*Original Research*

# Effects of Some Water Quality Parameters on the Dissolved Oxygen Balance of Streams

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**Abstract**

The Galyan Stream basin supports the water of Atasu Dam, which will provide domestic water for Trabzon province in Turkey. The Galyan Stream empties into Değirmendere Stream and their water into the Black Sea that these streams are important watersheds in northeastern Turkey. Water samples were periodically taken from Temelli site (Galyan Stream), Değirmen site (Kuştul Stream) and Çiftdere site (Galyan Stream).

In this study, at first, variations of dissolved oxygen profile are determined from dissolved oxygen, temperature and carbonaceous biochemical oxygen demand measurements by using Point Resources Streeter-Phelps equation. Water samples are taken from the Galyan and Kuştul Streams. Water quality parameters were analyzed for both streams and evaluated according to the Turkish Water Pollution Control Regulation (TWPCR). Critical dissolved oxygen deficiency values, which were calculated for monthly average (2004 April-2005 January) and annual averages (2000-2004), are seen to be over the limit value in the Galyan Stream having first class water quality in terms of dissolved oxygen concentration, temperature and biochemical oxygen demand. In the following it is disclosed that treatment isn't required. That study shows that minimum dissolved oxygen limit value (8 $mgL^{-1}$), which is desired in domestic waters, is under the limit value in July, August and September months in case of a mixture.

**Keywords:** river pollution, watershed models, Streeter-Phelps equation, dissolved oxygen sag, critical dissolved oxygen deficiency

## Introduction

Water is among the most essential requisites that nature provides to sustain life for plants, animals and humans. The total quantity of fresh water on earth could satisfy all needs of the human population were it evenly distributed and accessible. Different regions of the world are faced with largely different types of problems associated with water resources occurrence, use and control, which may endanger a sustainable development of these resources. The observed status of a system at any point in time results from the collective interaction of all these processes, both natural and anthropogenic. Anthropogenic influences (urban, industrial and agricultural activities, increasing consumption of water resources) as well as natural processes (changes in precipitation inputs, erosion, weathering of crustal materials, physical conditions such as slope and bedrock geology) degrade surface waters and impair their use [1-3].

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Water quality modeling (WQM) is an attempt to relate specific water quality conditions to natural processes using mathematical relationships and has been around for several decades. A water quality model usually consists of a set of mathematical expressions relating one or more water quality parameters to one or more natural processes. Water quality models are most often used to predict how changes in a specific process or processes will change a specific water quality parameter or parameters. It is important to apply this technology correctly to water quality management. The cost and effort of a water quality modeling study is usually a small fraction of the implementation cost for a water quality management strategy. It is this aspect that has made water quality modeling an attractive approach for developing a management strategy [4, 5].

The pollution density, assimilation, and self-purification capacity directly affect river hydrogeometric properties (flow, velocity, dispersion, depth, witdh, slope, cross-sectional area etc.), because the degree of pollution is related to dilution of matter being discharged and therefore constitute the most important characteristic factor of pollution in a river [6, 7]. A wide spectrum of different pollutants originating from natural and anthropogenic emission sources occurs in the aquatic environment. The number of pollutants as well as the loads delivered into the aquatic environment due to human activities is increasing. Each year over 1000 new compounds appear in the environment due to the ever intensifying industrial activities of humans, and that, undoubtedly, leads to increased toxicological and ecotoxicological risks [8]. Since diluted organic matter in a river is transformed with self-biological oxidation. Velocity of biological stabilization depends on temperature and travel time. Self-purification capacity of a river is also related to its discharge, travel time, water temperature and aeration as oxygen is obtained from the atmosphere by way of aeration in a river. To make this event happen, a sufficient amount of dissolved oxygen must be present, sufficient transport time must be provided, sufficient dilution must be formed, toxic (mercury etc.) matters inhibiting biological oxidation and the matters (detergent etc.) impeding transference of oxygen into the water must not be present in a river [6, 7].

Critical dissolved oxygen deficiency, which is important for continuity of aquatic life, is calculated by saturation value of dissolved oxygen concentrations and BOD parameters. Biochemical oxygen depletion represents the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic conditions at a specified temperature. Biohemical oxygen and dissolved oxygen depletion that occur as a result of pollution in a river are linked with many factors. Importance and priority turn of these factors may be different according to characteristics of the researched section of a river. Any form in biohemical oxygen depletion or dissolved oxygen concentrations may be chosen as the main variable in oxygen balance modeling for a river. In this type of modeling, the common approach is to study the variations of biohemical oxygen demand depending on dissolved oxygen deficiency [7, 9-11].

A great deal of water quality studies related to river or stream pollution has been conducted and reported in different parts of the world and a lot of parameters being water quality indicators were investigated in these studies [11-18].

In this study, variations of dissolved oxygen profile are determined from dissolved oxygen and carbonaceous biochemical oxygen demand measurements by using point source Streeter-Phelps equation in the Galyan Stream for monthly average from April 2004 to January 2005 and annual average from 2000 to 2004 (since the collected waste waters are discharged into the streams as point sources in Turkey, especially in the Eastern Black Sea Region). Therefor a specific case where pollution is significant is investigated in the Galyan Stream.

## Material and Method

### Description of the Study Area

Trabzon province, located within eastern Turkey, is an ancient residential area. The Değirmendere River, passing through Trabzon and draining into the Black Sea, is an important watershed and a crucial source for municipal drinking water supply as well as for heavy and light industries and water dilution. The watershed covers 104,172 ha of land area and is also home for 110 villages with a population over 43,000 people. The Galyan River meets the Değirmendere River at a junction on the 17th km of Trabzon-Maçka highway. The Galyan watershed covers a total of 18,905 ha of land area [15]. There are twelve villages with 8,388 people within the Galyan Stream basin. These locations are Alataş, Çayırlar, Erginköy, Kuşçu, Oğulağaç, Ormaniçi, Şahinkaya, Yüzüncüyıl, Barışlı, Temelli, Yeniköy and Şimşirli villages [19].

The Galyan Stream basin supports the water of Atasu dam, which will provide domestic water for Trabzon province. The Galyan Stream pours into Değirmendere Stream at the Esiroğlu town from 39º 41’ 60” E and 40º 52’ 57” N geographical coordinates. The width of the Galyan Stream basin is 8.25 km, the main branch length of it is 25.5 km and this watershed covers 210.4 km$^2$ [19].

### Description of the Model

If the stream is originally unpolluted, dissolved oxygen levels above the discharge will be near saturation. The introduction of the untreated sewage will elevate the levels of both dissolved and solid organic matter. This has two impacts. The first is that the solid matter makes the water turbid. Thus light can not penetrate and plant growth is suppressed. Some of the solids settle downstream from the sewage outfall and create sludge beds that can emit anoxious odors. The second is that the organic matter provides food for heterotrophic organisms. Large populations of decomposer organisms break down the organic matter in the water and in the process deplete the dissolved oxygen. In addition decomposition of the organic matter takes places in the sludge bed and sediment oxygen demand supplements decay in the water [6].

Biochemical oxygen demand (BOD) is the amount of dissolved oxygen that is consumed by aerobic, heterogeneous populations of microorganisms to oxidize or degrade the carbonaceous and nitrogenous components of biodegradable organics in water. Excessive BOD loads are detrimental for the quality of river water as the resulting low DO concentration makes the river unsuitable for the life of flora and fauna. Consequently, a number of models for the prediction of water quality modifications have been formulated due to BOD discharges. BOD is one of the key variables in water-quality models. Researchers and engineers use it to evaluate the biological and chemical conditions of rivers, to model the dissolved oxygen dynamics and to study the effects of releases in rivers from waste water treatment plants, factories, farms, etc. The basic mathematical model that describes BOD dynamics along a river was formulated several decades ago. Afterwards, other models have been proposed in order to consider the many fluid dynamic, chemical and biological factors able to alter the decay rate of BOD (e.g., turbulence, temperature, suspended sediments, etc.) [20-22].

Dissolved oxygen concentration decreases in a river that waste matter are added into its texture since consumption velocity of oxygen is higher than production velocity of oxygen. Thus oxygen concentration decreases and eventually reaches to a minimum level. At this point, the value of dissolved oxygen deficiency is maximum, and is called critical dissolved oxygen deficiency. The time needed for water to reach from the beginning point to the critical oxygen deficiency point is named critical time. Reaeration (increasing of dissolved oxygen contents by aerating the waters) of waste water and polluted rivers are very important for removal of the organic matters in the water. As a result, microorganisms in waste water or a river can have sufficient oxygen and oxidized organic materials and transform these materials into inorganic materials. Oxygen contents of polluted waters and their variation according to time can be studied by DO Sag, assuming that the flow in the river is regular and steady-state. DO and BOD values of discharges of another stream connecting to the river or plant wastes may be accepted to be continuous in a specified time. Wastes added to the river are entirely mixed with the river water in a short distance, and BOD and DO concentrations decrease proportionally with BOD present in the water. The amount of BOD added from river bottom sludge to top water is fixed in unit time, DO concentration increases direct proportionally with DO deficiency, the amount of oxygen produced by way of photosynthesis is fixed, and the effect of dispersion is neglected because of its negligible effect [4, 6, 7, 23-31]. SAG curve equation giving profile of dissolved oxygen deficiency (Total Streeter-Phelps Model) along the river is generally written as follows:

$$D_t = \frac{K_d \cdot L_o}{K_a - K_r} \cdot (e^{-K_r \cdot t} - e^{-K_a \cdot t}) + \frac{K_n \cdot N_0}{K_a - K_n} \cdot (e^{-K_N \cdot t} - e^{-K_a \cdot t}) + \frac{SOD}{K_a \cdot H} \cdot (1 - e^{-K_a \cdot t}) - \frac{P}{K_a} \cdot (1 - e^{-K_a \cdot t}) + \frac{R}{K_a} \cdot (1 - e^{-K_a \cdot t}) + \frac{ZOD}{K_a \cdot H} \cdot (1 - e^{-K_a \cdot t}) + D_0 \cdot e^{-K_a \cdot t} \tag{1}$$

where:

$D_t$: Dissolved oxygen deficiency at time t ($mgL^{-1}$)
$K_d$: In-stream deoxygenation rate ($d^{-1}$)
$L_0$: Carbonaceous biochemical oxygen concentration at the beginning ($mgL^{-1}$)
$K_a$: In-stream reaeration coefficent ($d^{-1}$)
$K_r$: In-stream CBOD removal rate ($d^{-1}$)
$K_n$: In-stream nitrification constant ($d^{-1}$)
$N_0$: Nitrogenous biochemical oxygen concentration ($mgL^{-1}$)
SOD: Sediment oxygen demand (mg $O_2m^{-2}d^{-1}$)
ZOD: Zebra mussel oxygen demand (mg $O_2m^{-2}d^{-1}$)
H: Average depth of the stream (m)
P: Algal photosynthesis (mg $O_2L^{-1}d^{-1}$) (daily average oxygen production rate)
R: Algal respiration (mg $O_2L^{-1}d^{-1}$) (daily average respiration rate)
$D_0$: Dissolved oxygen deficiency at the beginning ($mgL^{-1}$)
t: Time (d)

Waste water collected from the basin is discharged into the Galyan Stream without any treatment as point source. Therefore, specifically the Galyan Stream is modeled with the single point source of BOD in this study. As occurred in the Galyan Stream the reach is at steady-state and is characterized by plug flow with constant hydrology and geometry. This is the simplest manifestation of the classic Streeter-Phelps model that ties together the two primary mechanisms governing dissolved oxygen in a stream receiving sewage: decomposition of organic matter and oxygen reaeration can be written as [6, 32, 33].

$$D_t = \frac{K_d \cdot L_o}{K_a - K_r} \cdot (e^{-K_r \cdot t} - e^{-K_a \cdot t}) + D_0 \cdot e^{-K_a \cdot t} \tag{2}$$

It is possible that the magnitude of a CBOD discharge is so great that a stream will be devoid of oxygen like in the Galyan Stream. For such cases the Streeter-Phelps model must be modified. For simplicity the equations are expressed in terms of travel time. In addition, it is assumed that $K_d = K_r$ *(that is, there are no settling losses)*. For this situation the Streeter-Phelps model is:

$$D_t = \frac{K_d \cdot L_o}{K_a - K_d} \cdot (e^{-K_d \cdot t} - e^{-K_a \cdot t}) + D_0 \cdot e^{-K_a \cdot t} \tag{3}$$

If complete mixing is assumed at the discharge location, DO ($O_0$) and CBOD ($L_0$) concentrations of the mixture, an initial dissolved oxygen concentration (Do), critical time ($t_{cr}$), maximum value of dissolved oxygen demand for the critical time ($Dt_{cr}$), which the location and magnitude depends on a number of factors, including the size of the loading, the stream's flow and morphometry, water temperature etc., and critical dissolved oxygen deficiency value (Dc) are also calculated by using the following equations as the flow-weighted average of the loading [5, 6].

$$O_0 = \frac{Q_W \cdot (DO)_W + Q_S \cdot (DO)_S}{Q_W + Q_S} \tag{4}$$

$$L_0 = \frac{Q_W \cdot (CBOD)_W + Q_S \cdot (CBOD)_S}{Q_W + Q_S} \tag{5}$$

$$t_{cr} = \frac{1}{K_a - K_d} \cdot \ln\left\{\frac{K_a}{K_d} \cdot \left[1 - \frac{D_0 \cdot (K_a - K_d)}{L_0 \cdot K_d}\right]\right\} \tag{6}$$

$$Dc = Cs - Dt_{cr} \tag{7}$$

$$Cs = \frac{468}{31.6 + T} \tag{8}$$

...where $Cs$: saturation of dissolved oxygen at temperature ($mgL^{-1}$).

All other things being equal, attached bacteria generally are more effective decomposers than free-floating bacteria. Bottom decomposition can be parameterized as a mass transfer flux of BOD. Thus in a way similar to settling, bottom decomposition becomes more pronounced in shallower systems because the effect becomes more relative to the volumetric decomposition in the water. This trend has been fit by the following equation:

$$K_d = 0.3\left(\frac{H}{8}\right)^{-0.434} \quad 0 \le H \le 8 \text{ ft} \tag{9}$$

BOD removal rates tend to increase with temperature and be higher immediately downstream from point resources. The latter effect is more pronounced for untreated waste water. In addition, enhanced settling and bed effects means that shallower systems typically exhibit higher BOD removal rates than deeper waters [6].

Many investigators have developed formulas for predicting reaeration in streams and rivers. The "approximate delta method" is a simple procedure for simultaneous calculation of the stream reaeration coefficient, primary production rate, and respiration rate from a single-station stream diurnal profile of DO [34]. Numerous formulas have been proposed to model stream aeration. One of these formulas, very commonly used, is expressed as [6, 35]

$$K_a = 3.93\frac{U^{0.5}}{H^{1.5}} \text{ (O'connor-Dobbins)} \tag{10}$$

## Sampling and Analysis

Water samples were periodically taken from Temelli (Galyan Stream, 39º40'45''E and 40º51'53''N), Değirmen (Kuştul Stream, 39º42'07''E and 40º51'10''N) and Çiftdere sites (Galyan Stream, 39º42'05''E and 40º51'05''N) between April 2004 and January 2005 (Fig. 1).

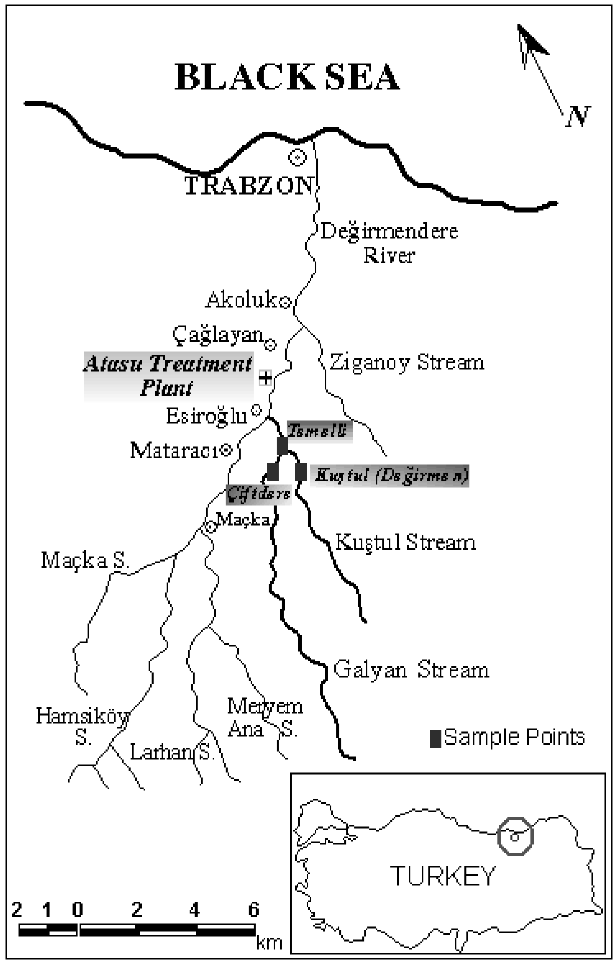

Fig. 1. The Galyan Stream basin.

The monthly averages of the flows were determined for the Galyan Stream (Temelli Site) by using a flowmeter (FP 201) and the average discharge was calculated with determination of the stream cross sectional area. The temperature (T) and dissolved oxygen (DO) were measured on-site. On the other hand, unfiltred (without TSS etc.) carbonaceous biochemical oxygen demand (CBOD) was measured on-laboratory. DO was determined according to the Winkler method. Temperature and CBOD were measured with Horiba U-10 type tool and UV-VIS spectrophotometer (Cadas 200), respectively.

## Results and Discussion

The monthly average (April 2004-January 2005) discharge, dissolved oxygen (DO), temperature and carbonaceous biochemical oxygen demand (CBOD) values for the Galyan Stream (Temelli Site) are given in Fig. 2.

The discharge values change between 2.03 $m^3s^{-1}$ in August (the lowest value) and 6.76 $m^3s^{-1}$ in April (the highest value). The discharge of the Galyan Stream increases due to the rains and melting snow in spring months. The CBOD values change between 0.86 $mgL^{-1}$ in September (the lowest value) and 2.24 $mgL^{-1}$ in June (the highest value).

The CBOD values of the samples for summer season are higher in comparison with the other seasons due to the increasing temperature. The temperature values change between 7.1ºC in January (the lowest value) and 19.47ºC in August (the highest value). The DO values change between 8.71 $mgL^{-1}$ in August (the lowest value) and 11.13 $mgL^{-1}$ in January (the highest value). The DO values of the water samples for winter season reach highest value due to the increasing temperature and some hydrogeometric properties as in the Galyan Stream. The measurement values show that the Galyan Stream has first class water quality in terms of dissolved oxygen concentration (DO $\geq$ 8 $mgL^{-1}$), temperature (T$\leq$ 5-25ºC) and carbonaceous biochemical oxygen demand (CBOD$\leq$ 4 $mgL^{-1}$) according to the Turkish Water Pollution Control Regulation (TWPCR) [36].

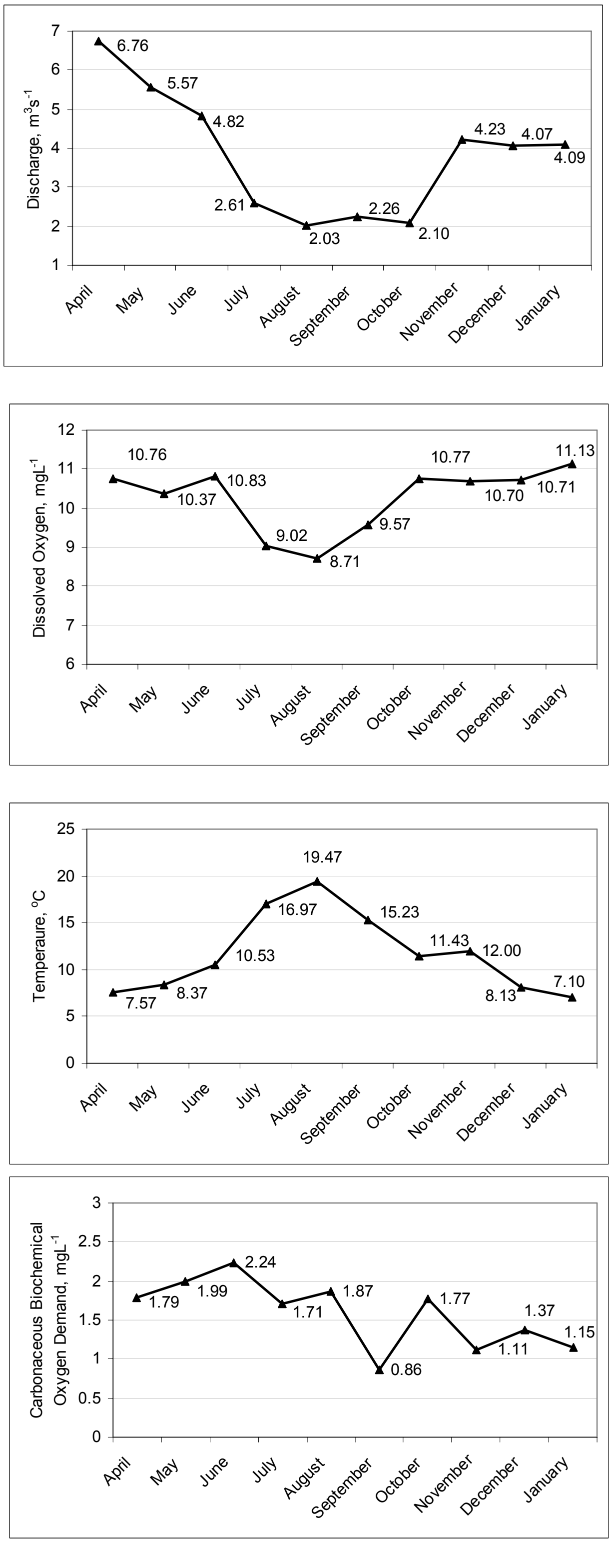


Fig. 2. Discharge, DO, temperature and CBOD values in the stream (April 2004-January 2005).

Discharge, CBOD and DO values of the stream and the values, which are 37$Ls^{-1}$ for the discharge of the waste water and 1 $mgL^{-1}$ for the dissolved oxygen concentration and 350 mg $L^{-1}$ for the CBOD concentration, are put into the Eqs. (3, 4, 5, 6, 7, 8). In these calculations, it is assumed that temperature of the waste water is equal to that of the stream water. The values, 0.28 $d^{-1}$ for deoxygenation rate and 0.30 $d^{-1}$ for reaeration coefficient, which are used in the point source Streeter-Phelps equations, are calculated by using Eq. 9 and Eq. 10, respectively.

DO ($O_0$) and CBOD ($L_0$) concentrations of the mixture, dissolved oxygen deficiency at the beginning ($D_0$), critical time ($t_{cr}$), maximum value of dissolved oxygen depletion ($Dt_{cr}$) and critical dissolved oxygen deficiency (Dc) values are calculated and the values are listed in Table 1 as monthly average for April 2004-January 2005. The variation of dissolved oxygen profile according to time is also given in Fig. 3 as monthly average for April 2004-January 2005.

This study primarily focuses on the Streeter-Phelps model parameters for April 2004-January 2005, but discharge, CBOD, DO and temperature parameters have been determined since the year 2000 in the study area. Therefore, the model parameters are also calculated for the years 2000-2004 according to the annual average obtained from the monthly values of every year and listed in Table 2 as annual average. The variation of dissolved oxygen profile according to time is also given in Fig. 4 as annual average for the years 2000-2004.

## Conclusions

In this study conducted with taken water samples from Temelli, Değirmen and Çiftdere sites in Trabzon between April 2004 and January 2005, variations of dissolved oxygen profile are determined by using the point source Streeter-Phelps model. When the municipal waste waters in the Galyan Stream basin are discharged into the stream, critical dissolved oxygen deficiency values calculated for 2004 April-2005 January months are 10.13 $mgL^{-1}$, 9.61 $mgL^{-1}$, 9.3 $mgL^{-1}$, 7.09 $mgL^{-1}$, 6.13 $mgL^{-1}$, 7.55 $mgL^{-1}$, 8.06 $mgL^{-1}$, 9.28 $mgL^{-1}$, 9.73 $mgL^{-1}$ and 10.17 $mgL^{-1}$, respectively. Critical dissolved oxygen deficiency values calculated for 2000-2004 are 8.19 $mgL^{-1}$, 8.32 $mgL^{-1}$, 8.91 $mgL^{-1}$, 7.73 $mgL^{-1}$ and 8.46 $mgL^{-1}$, respectively. It is required that critical oxygen deficiency should not be less than 4 $mgL^{-1}$ for the continuity of the living things in the river [35, 37, 38].

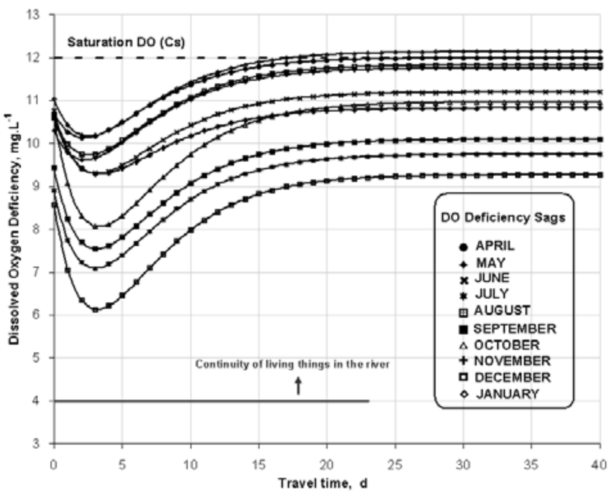


Fig. 3. Variation of DO profile according to time for the stream (the monthly average values).

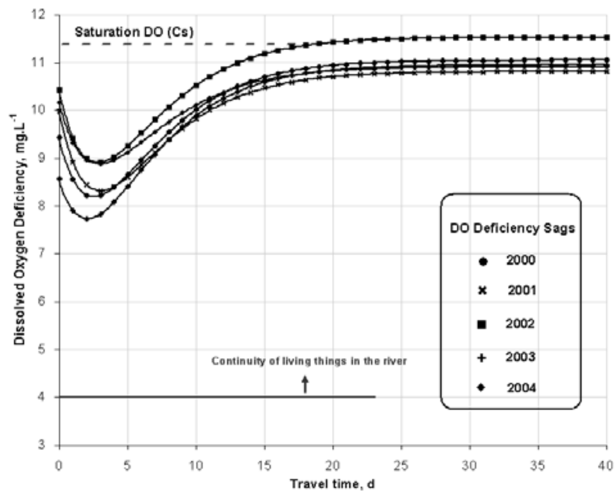


Fig. 4. Variation of DO profile according to time for the Stream (the annual average values).

Table 1. The Streeter-Phelps model parameters for the Galyan Stream (the monthly average values).

| Months | $O_0$ ($mgL^{-1}$) | Cs ($mgL^{-1}$) | $L_0$ ($mgL^{-1}$) | $D_0$ ($mgL^{-1}$) | $t_{cr}$ (d) | $Dt_{cr}$ ($mgL^{-1}$) | Dc ($mgL^{-1}$) |
|---|---|---|---|---|---|---|---|
| April | 10.71 | 12.00 | 3.69 | 1.29 | 2.19 | 1.868 | 10.132 |
| May | 10.31 | 11.76 | 4.29 | 1.45 | 2.23 | 2.146 | 9.614 |
| June | 10.76 | 11.20 | 4.89 | 0.44 | 3.13 | 1.901 | 9.299 |
| July | 8.91 | 9.75 | 6.58 | 0.84 | 2.99 | 2.658 | 7.092 |
| August | 8.57 | 9.27 | 8.10 | 0.70 | 3.14 | 3.138 | 6.132 |
| September | 9.43 | 10.10 | 6.48 | 0.67 | 3.08 | 2.554 | 7.546 |
| October | 10.60 | 10.97 | 7.80 | 0.37 | 3.28 | 2.906 | 8.064 |
| November | 10.62 | 10.83 | 4.14 | 0.21 | 3.27 | 1.547 | 9.283 |
| December | 10.62 | 11.83 | 4.51 | 1.21 | 2.48 | 2.101 | 9.729 |
| January | 11.04 | 12.14 | 4.28 | 1.10 | 2.52 | 1.971 | 10.169 |

Table 2. The Streeter-Phelps model parameters for the Galyan Stream (the annual average values).

| Years | $O_0$ ($mgL^{-1}$) | Cs ($mgL^{-1}$) | $L_0$ ($mgL^{-1}$) | $D_0$ ($mgL^{-1}$) | $t_{cr}$ (d) | $Dt_{cr}$ ($mgL^{-1}$) | Dc ($mgL^{-1}$) |
|---|---|---|---|---|---|---|---|
| 2000 | 9.43 | 11.05 | 6.18 | 1.62 | 2.5 | 2.861 | 8.189 |
| 2001 | 9.99 | 10.81 | 6.14 | 0.82 | 2.97 | 2.495 | 8.315 |
| 2002 | 10.43 | 11.53 | 6.17 | 1.10 | 2.81 | 2.623 | 8.907 |
| 2003 | 8.57 | 10.95 | 6.11 | 2.38 | 2.04 | 3.223 | 7.727 |
| 2004 | 10.16 | 10.91 | 4.91 | 0.75 | 2.90 | 2.453 | 8.457 |

In the Galyan Stream with first class water quality, treatment is not required in terms of dissolved oxygen concentration, temperature and biochemical oxygen demand because critical dissolved oxygen deficiency values calculated for both 2004 (monthly) and 2000-04 (yearly) are found to be higher than these limit values. It is seen that dissolved oxygen limit with minimum 8 $mgL^{-1}$ that is required in the domestic waters, however, is still under the limit values in July, August and September in the case of mixture. Pollution signs have just not been formed in terms of CBOD and DO in the situation of mixture. If it is continued to discharge the municipal and industrial waste waters into the stream as the receiving waters along with the increasing population and industrial developments in the stream basin area, the stream will turn into a water body that will need care and serious precautions for pollution control.

It is known that the Streeter-Phelps model becomes more complex in terms of increased number of parameters and variables, the error between simulations and measurements decreases while the overall model sensitivity increases. In spite of the disadvantages, Streeter-Phelps is important in terms of indicating the quality of time-based changes in dissolved oxygen deficiency in the Galyan Stream, in case of complete mixing starting from the point of waste water discharge downstream in this study. In this way, the model provides facility and anticipation in prediction of dissolved oxygen profile.

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