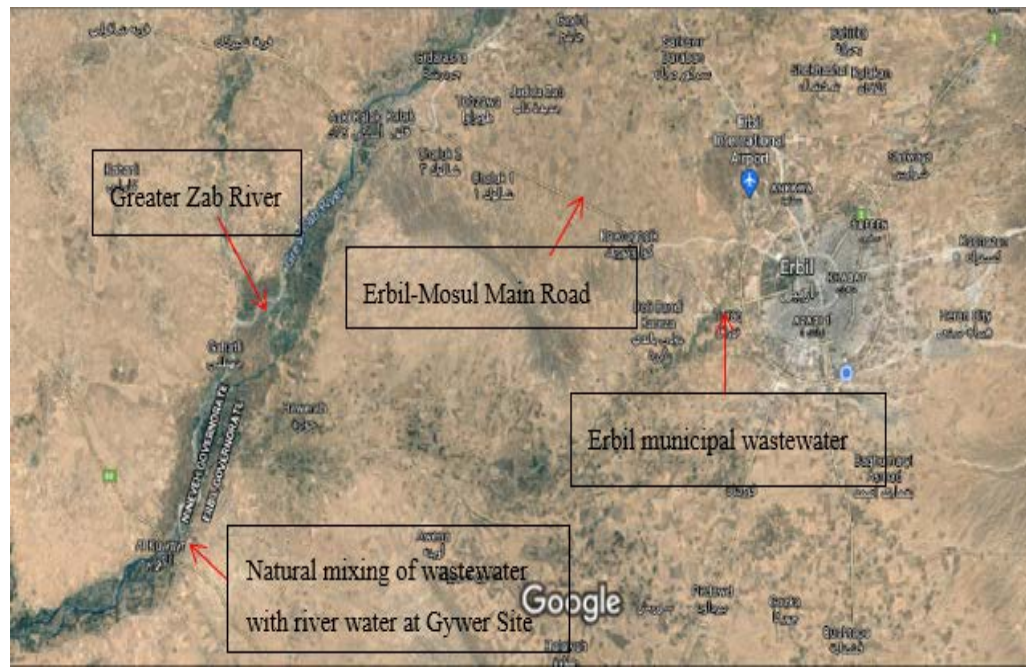
Figure 1. Different kinds of wastewater in Erbil city
Satellite image (https://www.google.iq/maps/@36.1593852,43.8110409,38506m/data=!3m1!1e3)

Table 1
Characteristics of different types of wastewater in Erbil City

No.	Types of wastewater	Q (m³/s)	Temp. (°C)	BOD$_5$ (mg/L)	k$_{20}$ (day^{-1}) Decay Rate	References
1	Slaughterhouse	2.3	22.60	400	0.12-0.23	
2	Tannery	2.6	18.86	320	0.12-0.23	
3	Erbil Municipal	3	21.86	44	0.12-0.23	Aziz and Ali, 2018
4	Landfill leachate	4.5	12.58	273	0.12-0.23	
5	Dairy	4	21.53	650	0.12-0.23	
6	Erbil Municipal	5.5	18	62.5	0.12-0.23	Aziz, 2004; Aziz, 2020
7	Kawergosk Oil Refinery	3	32.89	155	0.12-0.23	Aziz and Fakhrey 2016

Table 2
Characteristics of Greater-Zab River water in Erbil city

References	Aziz, 2009		Aziz and Fakhrey, 2016			
River	Months / 2006	Q (m³/s)	Months / 2015	Temp. (°C)	BOD$_5$ (mg/L)	DO (mg/L)
	Aug-06	165.78	Jan-15	6.3	0.2	9.11
Greater-Zab	Sep-06	146.49	Mar-15	13.37	0.2	5.95
	Oct-06	154.85	May-15	17.11	4.2	0.17
Average	-	155.706	-	12.26	1.533	5.076

oxygen after mixing provided results in a mass of oxygen per unit time (Davis and Cornwell, 2013).

$$Mass\ of\ pollutant\ in\ wastewater = Q_w\ C_w \quad (1)$$

$$Mass\ of\ pollutant\ in\ River = Q_r\ C_r \quad (2)$$

$$C_m = \frac{Mass\ of\ Concentraion\ after\ mixing}{Q_w + Q_r} = \frac{Q_w\ C_w + Q_r\ C_r}{Q_w + Q_r} \quad (3)$$

Where: Cm is the concentration of pollutants after mixing (g/m³), Q_w is the volumetric flowrate of wastewater (m³/s), Q_r is the volumetric flowrate of river

(m^3/s), C_w is concentration in the waste water (g/m^3), and C_r is concentration in the river (g/m^3).

The conservations of pollutants (such as DO and BOD) after mixing are the respective masses per unit time divided by the total flow rate of wastewater and river flow (Davis and Cornwell, 2013).
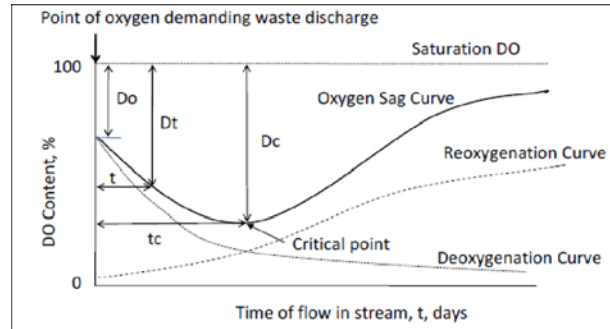

Figure 2. De-oxygenation, re-oxygenation and oxygen sag curve (Baba, 2020)

3. Results and Discussions

3.1. Characteristics of Wastewater

Commonly, the pollutants in the wastewaters exceeded the standard disposal limits. Accordingly, treatment processes are essential prior disposal to the natural environment (Bapeer, 2010; Shekha et al., 2010; Aziz and Ali, 2018; Aziz 2020). Published works revealed that different treatment techniques, such as sequencing batch reactor, adsorption, lagoons, oxidation ditch, wetland, and trickling filter, were applied for treatment of wastewaters in Erbil city (Fakhrey, 2016; Aziz et al., 2020). Of course, each treatment method has advantages and disadvantages. Additionally, initial cost, construction, operation and maintenance are other difficulties of the mentioned treatment process. Consequently, in the present work, treatment of various types of wastewaters using dilution

by river water was examined. Further details are given in the future sections. Commonly, Erbil municipal wastewater is considered as weak wastewater; While, landfill leachate is regarded as strong type wastewater (Metcalf and Eddy, 2014; Aziz and Ali, 2018; Aziz, 2020).

3.2. Greater-Zab River Water

The characteristics of Greater-Zab River water was aforementioned earlier from the published works (Aziz, 2004; Aziz, 2009; Shareef et al., 2009; Toma, 2013; Aziz and Fakhrey, 2016; Shekha, 2016; Aziz and Mustafa, 2019). In addition, the discharge of Greater-Zab River water was reported as well. It is clear that Greater-Zab river water needs treatment, if used for water Supply system (Aziz and Mustafa, 2019). Regarding BOD and NH$_3$-N values, Greater-Zab river water is considered as non-polluted water (Table 3). The minimum value of Greater-Zab River water flow was 57 m^3/s which was informed in September 2001. While, the maximum flow of 1,182 m^3/s was described in February 2006.

3.3. Treatment by Dilution Method

Ratios (Dilution factor) of Greater-Zab River water to wastewaters were calculated as given in Table 4. Values of dilution factors for different types of wastewaters varied from 10.36 to 513.91. Standards of dilution are shown in Table 5. If minimum flow of Greater-Zab river water was used, the wastewater should be treated thoroughly so that the effluent did not contain more than 30 mg/L of suspended solids and its BOD$_5$ at 18.3 °C did not exceed 20 mg/L. While, if maximum discharge was applied easier treatments were required. For maximum discharge of Greater-Zab River, commonly sedimentation was suggested prior dilution of wastewater with the Greater-Zab river water.

Table 3
Water quality standard for rivers (Aziz and Fakhrey, 2016)

No.	Water Quality/Item	Non (Slightly) polluted	Lightly-polluted	Moderately-polluted	Severely-polluted
1	DO (mg/L)	DO $\geq$ 6.5	6.5 > DO $\geq$ 4.6	4.5$\geq$ DO $\geq$ 2	DO < 2
2	BOD$_5$ (mg/L)	BOD$_5$ $\leq$ 3	3 < BOD$_5$ $\leq$ 4.9	5.0 $\leq$ BOD$_5$ $\leq$ 15	BOD$_5$ > 15
3	TSS (mg/L)	TSS $\leq$ 20	20 < TSS $\leq$ 49.9	50 $\leq$ TSS $\leq$ 100	TSS > 100
4	NH$_3$-N (mg/L)	NH$_3$-N $\leq$ 0.5	0.5 < NH$_3$-N $\leq$ 0.99	1 $\leq$ NH$_3$-N $\leq$ 3	NH$_3$-N > 3
5	Point sources	1	3	6	10
6	Pollution Index Integral Value	S $\leq$ 2	2 < S $\leq$ 3	3.1$\leq$ S $\leq$ 6	S > 6

Table 4
Ratio (Dilution factor) of Greater-Zab river water to wastewaters amount

No.	Types of wastewater	Q (m³/s)	References	Amount of Greater-Zab River/Wastewater	
				For Min. Q (57 m³/s)	For Max. Q (1,182 m³/s)
1	Slaughterhouse	2.3		24.78	513.91
2	Tannery	2.6		21.92	454.62
3	Erbil Municipal	3	Aziz and Ali, 2018	19	394
4	Landfill leachate	4.5		12.67	262.67
5	Dairy	4		14.25	295.5
6	Erbil Municipal	5.5	Aziz, 2020	10.36	214.91
7	Kawergosk Oil Refinery	3	Aziz and Fakhrey, 2016	19	394

Table 5
Standards of dilution (Punmia et al., 1998)

Dilution factor	Standards of purification required
Above 500	No treatment required. The raw sewage or wastewater can be discharged directly in the receiving water.
Between 300 to 500	Primary treatment consisting of plain sedimentation is required so that effluent does not contain more than 150 mg/L of suspended solids.
Between 150 to 300	Treatment such as sedimentation, screening and chemical precipitation are required, so that the effluent does not contain more than 50 mg/L of suspended solids.
Less than 150	The wastewater/sewage should be treated thoroughly so that the effluent does not contain more than 30 mg/L of suspended solids and its 5-day BOD at 18.3 °C does not exceed 20 mg/L.

3.4. Application of Mass Balance Approach

To obtain the required amount of Greater-Zab water for dilution of different types of wastewaters, the following equation was derived and applied.

$$Q_r = \frac{Q_w\,C_w - Q_w\,C_m}{C_m - C_r} \qquad (4)$$

The items of the equation were previously defined. Table 6 illustrates the calculated discharges of Greater-Zab river water for mixing of wastewaters with the river water. BOD of 3 mg/L was decided, because river water with this value of BOD was regarded as non-polluted river water, while, BOD of 15 mg/L was considered as moderately polluted river water (Table 3).

It was suggested to not change the quality of Greater-Zab River as non-polluted after disposal of the wastewaters to the river water. Minimum Greater-Zab water flow of 57 m³/s was suitable for treatment of Erbil municipal and treated Kawergosk oil refinery wastewaters. On the other hand, maximum discharge of 1,182 m³/s was sufficient for the treatment of all mentioned types of wastewaters in Erbil City.

Table 6
Required amount of Greater-Zab River water after mixing wastewaters

Raw Wastewater				Raw River Water		Wastewater plus River water		Discharge Required
Type	BOD (mg/L)	Q (m³/s)	References	BOD (mg/L)	Q (m³/s)	BOD (mg/L)	Q (m³/s)	Q (m³/s)
Slaughterhouse	400	2.3		3	57	15	59.3	73.79
Tannery	320	2.6	Aziz and Ali, 2018	3	57	15	59.6	66.08
Erbil Municipal	44	3		3	57	15	60	7.25
Landfill leachate	273	4.5		3	57	15	61.5	96.75
Dairy	650	4		3	57	15	61	211.67
Erbil Municipal	62.5*	5.5**	Aziz, 2004*; Aziz, 2020**	3	57	15	62.5	21.77
Kawergosk Oil Refinery	155	3	Aziz and Fakhrey, 2016	3	57	15	60	35.00

Mixing of wastewaters with river water caused depletion of DO in the river (Davis and Cornwell, 2013; Slewa et al., 2018). Percentage depletion of DO is given in Table 7. Furthermore, one of the main factors that influenced the decreasing of DO levels in the rivers was the ultimate BOD (La) and BOD rate constant (k). The numerical value of rate constant was dependent on the type of the wastewater that was discharged into the river, capability of organisms to operate the waste in the system, and the temperature of the water. Therefore, monthly temperature was measured and BOD_5 was experimentally tested behind the DO of the Greater-Zab River. For more simplification and implementation of the mass balance concept, the average value of DO was estimated to be 5.076 mg/L during the year of 2016.

The BOD rate constants k per day (d^{-1}) for compound wastewaters was to be supported by the proportionate of the various components. As explained in the references, the typical BOD rate constant at standard (20 °C) mixture temperature ranged between from 0.35 to 0.7 d^{-1} for raw sewage water, while for well-treated sewage and polluted river water was between 0.12 to 0.23 d^{-1} (Davis and Cornwell, 2013). These values showed that there was a lower rate constant for treated sewage compared to raw sewage result from the more quickly reducible of organism compound completely removed than less readily degradable organic compounds during wastewater treatment. Hence, the laboratory testing was done at a standard temperature of 20 °C, the BOD rate constant (k_{20}) was modified to the accommodate water temperature constant rate (k_T) by using the following equation:

$$k_T = k_{20} \; \theta^{(T-20)} \tag{5}$$

where: T is the temperature of the mixture in °C and θ is the temperature coefficient which was 1.135 for temperature range from 4 to 20 °C and equals to 1.056 for temperature range (20 to 30) °C.

In this investigation, the average typical value of BOD rate constant for Greater-Zab River polluted with different kinds of wastewaters was taken as average value of 0.175 d^{-1} then the ultimate BOD values for wastewater (L_w) were determined by equation:

$$L_w = \frac{BOD_5}{1 - e^{(-k\,T)}} \tag{6}$$

Greater-Zab River may contain large deposits of organic matter within the sediments at their bed. These may be natural deposits of leaves and dead aquatic plants or may be sludge deposits from different types of wastewaters that are not treated and discharged into the system of this river. In either case, decomposition of this organic matter places an extra capacity on the stream's oxygen resource since the oxygen demand must be supplied from the excessively water.

Aquatic plants may have a considerable effect on the DO levels. During the mid-day, their photosynthesis has a specific act to generate the oxygen that abundance the reaeration and may even cause oxygen supersaturation. However, plants consume oxygen for respiration processes. Although there's a net overall production of oxygen, plants respiration can severely lower DO levels during the night.

For these purposes, the contaminants inside the wastewaters or sewage should be transported by well treatment processes then convert it into an effluent that can be returned to the water cycle with acceptable impact on the environment, or reused for various purposes.

Table 7
Variation of BOD and DO in Greater-Zab River after mixing

No.	Wastewater Type	k_T (day^{-1})	Lw (mg/L)	After Mixing (wastewaters + Greater Zab River)	La (mg/L)	DO (mg/L)	% DO depletion in river
1	Slaughterhouse	0.2016	404.2422		7.3953	5.0029	1.4742
2	Tannery	0.1515	339.5047		7.0841	4.9935	1.6665
3	Municipal*	0.1937	44.6474		2.3483	4.9809	1.9228
4	Landfill Leachate	0.0684	473.1661		14.7809	4.9344	2.8842
5	Dairy	0.1902	661.0060		18.0504	4.9498	2.5637
6	Municipal **	0.1358	68.43		6.8978	4.9038	3.5251
7	Kawergosk Oil Refinery	0.8952	155		2.9221	4.9809	1.9228

* Aziz and Ali (2018)
** Aziz, 2004
L_w is ultimate BOD of the waste water (mg/L).
La is the initial ultimate BOD after mixing.

4. Conclusions

Treatment of different types of wastewaters (such as slaughterhouse, tannery, municipal, landfill leachate, dairy, and oil refinery) using dilution by Greater-Zab River water was studied. Wastewaters need treatment before disposal to the water sources. The following conclusions were outlined:

- Types of wastewaters varied from weak (municipal wastewater) to strong wastewaters (landfill leachate).
- Greater-Zab River was considered as non-polluted river according to BOD_5, NH_3-N, and DO values.
- Dilution factor for Erbil wastewaters varied from 10.36 to 513.91. Mixing the wastewaters with Greater-Zab river water led to decreasing of DO in the river water by 3.525 %.
- Commonly sedimentation was suggested as a step taken prior to the dilution of wastewater with the Greater-Zab River water.
- Maximum discharge of 1,182 m^3/s was sufficient for treatment all mentioned types of wastewaters in Erbil City.
- Dilution using various quantities of raw river water via applying mass balance approach resulted in decreasing the pollutants in the wastewaters to an acceptable level and it was regarded as treatment process.
- Further, each type of wastewater needs a definite quantity of raw water for the treatment.

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Primena tehnike smanjenja masenog bilansa za odlaganje otpadnih voda u reku Gornji Zab u Erbilu u regiji Irački Kurdistan

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I Z V O D

Prečišćavanje otpadnih voda pre njivog puštanja u životnu sredinu ili izvore vode predstavlja neophodan korak. Za prečišćavanje različitih vrsta otpadnih voda primenjuju se brojne tehnike. Do sada nije zabeležena primena postupka smanjenja masenog bilansa za prečišćavanje različitih vrsta otpadnih voda u gradu Erbilu koji se nalazi u regiji Irački Kurdistan. Shodno tome, cilj ovog rada je ispitivanje primene metode smanjenja masenog bilansa dodavanjem rečne vode za prečišćavanje različitih vrsta otpadnih voda. Ispitivane su osobine različitih vrsta otpadnih voda, kao i osobine vode u reci Gornji Zab koja protiče kroz Erbil. Ispitivane su osobine otpadnih voda iz klanica, pogona za štavljenje, komunalni otpad, procedne vode, kao i otpadne vode iz mlekara i rafinerija koje se nalaze u Erbilu. Postupak koji uključuje maseni bilans je primenjen da bi se potvrdilo smanjenje različitih vrsta otpadnih voda u prisustvu vode iz reke Gornji Zab. Izračunat je faktor smanjenja i potrebna količina rečne vode. Temperatura, biohemijska potrošnja kiseonika (BPK) i rastvoreni kiseonik su takođe ispitani. Rezultati su pokazali da je faktor smanjenja kod ovih otpadnih voda varirao između 10,36 i 513,91. Mešanje otpadnih voda i vode iz reke Gornji Zab je dovelo do smanjenja količine rastvorenog kiseonika u rečnoj vodi za 3,525 %, kao i do povećanja biohemijske potrošnje kiseonika u vodi Gornjeg Zaba. Smanjnje masenog bilansa koristeći različite količine neobrađene rečne vode je dovelo do smanjenja zagađivača u otpadnim vodama na prihvatljiv nivo i voda se smatrala prečišćenom. Za prečišćavanje različitih vrsta otpadnih voda potrebna je određena količina neobrađene vode. Sedimentacija je postupak koji se obično preporučuje pre primene postupka smanjenja masenog bilansa vodom iz Gornjeg Zaba. Maksimalni protok od 1.182 m^3/s smatra se dovoljnim za tretman svih pomenutih vrsta otpadnih voda na teritoriji grada Erbil.