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Effect of Alton Kopri Wastewater on Lesser-Zab Raw Water

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A B S T R A C T

This work aimed to study the impact of Alton Kopri wastewater on the Lesser-Zab River water. Specifically, the study aimed to determine the impacts of the formed wastewater on the Lesser-Zab River using the mass balance principle (MBP) and provide appropriate solutions to this problem. Fresh samples from Alton Kopri wastewater and the Lesser-Zab River water were collected from February 2013 to September 2013. The samples were analyzed for temperature, pH, total alkalinity, total hardness, total acidity, chloride, turbidity, solids, dissolved oxygen, 5-day biochemical oxygen demand, and sulfate. Results presented graphically demonstrated that Alton Kopri wastewater can be classified as medium- to strong-type wastewater, whereas the Lesser-Zab River can be categorized as a moderately polluted river and moderately hard to hard water. The application of MBP revealed that Alton Kopri wastewater affected the Lesser-Zab River water; hence, appropriate solutions were outlined to minimize the impact of the former on the water resource and treatment of the latter.

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تأثير مياه الصرف الصحي لمدينة التون كوبري على مياه نهر الزاب الأسفل

الخلاصة

الهدف من هذا العمل هو تحديد خصائص مياه الصرف الصحي لمدينة ألتون كوبري وخصائص مياه نهر الزاب الأسفل وبالأخص تحديد آثار مياه الصرف الصحي الناتجة من التون كوبري على مياه نهر الزاب الأسفل باستخدام مبدأ التوازن الكتلي وتقديم الحلول المناسبة لهذه المشكلة. حيث تم جمع عينات من مياه الصرف الصحي لمدينة ألتون كوبري ونماذج من مياه نهر الزاب الأسفل من شهر شباط للعام 2013 إلى شهر ايلول من العام نفسه، وتم تحليل العينات لدرجة الحرارة، الأس الهيدروجيني، القاعدية الكلية، العسرة الكلية، الحامضية الكلية، كلورايد، الكدرة، المواد الصلبة، الأوكسجين المذاب، المتطلب البايوكيميائي للأوكسجين، والكبريتات. أظهرت النتائج أن مياه الصرف الصحي لمدينة ألتون كوبري تصنف من نوع المتوسط إلى نوع القوي في حين ان مياه نهر الزاب الأسفل يمكن تصنيفها بأنها معتدلة التلوث ويعتبر ماء النهر متوسط العسرة الى ماء عسر. كشفت تطبيق استخدام مبدأ التوازن الكتلي بان مياه الصرف الصحي لمدينة ألتون كوبري له تأثير على مياه نهر الزاب الأسفل ولأجل ذلك وضعت الحلول المناسبة لتقليل تأثير مياه الصرف الصحي للمدينة المذكورة اعلاه على مصدر مياه نهر الزاب الأسفل ومعالجته لاحقا.

1. INTRODUCTION

The Lesser-Zab River is one of the five key catchments in the Northern Iraq area. The other four catchments are Khabour, Greater-Zab, Ozem, and Sirwan (Diyala) [1]. The Lesser-Zab (also known as Little Zab or Lower Zab) originates in Iran and mixes with the Tigris River in Iraq. The Lesser-Zab tributary forms one of the chief tributaries of the Tigris River, with a length extending 400 km over an area of 22,250 km^2 from its origin in Iran [2,3]. The River is normally replenished by rainfall and snowmelt, resulting in a peak flow in spring and low-water quantity in the summer and early fall seasons. Two dams (i.e., Dukan and Dibis) were constructed on Lesser-Zab to regulate the river flow. These dams provide water for irrigation, attract tourists, support fish production, and generate electricity. At present, the Lesser-Zab River water is commonly used for drinking (after treatment processes), irrigation, and fishing purposes.

The environmental impact of used water and the Lesser-Zab River on the Alton Kopri Area is expected. Therefore, another part of this research is related to the characteristics of Alton Kopri wastewater. The formed wastewater from the Alton Kopri Sub-District that is normally disposed to the Lesser-Zab River without any treatment process. Often, the generated municipal and slaughter house wastewaters are discharged to the river. Using sewers decreases the

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penetration of fresh wastewater to water sources. Thus far, scientific documents on the characterization of surface water, such as Lesser-Zab, and the produced wastewater in Alton Kopri, have been unavailable.

Aziz [4] studied the seasonal variation of some physical and chemical parameters for the Greater-Zab River, groundwater, and Erbil municipal wastewater. Another study monitored the Greater-Zab River water for 14 months [5]. Toma [6], Saeed et al. [7] and Fakhrey [8] conducted different studies on the Greater-Zab River water. Several works examined the limnological effects of Lesser-Zab on the quality of the Tigris River water [1,2]. However, there exists a knowledge gap in the variation of some physical and chemical water quality parameters for both the Lesser-Zab River and Alton Kopri wastewater. To bridge the gap, the present work focused on the fresh water characterization of Lesser-Zab River and Alton Kopri wastewater by examining various characteristics, such as temperature, pH, total alkalinity, total hardness, total acidity, chloride, turbidity, total solids, suspended solids, dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD_5), and sulfate, from February 2013 to September 2013. The variations of the aforementioned parameters for both water and wastewater were then presented graphically. Such information may be used for any water supply treatment plant, irrigation project, river water contamination, and wastewater treatment process. In addition, the water and wastewater quality parameters were compared with the water quality standards and typical characteristics of wastewaters. The effects of wastewater on river waters and suitable solutions were then provided. To the best of our knowledge, this is the first study to undertake this kind of investigation.

2. MATERIALS AND METHODS

2.1. Description of the Site

The Lesser-Zab River originates from Iran. The River covers an area of 15,600 km^2, and has a total perimeter of 1398 km. The total area of this watershed is 20,030 km^2, and its total perimeter is 1537 km. Approximately 76% of the watershed area is located within the border of Iraq; thus, the rest is located within the Iranian border (Figs. 1 and 2). The elevations of this watershed range approximately from 100 m to 3550 m above sea level [9]. The Lesser- Zab watershed is located approximately between SN Latitude 35.16 º to 36.79 º and WE Longitude 43.39 º to 46.26 º [1]. In Iraq, its length extends approximately 175 km with a width of approximately 200 m. The base of Lesser-Zab consists of gravel base [3]; its average flow is 197.8 m^3/s, whereas the maximum recognized discharge is 3420 m^3/s. The recorded discharge for Lesser-Zab from 1930 to 2005 is shown in Fig. 3. From the north side, the Lesser-Zab is bounded by the Greater-Zab Basin, and on the north side, the River is bordered by the basins of the Ozem and Diyala Rivers. The parallel mountain ranges of the Zagros consist of limestone folds rising to heights of more than 3000 m. Water erosion fills the Lesser-Zab valley, whereas the foot hill zone, located southwest of the Zagros, is filled with layers of conglomerate, gravel, and sandstone. The annual precipitation along the course of the River ranges from over 1000 mm in the Iranian Zagros to less than 200 mm at the area where the Lesser-Zab River meets with the Tigris River. The river valleys are characterized by water-loving plants and marshy zones resulting from the absence of drainage. These zones are breeding grounds for malaria-carrying mosquitoes. The foothill zone, particularly the plain of Erbil, is significantly cultivated, and patches of natural vegetation remain along with plenty of Phlom herbs [10].

Raw wastewater samples from the Alton Kopri Sub-District in Kirkuk, Iraq were collected. The location of sample collection is illustrated in Fig. 2. The produced wastewaters from domestic, commercial, and institutional structures and slaughterhouses are mixed and disposed to Lesser-Zab River without any further treatment.

2.2. Sample Collection

The Lesser-Zab River raw water samples and Alton Kopri wastewater samples were collected monthly from February 2013 to September 2013. The researchers collected the samples using polyethylene containers rinsed with water sample and then filled and tightly sealed. The samples were kept at the laboratory under a dark and cool condition and maintained according to standards. Specifically, the samples were stored at 4 °C in the laboratory to deactivate the microorganisms [11].

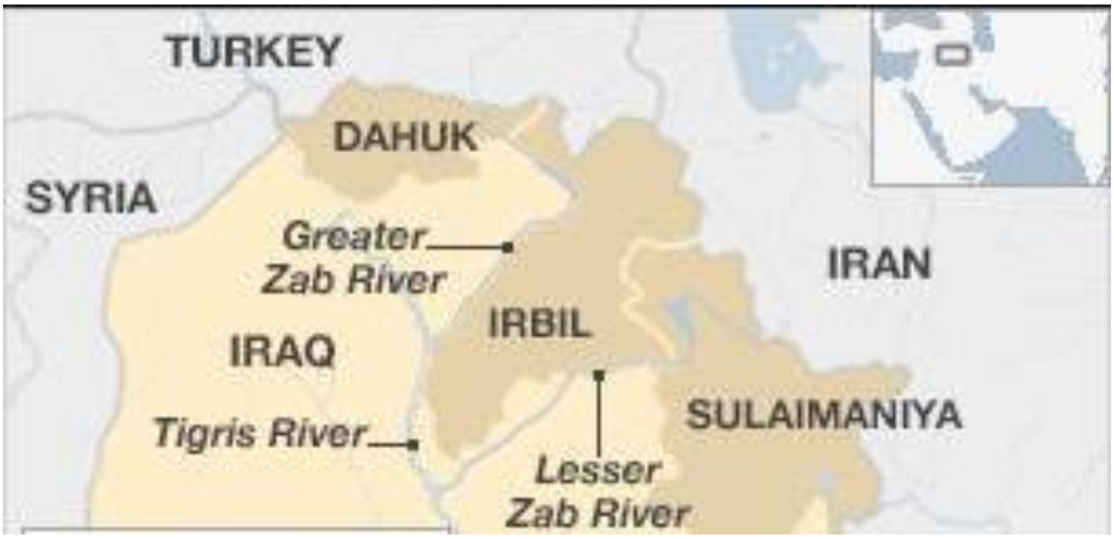


Fig. 1. Location of Lesser-Zab River.

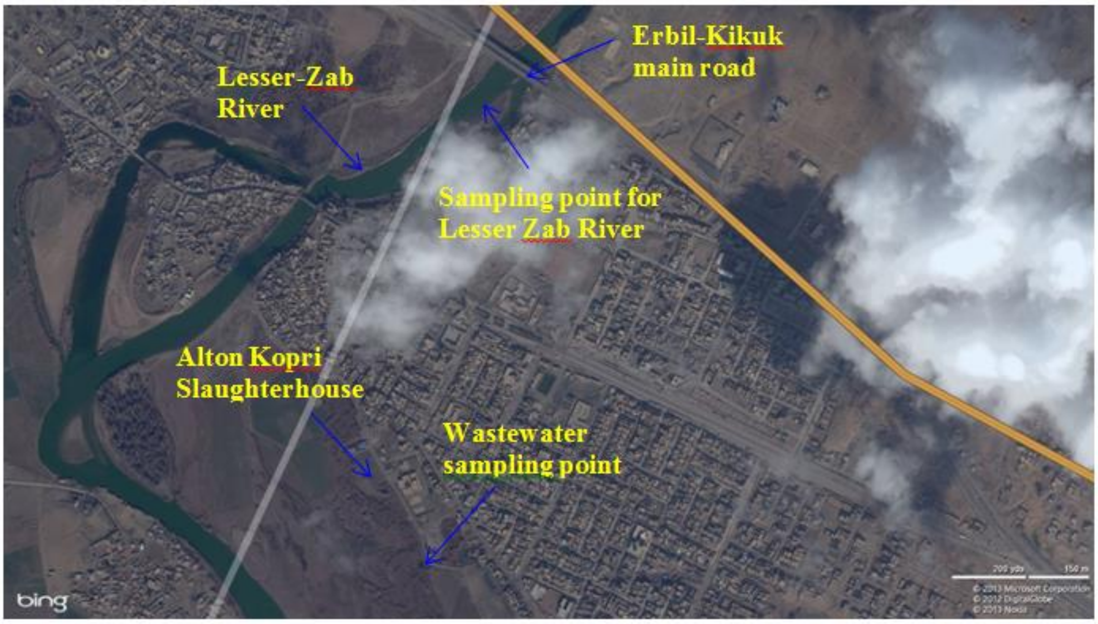


Fig. 2. Satellite image of Lesser-Zab River and Alton Kopri wastewater sampling points.

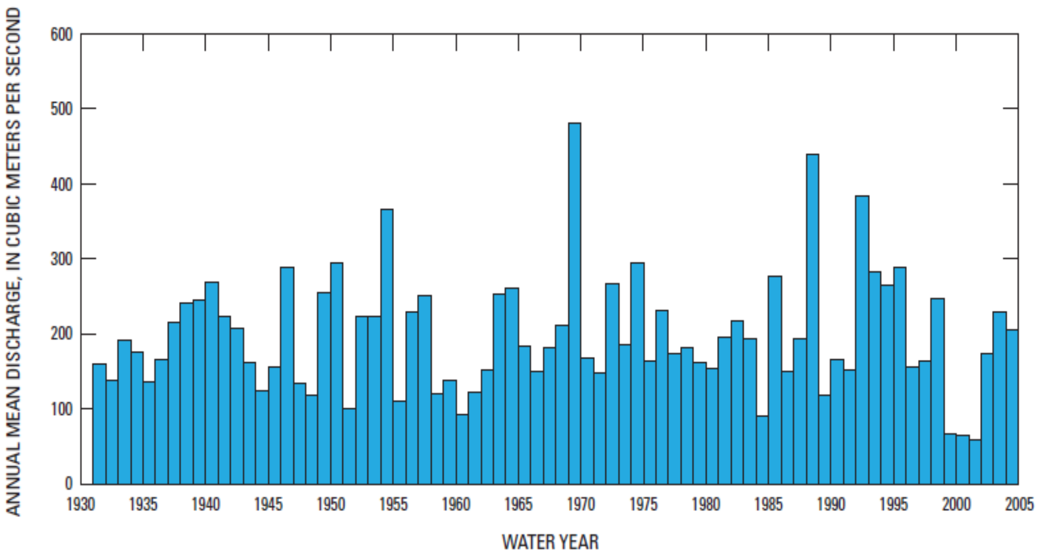


Fig. 3. Annual average discharge for Lesser-Zab at Dokan during 1931–2004 [12,26].

2.3. Water and Wastewater Characterization

Several physical and chemical experiments were conducted to examine the collected samples. Specifically, the samples were analyzed for temperature, pH, total alkalinity, total hardness, total acidity, chloride, turbidity, total solids, total suspended solids, DO, BOD_5, and sulfate. The tests were conducted at the College of Engineering laboratory of the Salahaddin University–Erbil, Iraq. All physical and chemical examinations were conducted according to the standard procedures [11].

2.4. Instruments and Experiment Methods

The water temperature of the samples was measured in the field, using a clean mercury thermometer with an accuracy of 0.1 °C. Turbidity model, WTW, and Turb 550 (Germany) were used to measure turbidity. EC and pH were measured using Combined CCMD 625, a combined conductivity/pH meter, Fig. 4. The total salts were determined mathematically from the EC values. Total acidity, total alkalinity, total hardness, and chloride were determined using titration methods in accordance with the APHA standard [11]. BOD_5 values were determined on the basis of the DO figures upon initial collection and after 5 days. The total solids and suspended solids were determined using oven, filter paper, evaporating dish, flasks, and sensitive electrical balance. The sulfate for the samples were detected according to the standard procedures, APHA Method 4500 Sulfate was used for determination of sulfate in the samples [11].

3. RESULTS AND DISCUSSIONS

3.1. Characteristics of the Lesser-Zab River Water and Alton Kopri Wastewater

3.1.1. Temperature

The variations of water temperature and atmospheric temperature versus time during the study period are shown in Fig. 5. As shown in Fig. 5, the minimum and maximum temperatures for the Lesser-Zab River water were 12.4 °C and 21.2 °C, respectively, whereas the temperature values for the atmosphere were 14.6 °C and 38.6 °C. These results

Thermometer

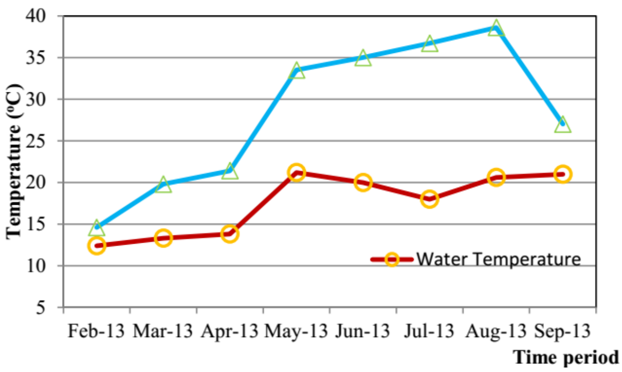
pH meter

Turbidity meter

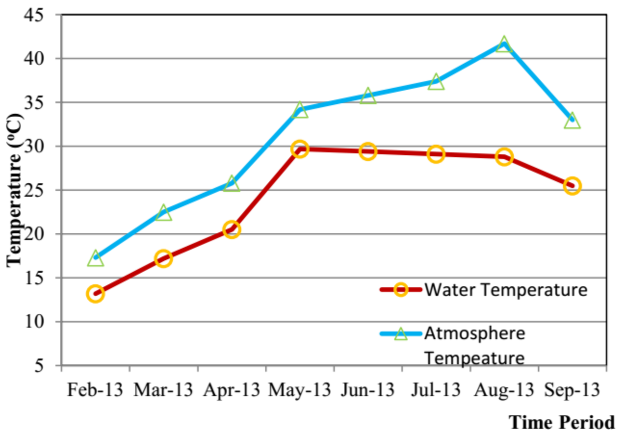
EC meter

Fig. 4. Instruments used for measuring Temperature, pH, Turbidity, and EC

are in accordance with previous finding of 7.5 °C to 27.7 °C as reported by Kassim et al. [2]. In comparison, previous authors have reported that the temperature for Lesser-Zab water and the ambient temperature ranged from 10 °C to 27 °C and from 12 °C to 36 °C, respectively [3]. The variations of temperatures for Greater-Zab water during the 14 months ranged from 7 °C to 30 °C [5]. The obtained results for Lesser-Zab in the current study are in accordance with previously reported findings [2-5,12]. The reported temperatures in this study indicated that the atmospheric temperatures were higher than the water temperature, coinciding with the finding published by Abdul Jabar et al. [3]. In Iraq, the recorded temperatures from May to August are commonly the highest values and tend to decrease in September. Thus, this study focused on the hot and cold seasons. Overall, the published data by previous researchers supported the current results [3].



(i) Total alkalinity (mg/L)



(ii) Total hardness (mg/L)

Fig. 5. Variation of water temperature and atmospheric temperature versus time

The minimum and maximum temperatures in Alton Kopri wastewater were 13.2 °C and 29.7 °C, respectively. Amin and Aziz [13] reported similar values (11 °C to 28 °C) for municipal wastewater in Erbil City. The atmospheric temperatures were higher than those of wastewater, whereas the temperatures of wastewater samples were higher than the those of the Lesser-Zab River water samples. This phenomenon might be attributed to the mixing of animal blood and domestic wastewater, thereby resulting in the increase of temperatures.

3.1.2. *pH (Potential of Hydrogen)*

The variations of pH values for the Lesser-Zab River water and Alton Kopri wastewater are illustrated in Fig. 6. As can be seen, the pH values for the River water ranged from 7.41 to 8.18. The previous findings on the pH values of the Lesser-Zab River water are in accordance with those obtained in the present work [2,3]. A similar range of pH values from 7.45 to 8.82 for Greater-Zab water has been reported by Aziz [4]. The pH values in the current work are also in agreement with the reported data for Greater-Zab water [4-6]. Furthermore, the pH values fell within the allowable limits for drinking water standards [14-16].

The minimum and maximum pH values for Alton Kopri wastewater were 7.17 and 7.91, respectively. The obtained results (pH values of 6.82 to 8.2) in Erbil municipal wastewater agree with the previously published data [4]. Neutral pH values are ideal for treatment processes, particularly biological treatment systems [17].

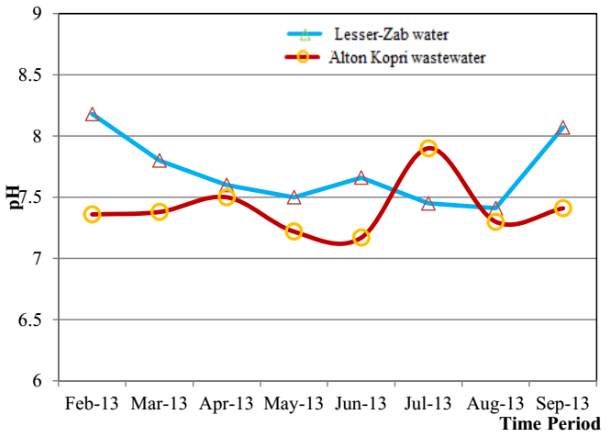


Fig. 6. Variation of pH for Lesser-Zab water and Alton Kopri wastewater versus time.

3.1.3. Total Alkalinity and Total Hardness

Figure 7 shows the plot of total alkalinity and total hardness versus time. The total alkalinity for the Lesser-Zab River water ranged from 138 mg/L to 188 mg/L, whereas that for Alton Kopri wastewater ranged from 165 mg/L to 440 mg/L. A wider range of 52 mg/L to 208 mg/L for Lesser-Zab has been previously reported [3]. The current results for the Lesser-Zab (146 mg/L to 212 mg/L) and Greater-Zab Rivers (151 mg/L to 187 mg/L) fall within the ranges previously reported by Aziz [4] and Toma [6], respectively. The greater values for wastewater might be attributed to the pollutants available in the wastewater.

Alton Kopri wastewater is considered medium to strong wastewater because its total alkalinity values are greater than 50 mg/L [17]. Aziz [4] reported that the total alkalinity for Erbil wastewater varied from 230 mg/L to 300 mg/L. Shekha [18] and Ali [18] demonstrated that the total alkalinity for Erbil wastewater varied from 211 mg/L to 347 mg/L and from 310 mg/L to 422 mg/L, respectively. The obtained results in the current research coincide with the published data [4, 18,19].

The total hardness values for Lesser-Zab water ranged from 108 mg/L to 180 mg/L. Kassim et al. [2] reported a high value of 376.2 mg/L for Lesser-Zab, which led them to classify Lesser-Zab as hard water. Another study reported that the total hardness values for Lesser-Zab water varied from 65 mg/L to 540 mg/L [3]; hence, it was considered very hard water. In comparison, the total hardness values for Alton Kopri wastewater ranged from 56 mg/L to 360 mg/L. The high values of 170 mg/L to 246 mg/L for Greater-Zab water and similar values of 167 mg/L to 288 mg/L have been previously reported for Erbil wastewater [4]. In the current study, the values for alkalinity were greater than total hardness values. Alkalinity components and hardness in water are related [11]. In the literature, the Lesser-Zab River water is considered moderately hard to hard water [4]. The results of the current study demonstrate that all total alkalinity and total hardness values for Lesser-Zab Water remain within the standard values for drinking water [14,15].

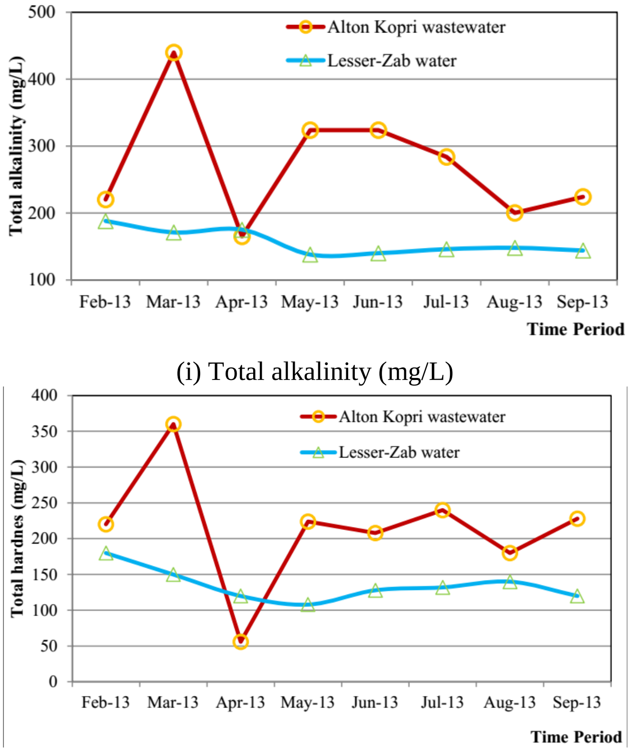


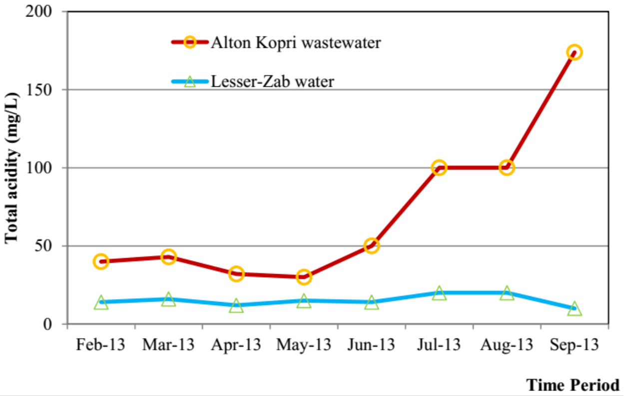
Fig. 7. Variation of total alkalinity and total hardness versus time.

3.1.4. Total Acidity and Chloride

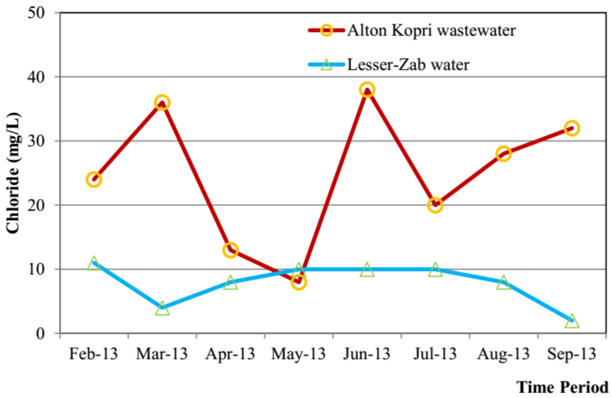
The values of total acidity and chloride for Lesser-Zab water and Alton Kopri wastewater are presented in Fig. 8. The total acidity values for Lesser-Zab water ranged from 12 mg/L to 20 mg/L, whereas the minimum and maximum values for Alton Kopri wastewater were 30 and 174 mg/L. In general, the quality of water resources in the north of Iraq remains within the standard alkaline range because of the geological formation, which mainly contains limestone. Contaminants tend to increase the values of total acidity in Alton Kopri wastewater compared with Lesser-Zab River water.

The minimum and maximum values for chloride in Lesser-Zab samples were 2 and 11 mg/L, respectively, whereas those for Alton Kopri wastewater were 8 and 38 mg/L. For chloride, large values ranging from 23.1 mg/L to 65.7 mg/L in Lesser-Zab water have been reported [3]. Similar ranges of 10.6 mg/L to 28.4 mg/L for Greater-Zab and 7.1 mg/L to 53.2 mg/L for Erbil wastewater have also been reported in the literature [4]. Toma [6] explained that chloride values for Greater-Zab varied from 6.6 mg/L to 12.8 mg/L. The present findings confirm previous results reported in the literature, namely, chloride values ranging from 2.4 mg/L to 6 mg/L for Greater-Zab water [20].

Pertaining to total acidity, the pollutants increased the concentration of chloride inside Alton Kopri wastewater. In general, high chloride concentration values are recorded during summer. This phenomenon might be attributed to the increase in temperature and evaporation with decreased flow, whereas the concentration during December might be attributed to dilution by rain [4]. The total acidity and chloride values are all within the drinking water quality standards [14-16]. The chloride values also demonstrate that Alton Kopri wastewater can be considered a weak wastewater [17].



(i) Total acidity (mg/L).



(ii) Chloride (mg/L).

Fig. 8. Variation of total acidity and chloride versus time.

3.1.5. Turbidity

Turbidity values for Lesser-Zab water and Alton Kopri wastewater are shown in Fig. 9. The plotted data for the Lesser-Zab showed that minimum and maximum values of turbidity were 13.7 and 127 FTU, respectively. The present results are within the range of 0.73 NTU to 111 NTU reported for the Lesser-Zab River [3]. A similar range of 39.2 NTU to 123 NTU for Greater-Zab has also been reported [6]. According to the Iraqi standards for drinking water, water turbidity must be less than 10 NTU [14]. In relation to this, treatment processes are essential to remove impurities caused by the increase in turbidity. In January, maximum turbidity resulting from rainfall and surface runoff to the river was observed. Turbidity values also increased from May to August because of fishing, swimming, and agricultural activities. Direct filtration process is a cost-effective solution for the treatment of turbidity values of less than 100 NTU as it can decrease total treatment cost by approximately 30%. Similar values and suggestions have been reported in a study, whose authors authors proposed the use of the direct filtration process for the Tigris River and the Greater-Zab River [21,22].

The direct filtration process varies according to conventional treatment techniques. According to the committee for the coagulation–filtration processes of AWWA's water quality detachment, direct filtration involves any water treatment process wherein filtration is not preceded by in-plant sedimentation of flocculated water [21].

In the current study, the turbidity values for Alton Kopri wastewater ranged from 4.7 FTU to 64.4 FTU. That low turbidity values were reported during May to August can be attributed to the dilution of wastewater by domestic waters and the absence of rainfall in these months. Rainfall and surface runoff may have also helped increase turbidity values from January to March.

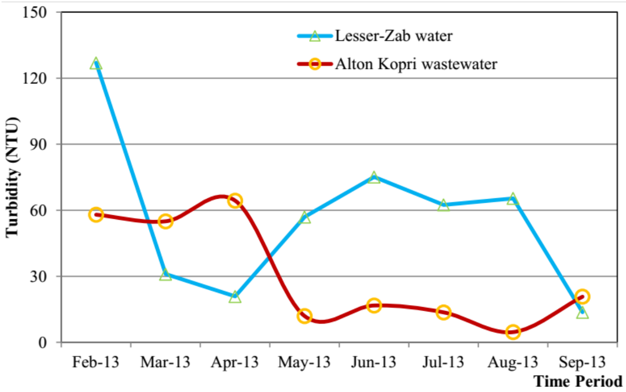
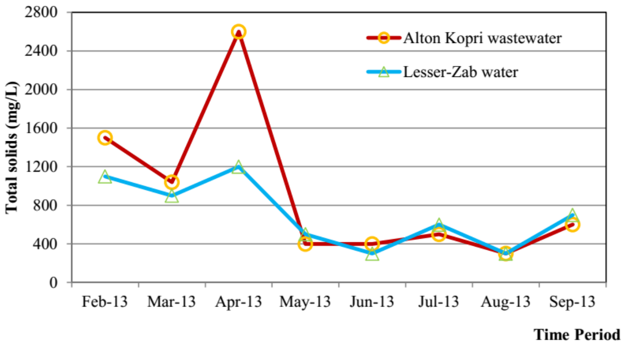


Fig. 9. Variation of turbidity for Lesser-Zab water and Alton Kopri wastewater versus time.

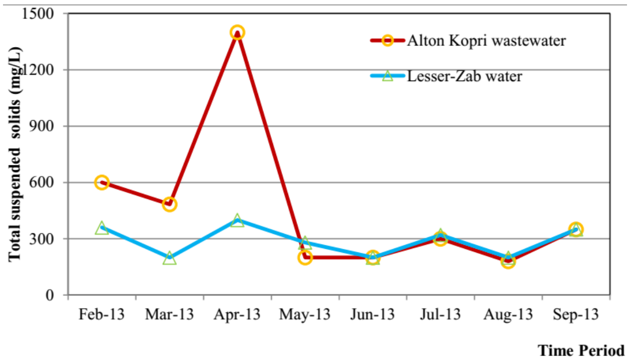
3.2. Total Solids and Suspended Solids

Total solids and suspended solids for both Lesser-Zab water and Alton Kopri wastewater samples are illustrated in Fig. 10. The total solids for Lesser-Zab water ranged from 300 mg/L to 1200 mg/L, whereas suspended solids for Lesser-Zab water ranged from 200 mg/L to 400 mg/L. A previous study reported a range of 8.8 mg/L to 42.1 mg/L for suspended solids in Lesser-Zab [2], whereas another study reported similar ranges for total solids (500 mg/L to 900 mg/L) and suspended solids (200 mg/L to 600 mg/L) for the Greater-Zab River [20]. According to the drinking water standards, the total solids value should be less than 500 mg/L [14,15]. The majority of the measured values for total solids in the current study surpassed the standards for drinking water. Treatment units, particularly sedimentation and filtration, are needed to eliminate excessive amounts of solids. Meanwhile, suspended solids for Lesser-Zab water were greater than 100 mg/L. Thus, Lesser-Zab may be regarded as a severely polluted river [23].

The minimum and maximum values of the total solids for Alton Kopri wastewater were 300 and 2600 mg/L, respectively, whereas those for suspended solids ranged from 200 mg/L to 1400 mg/L. The amount of solids revealed that Alton Kopri wastewater can be classified as medium to strong wastewater [17]. Wastewater treatment plants aim to decrease suspended solids to less than 30 mg/L [17]. Hence, decreasing suspended solids values for Alton Kopri wastewater to less than 30 mg/L is important.



(i) Total solids (mg/L).



(ii) Total suspended solids (mg/L).

Fig. 10. Variation of total solids and suspended solids versus time.

3.2.1. DO and BOD_5

The DO values for the Lesser-Zab water ranged from 5.2 mg/L to 9.3 mg/L. The River is in an aerobic condition, and the environment is appropriate for fish and other aquatic animals.

The present results showed that Lesser-Zab water was well aerated because of the high mixing processes, water discharge, and low organic matters. A previous study reported the same findings [2]. The close range of 5.2 mg/L to 10.4 mg/L for DO in Lesser-Zab has also been reported [3]. The current results agree with the published data (5.85 mg/L to 7.6 mg/L) for Greater-Zab water [7]. On the contrary, Aziz [24] reported high DO values (9.2 mg/L to 10.2 mg/L) for Greater-Zab. The obtained DO results and EPA [23] classify the Lesser-Zab River as a non-polluted (DO $\geq$ 6.5 mg/L) and lightly polluted (6.5 mg/L < DO $\geq$ 4.6 mg/L) river, respectively.

The BOD_5 values for Lesser-Zab water ranged from 0.7 mg/L and 6 mg/L. The range of BOD_5 from 0.6 mg/L to 4.6 mg/L for Lesser-Zab water reported in a previous study Abdul Jabar et al. [3] support the current finding. The obtained BOD_5 values also agree with the BOD_5 values for Greater-Zab reported by Aziz [24] (1.3 mg/L to 4.6 mg/L) and Aziz and Fakhrey [20] (0.2 mg/L to 4.2 mg/L). Lesser-Zab can be regarded as non-polluted ($BOD_5 \leq$ 3 mg/L) to moderately polluted (5 mg/L $\leq BOD_5 \leq$ 15 mg/L) depending on the obtained BOD_5 values [23]. In the literature, DO decreases in hot season because of the increase of organic matters in the wastewater and the high temperature; furthermore, consuming organic materials needs a significant amount of oxygen [4, 11].

The minimum and maximum values of DO for Alton Kopri wastewater were 3.6 and 8.7 mg/L, respectively, whereas the BOD_5 values varied from 4 mg/L to 250 mg/L. A range of 13 mg/L to 110 mg/L for Erbil wastewater has been reported [4]. On the contrary, Mustafa and Sabir (2001) reported the range of 80 mg/L to 105 mg/L for BOD5 in Erbil wastewater. The finding of the current study agrees with the data published for Erbil wastewater by these aforementioned studies. BOD removal is the main goal of treatment processes. According to the BOD_5 values, Alton Kopri wastewater can be regarded as weak to medium wastewater [17].

3.2.2. Sulfate

All sulfate values for Lesser-Zab water and Alton Kopri wastewater during the period of data collection were 0 mg/L. In the literature, the high values of 63.57 mg/L to 140.67 mg/L and 70 mg/L to 700 mg/L have been reported for Greater-Zab water [5]. On the contrary, the sulfate values of 68 mg/L to 78 mg/L for Greater-Zab water have been reported by Toma [6]. The concentration of sulfate in Lesser-Zab water was less than 250 mg/L in the current study. Thus, Lesser-Zab water remains safe [16]. Moreover, the sulfate values in Lesser-Zab and Greater-Zab probably varied because of the distinct geological formation and sources of the river water and wastewater.

3.2.3. Mass Balance Principle (MBP) and Impacts on Water Resources

In this study, the measured parameters for Alton Kopri wastewater, such as temperature, pH, total alkalinity, total hardness, total acidity, chloride, turbidity, solids, DO and BOD_5, and sulfate, were generally higher than for the Lesser-Zab River water. The presence of contaminants results in the increase of these values. Furthermore, the disposal of fresh wastewater produced from the Alton Kopri area affected the characteristics of the Lesser-Zab River water, making it difficult to carry out treatment processes.

MBP was employed to determine the effects of the contaminants (particularly DO, BOD_5, and temperature) on Lesser-Zab. The explanation of conservative mass balance diagram (for oxygen as example) according to Davis and Cornwell [25] is shown in Fig. 11. The product of the water flow and the DO concentration yields a mass of oxygen per unit of time

$$\text{Mass of DO in wastewater} = \text{Qw Dow} \tag{1}$$

$$\text{Mass of DO in river} = \text{Qr DOr} \tag{2}$$

where Qw is the volumetric flow rate of wastewater, m^3/s; Qr is the volumetric flow rate of the river, m^3/sec; DOw is the DO concentration in the wastewater, mg/L; and DOr is DO concentration in the river, mg/L.

The mass of DO in the river after mixing equals the sum of the mass flows expressed as:

$$\text{Mass of DO after mixing} = (\text{Qw Dow}) + (\text{Qr DOr}) \quad (3)$$

In a similar way for the BOD,

Mass of BOD after mixing = QwLw + Qr Lr,

where Lw is the ultimate BOD of the wastewater, mg/L, and Lr is the ultimate BOD of the river, mg/L.

The DO concentration and BOD after mixing are the respective masses per unit time divided by the total flow rate:

$$D_o = \frac{Q_w DO_w + Q_r QO_r}{Q_w + Q_r} \quad (4)$$

$$L_a = \frac{Q_w L_w + Q_r L_r}{Q_w + Q_r} \quad (5)$$

where La = initial ultimate BOD after mixing.

The temperature after mixing can be determined by using:

$$T_f = \frac{Q_w T_w + Q_r T_r}{Q_w + Q_r} \quad (6)$$

where T_f is final river temperature after mixing (°C).

The application of MBP for evaluating DO, BOD_5, and temperature is presented in Table 1. The results indicated that Lesser-Zab water was affected by the mixing/disposal of Alton Kopri wastewater to the former (Table 1). At the moment, the effect is limited. However, if the quantity of wastewater or the concentration of contaminants increases in the future, then the Lesser-Zab River will be highly affected. Several solutions are outlined in the next section to protect Lesser-Zab from pollution.

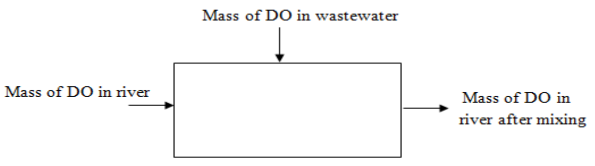


Fig. 11. Conservative mass balance for DO mixing.

Table 1

Results of mass balance principle.

Items	Lesser-Zab River	Alton Kopri Wastewater	Lesser-Zab after mixing
DO $_{avg.}$ (mg/ L)	6.82	5.52	6.80
$BOD_{5\ avg.}$ (mg/L)	3.0	53.6	3.5
Temperature $_{avg.}$ (°C)	17.54	23.42	17.60
Estimated Flow (m^3/s)	197.8*	2.0**	199.8

* Saleh [26], and ** Based on Mustafa and Sabir [27]

3.2.4. Solutions

The raw water from Lesser-Zab needs treatment, and for this purpose, normal treatment processes for river water can be applied. The proposed treatment processes include intake, plain sedimentation (optional), coagulation, flocculation, clarification, filtration, and disinfection [28,29]. Similar treatment processes are available at the Ifraz treatment plants located near the Greater-Zab River. In summer, the turbidity of river water becomes less than 100 NTU (Fig. 9). Direct filtration is an economical solution for low turbidity waters, saving 30% of the total cost of the treatment plants [21,22]. In direct filtration, coagulated and flocculated waters are directly discharged to the filtration unit.

The following solutions are outlined to protect the Lesser-Zab River water from pollution through wastewater disposal: (1) lining of wastewater channels to protect groundwater and soil from pollution, (2) diversion of natural wastewater path to an area far from Lesser-Zab River water and in downstream area, (3) providing small wastewater unit at the Alton Kopri Slaughter house to minimize pollutants to acceptable limits, and 4) providing suitable and economical wastewater treatment processes prior to disposal to the natural environment. Suggested solutions include aerated lagoons, wet lands, aerobic biological processes, and oxidation ditches [17, 27].

4. CONCLUSIONS

Fresh samples were collected from the Lesser-Zab River and Alton Kopri wastewater. The Lesser-Zab River is commonly classified as moderately polluted and moderately hard to hard water. Despite the presence of contaminants, the water quality parameters for Lesser-Zab generally remain within the drinking water standards. Still, Lesser-Zab water needs proper treatment processes before being supplied to consumers. By contrast, Alton Kopri wastewater is generally categorized as medium- to strong-type wastewater. The application of MBP proves that the normal disposal of Alton Kopri wastewater affects Lesser-Zab water. The lining of the sewage channel, diversion of the path, and treatment of the produced wastewater are essential solutions to minimize the effects of pollution on the Lesser-Zab River.

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