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Determination of Deoxygenation Coefficient for Al-Robat and Al-Jubyla Creeks in Basrah City/ South of Iraq

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Abstract

Al-Robat and Al-Jubyla creeks, which composes the study area, are two of the main six creeks branched from Shatt Al- Arab river in Basrah province, south of Iraq. They are used as open drains for discharging untreated sanitary sewage which caused the depletion of their dissolved oxygen and subsequently the deterioration of their water quality. To study the impact of discharging untreated sanitary sewage on study area water quality, measured in terms of dissolved oxygen concentration, it is necessary to determine the values of deoxygenation coefficient (K_1). The aim of this study is to find K_1 values for the study area using laboratory results of BOD time series analyses. For this purpose, water samples were collected from eight locations distributed along the study area. Thomas graphical method was applied to calculate K_1. The results showed that the K_1 values for Al-Robat and Al-Jubyla creeks ranged from 0.279 to 0.488 day $^{-1}$ at 20 °C with ultimate BOD values varied over the range (40.5-258.6) mg/l. These results revealed that the water in Al-Robat and Al-Jubyla creeks has the characteristics of raw sewage.

Keywords: Deoxygenation coefficient, Al-Robat and Al-Jubyla creeks, Thomas graphical method.

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1. Introduction

Deoxygenation coefficient (K_1) is a constant represents the rate at which microorganisms consume DO to decompose organic matter aerobically [1]. It is necessary to determine K_1 to predict the impact of wastewater discharge on BOD and DO values in the stream and, subsequently, on aquatic life [2]. K_1 value is dependent on biodegradability of the waste (readily biodegradable, slowly biodegradable or non-biodegradable), the capacity of the microorganisms inside the stream to utilize the waste and water temperature [3]. At a temperature of 20 °C, the typical K_1 value (base e) for polluted rivers and raw sewage varied on the range (0.12-0.23) day^{-1} and (0.35-0.7) day^{-1}, respectively [3]. Whereas Tchobanoglous [4] and Nuruzzaman [5] specified the range of K_1 values for raw sewage to be varied on the ranges (0.12-0.46) and (0.2-0.5) day^{-1}, respectively.

Many previous studies were conducted for K_1 determination. Fang et al. [6] simulated the distribution of BOD in Qiantang River in China using QUAL2K model. They calibrated and verified the model using field data collected during the years (2000-2002) and (2003-2004), respectively. After the model calibration and verification, Fang et al. indicated that the values of K_1 (base e) for Qiantang River varied on the range (0.2-0.65) day^{-1}. Ostapenia et al. [7] determined K_1 for six lakes using laboratory analysis results of BOD. They indicated that the values of K_1 (base 10) varied over the range (0.044-0.14) day^{-1}. Where K_1 (base 10) equals K_1 (base e) divided by 2.303 [4]. Yustiani et al. [8] determined K_1 for Citepus River in Indonesia using an empirical equation (Hydroscience equation) relating K_1 value to water depth in the river (H) as:

$$K_1 = 0.3\left(\frac{H}{8}\right)^{-0.434} \quad (1)$$

Where, K_1 in day^{-1} and H in ft. Yustiani et al. compared the calculated K_1 values with those determined from laboratory analysis of BOD with the application of Thomas method. The study results showed that the K_1 values for Citepus River varied on the ranges (0.06-0.48) and (0.42-0.64) day^{-1} when applying Thomas method based on laboratory analysis of BOD and the empirical equation, Eq. (1), respectively. The authors pointed out that the empirical equation has resulted in overestimated K_1 values. In addition, they pointed out that the laboratory analysis is the best method for K_1 determination.

Nuruzzaman et al. [5] conducted experiments using synthetic polluted river water prepared by mixing different proportions of raw sewage, treated sewage, river water and tap water. Nuruzzaman et al. performed 12 experiments and during each experiment they measured the concentration of BOD at six locations along the flume. They determined K_1 values by fitting the BOD data in the first order decay equation of BOD. The study results showed that the K_1 values varied on the range (0.191-0.92) day^{-1}. In addition, Nuruzzaman et al. presented a review for K_1 values based on 24 studies conducted on different rivers around the world during the years 1981-2014 and the review results shown that most of K_1 values were within the range (0.1-0.6) day^{-1}. It shows, also, that K_1 may reach a value of 4.24 day^{-1}.

Yustiani et al. [9] determined K_1 for Rangkui River in Indonesia during the dry season. They calculated K_1 by adopting two approaches. In the first approach, they obtained K_1 from laboratory analysis of BOD during a period of ten days with adopting of Thomas method whereas in the second approach they used Hydroscience equation, Eq. (1). For laboratory analysis, they collected water samples from six locations distributed along the river. For Rangkui River, the study results showed that the ranges of K_1 values obtained from laboratory analysis and Hydroscience equation were (0.14-0.41) and (0.49-0.55) day^{-1}, respectively. These outcomes matched those of Yustiani et al. [8] which indicate that K_1 results of Hydroscience equation were higher than those of laboratory analysis.

Yustiani et al. [10] determined K_1 values for Cimanuk River in Indonesia applying laboratory analysis of BOD with Thomas slope method and Hydroscience equation, Eq. (1). They performed the laboratory analysis on water samples collected from two locations in the study area. For Cimanuk River, the study results showed that the ranges of K_1 values obtained from laboratory analysis and Hydroscience equation were (0.06-0.12) and (0.422-0.462) day^{-1}, respectively. These outcomes matched those of Yustiani et al. [8] and Yustiani et al. [9] which indicate that K_1 results of Hydroscience equation were higher than those of laboratory analysis.

The aim of this work is to determine the K_1 values for Al-Robat and Al-Jubyla creeks in Basrah City, south of Iraq. This work is a part of comprehensive study concerning the enhancement of self-purification capacity of these creeks.

2. Materials and methods

2.1. Study area

The study area consists of Al-Robat and Al-Jubyla creeks with the link between them, see Fig. 1. It has a total length of 9.818 km distributed as: 4.3 km along Al-Robat creek, 1.7 km along the link and 3.818 km along Al-Jubyla creek. The two creeks extend into the center of Basrah City and along main streets in it. Their two banks are bounded by residential and commercial zones. The existing of residential zones along the study area with the bad management of sewerage projects in Basrah City were the reasons behind transformation of the study area to open drains for disposing the untreated sanitary sewage.

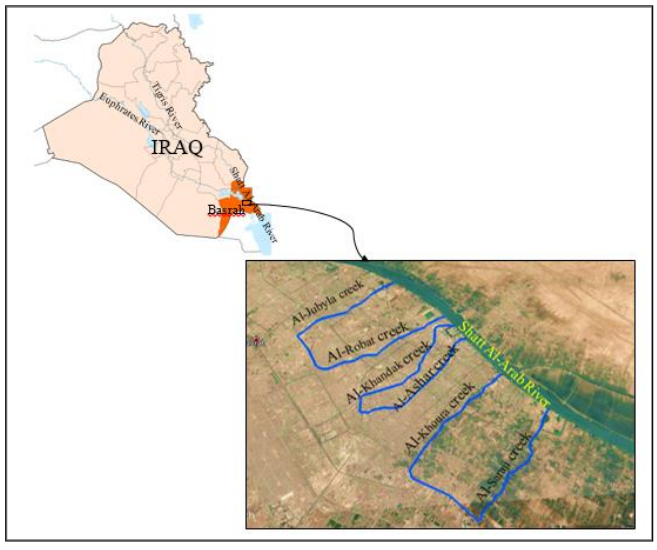

Fig. 1 Al-Robat and Al-Jubyla creeks location.

The consequences of study area water pollution by the discharge of untreated sanitary sewage are; deterioration of water quality which became unsuitable for any use including fishing [11] and destruction of aquatic life which is obvious for any water observer in Basrah Province.

2.2. Experimental work

2.2.1. Water Sampling

Water samples were collected from eight points distributed along the study area. Fig. 2 shows the locations of water sampling points. Locations Nos. 1, 2 and 3 were at Al-Robat creek, locations No. 4, 5, 6 and 7 were at Al-Jubyla creek and location No. 8 was at the link between Al-Robat and Al-Jubyla creeks. The coordinates of water sampling point locations are presented in Table 1. The water samples were collected from locations No. 1, 2, 3 and 4 (indicated by red color) during summer season, Aug. /2020. Whereas, the water samples were collected from locations No. 5, 6, 7 and 8 (indicated by green color) during spring season, Apr. /2021. They were collected by dipping sampling container at approximately depth of 10-15 cm from water surface. The water samples were put into glass containers. The containers were encased using black plastic casing and kept into a cooling box, then, they were transported to the laboratory for the time series analysis of BOD.

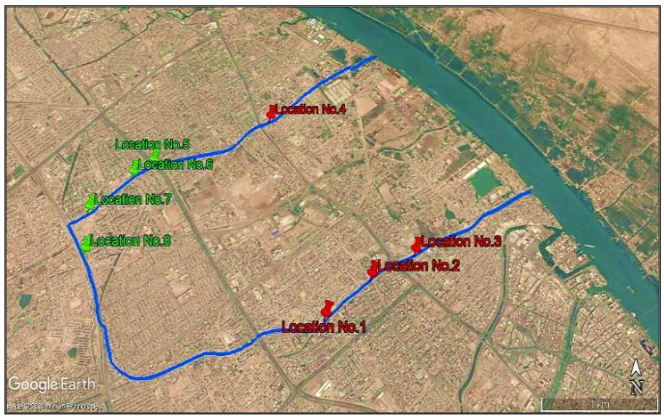

Fig. 2 Distribution of sample point locations.

Table 1. Coordinates of water sampling point locations (UTM).

Location No.	Latitude	Longitude
1	30° 31' 11.64"	47° 48' 47.592"
2	30° 31' 23.4192"	47° 49' 4.0548"
3	30° 31' 31.0224"	47° 49' 20.226"
4	30° 32' 19.1652"	47° 48' 24.1596"
5	30° 32' 2.0544"	47° 47' 39.0408"
6	30° 31' 57.5616"	47° 47' 31.7724"
7	30° 31' 45.0588"	47° 47' 17.736"
8	30° 31' 31.2312"	47° 47' 19.6368"

2.2.2. BOD analysis

In this study, OxiTop, WTW digital instrument was used to find the BOD values of study area water as a function of time. The principle of BOD measurement using OxiTop instrument is that, as the microorganisms in a water sample consume the dissolved oxygen in the sample, CO_2 gas will form. This gas is observed by NaOH and, thus, a vacuum

(pressure drop) occurs which is automatically transformed to BOD reading in mg/l [12]. OxiTop instrumentation is composed of Oxi units (sample bottles with reading heads), stirrer base, and incubator, see Fig. 3. The obtained results of BOD versus incubation time for the eight samples drawn from the study area are given in Table 2.

Fig. 3 OxiTop instrumentation.

Table 2. Bod test results of Al-Robat and Al-Jubyla creeks.

Time (day)	BOD (mg/l) at indicated sample No.							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	30	25	25	75	22	18	22	10
2	40	40	30	100	31	27	36	19
3	50	60	40	140	32	32	39	24
4	55	65	45	175	32	36	42	27
5	60	70	45	210	32	39	45	29
7	60	75	50	220	32	41	48	33
10	75	85	60	225	32	44	49	37
13	80	90	65	225	32	46	49	39

2.3. Determination of deoxygenation coefficient

Many methods are available for deoxygenation coefficient (K_1) determination. Tchobanoglous [4], Butts et al. [13], and Singh [14] reviewed the most common six methods for K_1 determination. These methods included, (1) least squares method, (2) the method of moments, (3) Thomas graphical method, (4) daily difference method, (5) rapid ratio method, and (6) Fujimoto method. All these methods computed K_1 value based on time series of BOD measurements. Thomas graphical method is the most applied method for K_1 determination and thus it has been applied in this. Thomas developed the following linear equation for simultaneous determination of K_1 and ultimate BOD, L, (the total oxygen amount consumed when the biochemical reaction is allowed to proceed to completion) [15]:

$$\left(\frac{t}{y}\right)^{1/3} = (K_1 L)^{-1/3} + \frac{K_1^{2/3}}{6\,L^{1/3}}\,t \qquad (2)$$

where:

y = BOD that has been exerted in time interval t (mg/l).
K_1 = deoxygenation coefficient (day^{-1}).
L = ultimate BOD (mg/l).
t = time (day).

Eq. (2) has a form of straight-line equation:

$$Z = a + b\,t \qquad (3)$$

Where,

$$z = \left(\frac{t}{y}\right)^{\frac{1}{3}} \quad ; \quad a = (K_1 L)^{-1/3} \quad ; \quad b = \frac{K_1^{2/3}}{6\,L^{1/3}}$$

z can be plotted as a function of t. The slope (b) and the intercept (a) of the line of the data best fit can then be used to calculate K_1 and L as:

$$K_1 = \frac{6\,b}{a} \qquad (4)$$

$$L = \frac{1}{6\,b\,a^2} \qquad (5)$$

Laboratory analysis of BOD is done at a temperature 20 °C. The K_1 value obtained from laboratory analysis can be adjusted considering the ambient temperature of the stream as [3]:

$$K_{1T} = K_{1_{20\,^\circ C}}\,\theta^{T-20} \qquad (6)$$

Where θ equals 1.135 for water temperatures vary on the range (4 - 20) °C and equals 1.056 for water temperatures vary on the range (20 - 30) °C [3].

3. Results and Discussion

In this study, eight sampling locations were tested during the summer and spring seasons in order to determine the Deoxygenation rate coefficient (K_1) by laboratory method. This method involves the measuring of BOD values for each sample as shown in Table 2. Then by using Thomas graphical method the value of K_1 for each sample was determined. The graphs necessary for applying Thomas method on BOD time series results of the eight water samples are shown in Figs. 4 to 19. Two figures are presented for each water sample, the first figure was used to determine the lag in time and the second one was used to determine the intercept (a) and the slope (b) of the best line fitted the relation between $(t/\text{BOD})^{1/3}$ and t. The lag in time is defined as the delay in the start of BOD exertion. The K_1 and L values were determined for each sample using Eqs. (4) and (5), respectively.

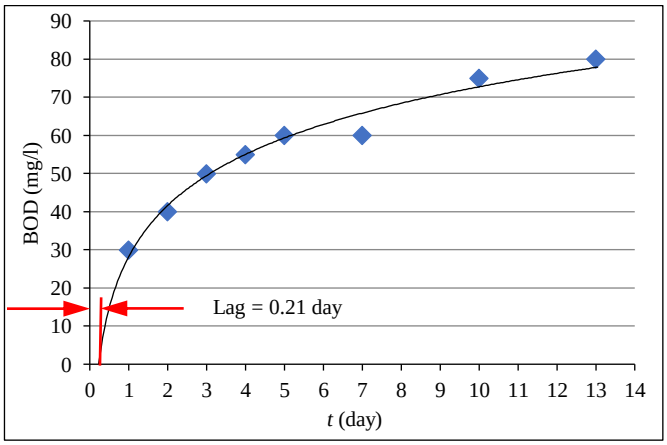

Fig. 4 BOD versus t sample No.1

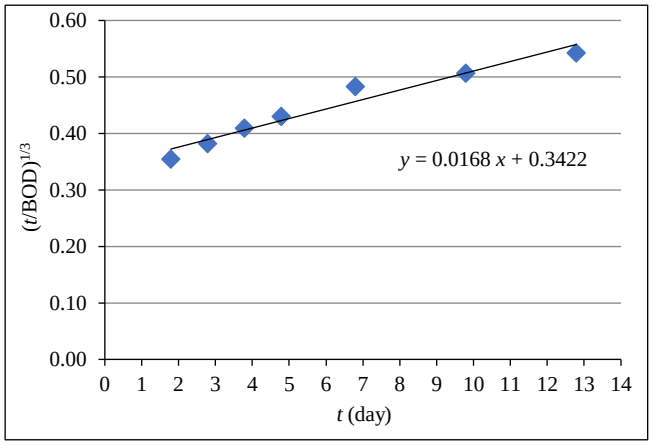

Fig. 5 $(t/BOD)^{1/3}$ versus t for sample No.1

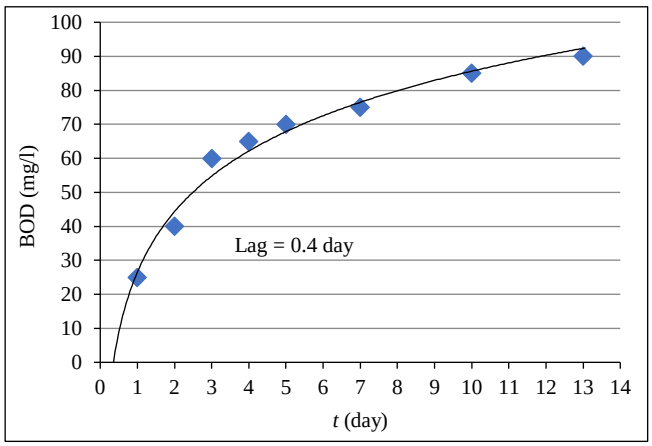

Fig. 6 BOD versus t for sample No.2

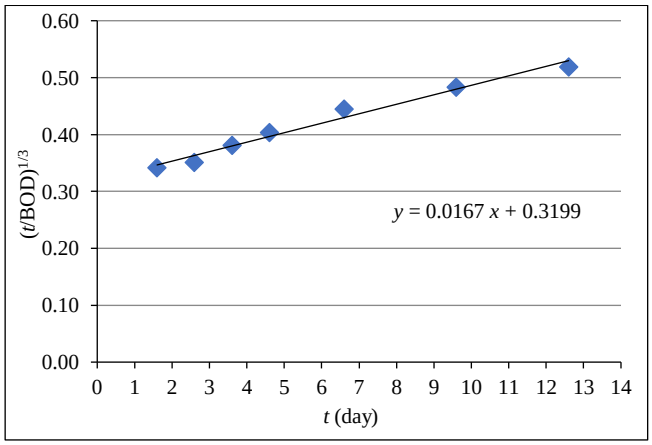

Fig. 7 $(t/BOD)^{1/3}$ versus t for sample No.2

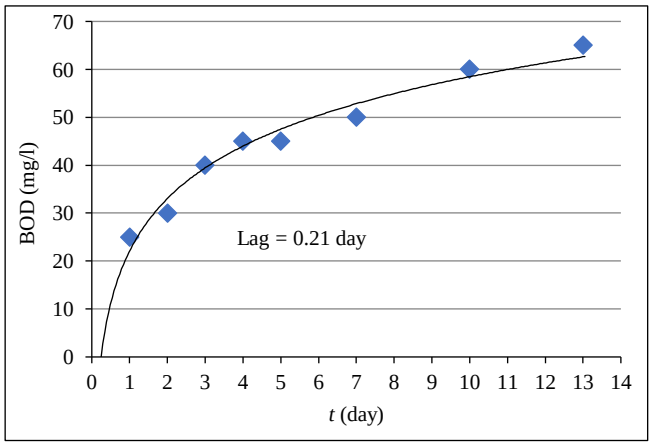

Fig. 8 BOD versus t for sample No.3

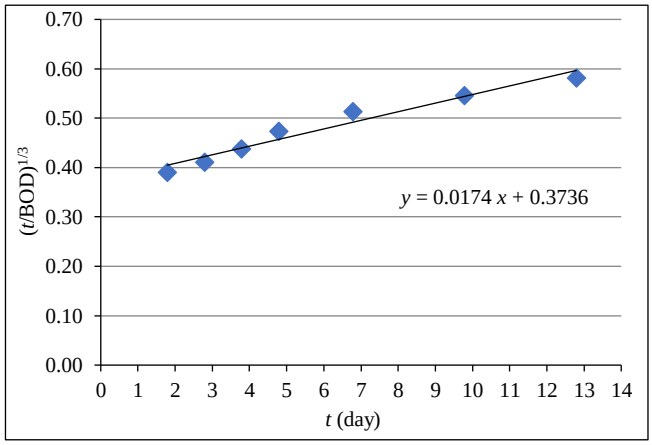

Fig. 9 $(t/BOD)^{1/3}$ versus t for sample No.3

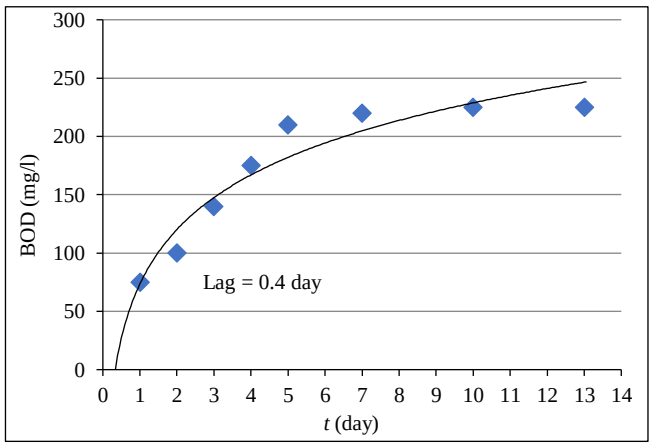

Fig. 10 BOD versus t for sample No.4

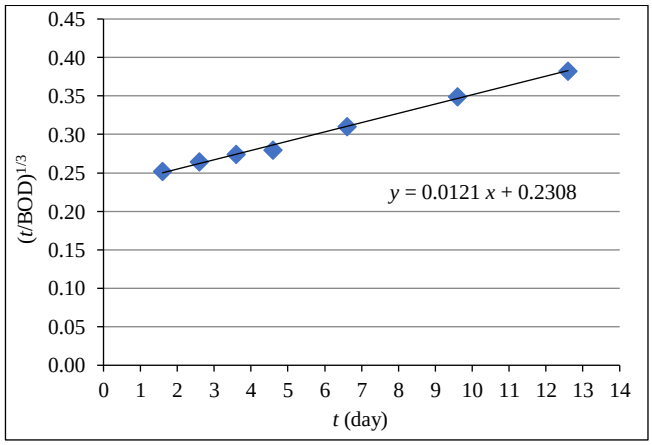

Fig. 11 $(t/BOD)^{1/3}$ versus t for sample No.4

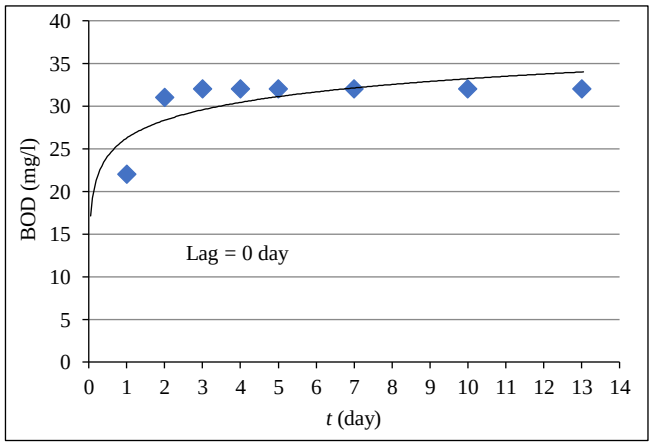

Fig. 12 BOD versus t for sample No.5

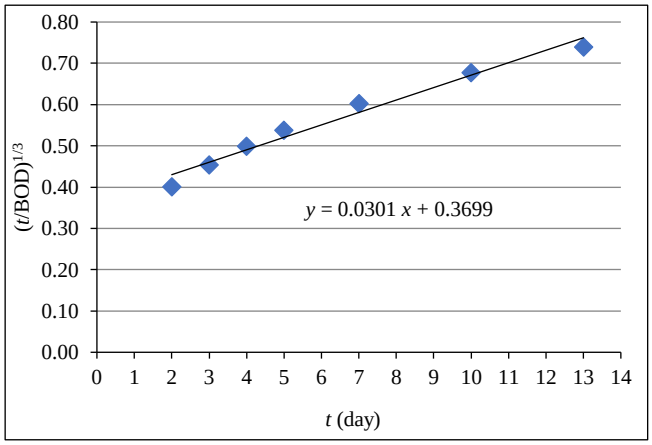

Fig. 13 $(t/BOD)^{1/3}$ versus t for sample No.5

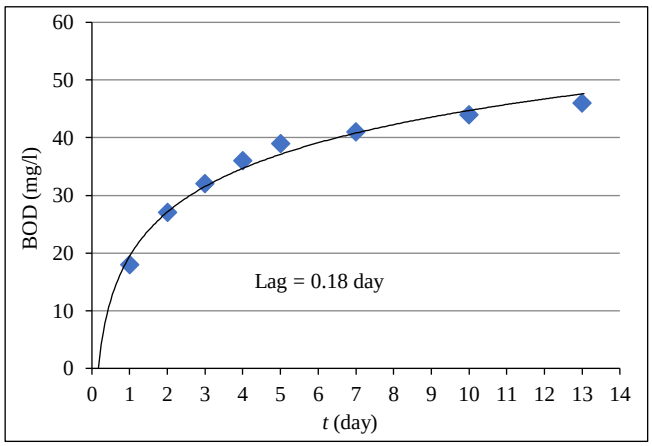

Fig. 14 BOD versus t for sample No.6

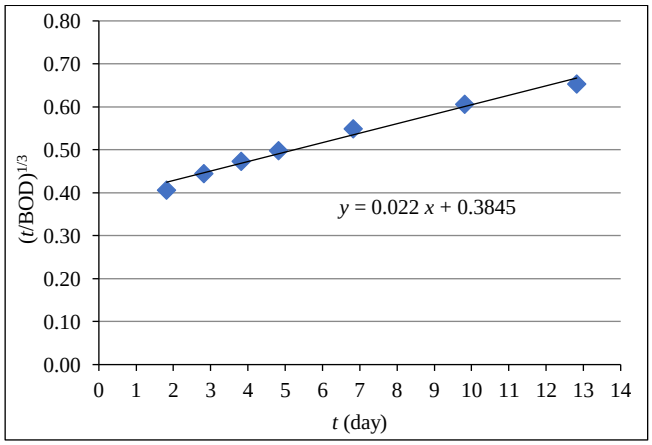

Fig. 15 $(t/BOD)^{1/3}$ versus t for sample No.6

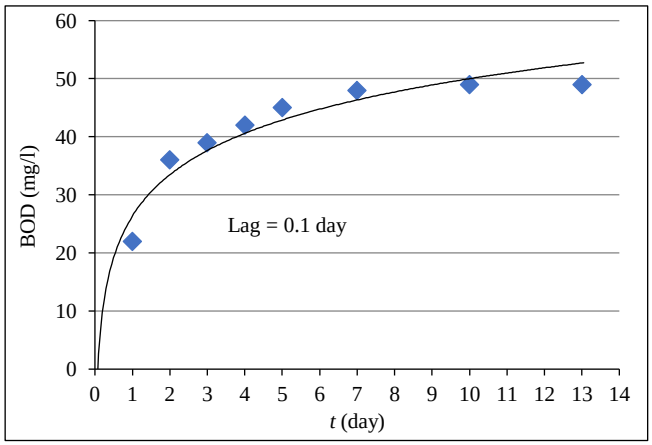

Fig. 16 BOD versus t for sample No.7

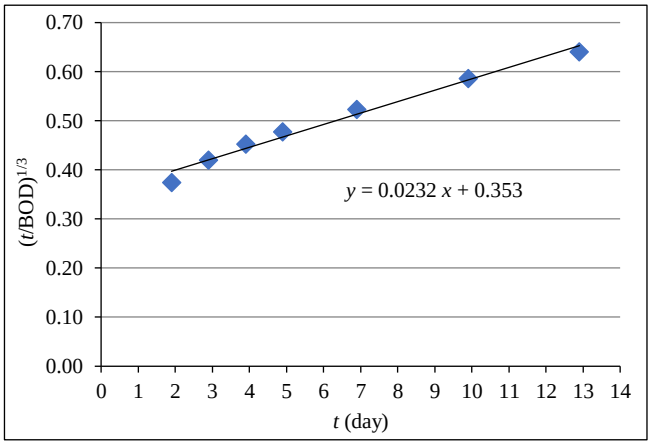

Fig. 17 $(t/BOD)^{1/3}$ versus t for sample No.7

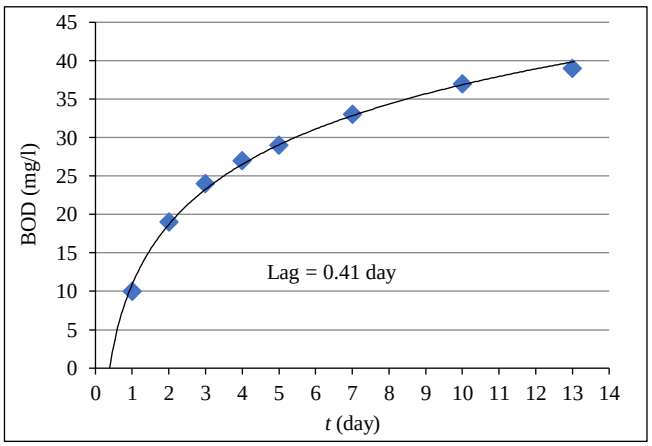

Fig. 18 BOD versus t for sample No.8

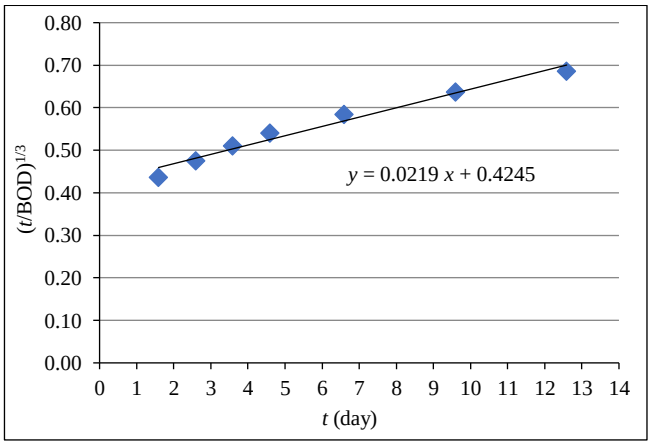

Fig. 19 $(t/BOD)^{1/3}$ versus t for sample No.8

Table 3 presents the values of a, b, K_1 and L for the eight water samples. It shows that the values of deoxygenation coefficient (K_1) ranged from 0.279 to 0.488 day^{-1} at a water temperature of 20 °C. According to the typical K_1 values given in the previous studies, the K_1 values for the study area were fall within the range of untreated wastewater (raw sewage) which is (0.20 - 0.50) day^{-1} [8].

Table 3. Deoxygenation coefficient and ultimate bod values for Al-Robat and Al-Jubyla creeks.

Sample No.	Results on Figure	*a*	*b*	K_1 (day^{-1})	*L* (mg/l)
1	5	0.3422	0.0168	0.295	84.7
2	7	0.3199	0.0167	0.313	97.5
3	9	0.3736	0.0174	0.279	68.6
4	11	0.2308	0.0121	0.315	258.6
5	13	0.3699	0.0301	0.488	40.5
6	15	0.3845	0.022	0.343	51.2
7	17	0.353	0.0232	0.394	57.7
8	19	0.4245	0.0219	0.310	42.2

All the K_1 values presented in Table 3 are at a water temperature of 20 °C. The water temperature in Al-Robat and Al-Jubyla creeks vary on the range (22 - 31) °C [16]. Thus, all the K_1 values were adjusted for the high and low water temperatures in in the study area. That was done using Eq. (6) with substitution of θ value to be 1.056. Considering the dependency of K_1 on temperature, the ranges of K_1 values for the study area were (0.311 - 0.544) and (0.508 - 0.889) day^{-1} at water temperatures of 22 and 31 °C, respectively, as shown in Table 4. The K_1 value is directly proportional with the temperature because of the microorganism activity increases with the increase of temperature [3]. At high water temperature K_1 value was higher than the value at low water temperature.

Table 4. Deoxygenation coefficient values for Al-Robat and Al-Jubyla creeks at temperatures of 22 and 32 °C.

Sample No.	K_1 (day^{-1}) at indicated	
	22 °C	31 °C
1	0.328	0.537
2	0.349	0.569
3	0.311	0.508
4	0.351	0.573
5	0.544	0.889
6	0.382	0.624
7	0.439	0.717
8	0.345	0.564

The results show that K_1 value for samples No. 4, 5, 6 and 7 which are located at Al-Jubyla creek were relatively higher than those at Al-Robat creek (samples No. 1, 2 and 3). This might be caused by the large number of sewage disposal points which increased the organic content of water and stimulated the growth of microorganisms responsible for the decay of organic matter and subsequently the deoxygenation rate. This fact is revealed through the ultimate BOD values in Al-Jubyla creek which reached a value of 258.6 mg/l. The variations of K_1 (at temperature of 20 °C) and ultimate BOD along the study area is shown in Figs. 18 and 19 respectively. In these Figures the distance zero represents the confluence of Al- Robat creek with Shatt Al-Arab river.

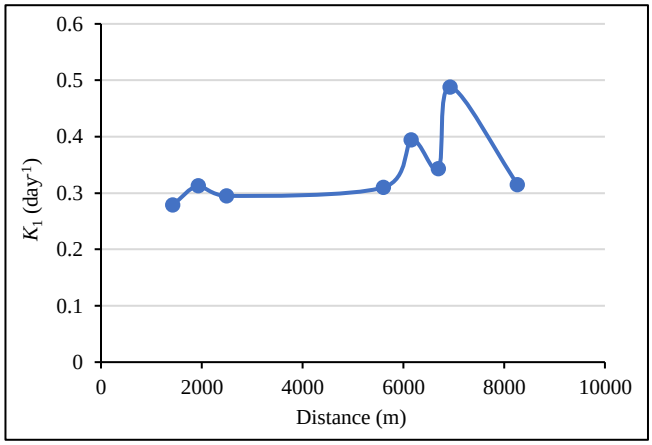

Fig. 18 Variation of K_1 along the study area.

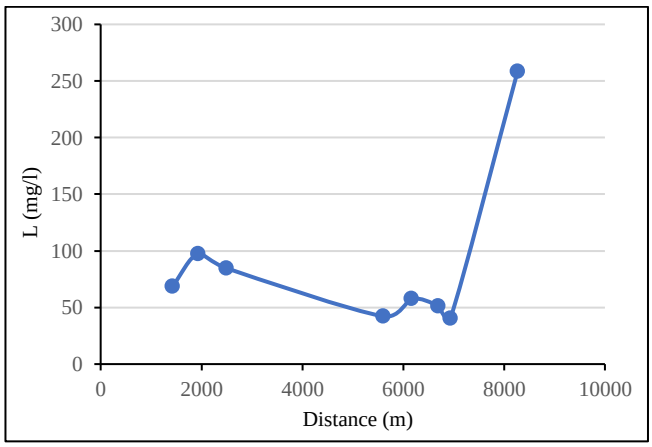

Fig. 19 Variation of ultimate BOD values along the study area.

4. Conclusions

The results of deoxygenation coefficient for Al-Robat and Al-Jubyla creeks, obtained using laboratory analysis results of time series BOD data with the adoption of Thomas graphical method, ranged from 0.279 to 0.488 day^{-1} at water temperature of 20 °C. While at water temperatures 31 and 22 °C, the maximum and minimum K_1 values were 0.889 and 0.311 day^{-1} respectively, and the ultimate BOD values ranged from 40.5 to 258.6 mg/l. The obtained K_1 values are located within the range specified by Nuruzzaman [5] for raw sewage which is (0.2 - 0.5) day^{-1} respectively.

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