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Analyzing the Effect of Temperature on DO and BOD of the Tapi River using QUAL2Kw Model

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Abstract: ***Environmental pollution and climate change is the ultimate result of rapid urbanization. The change in environmental conditions due to undesirable human activities increases local ambient temperature hence it is leading to a rise in the river water temperature. Tapi river is the main source of drinking water for Surat city, Gujarat, India. A stretch of river Tapi has been studied from Kamrej to Causeway which has a stretch of about 22.39 km. The river water quality was found to be degraded due to the excessive discharge of pollutants from various points and non-point sources. Extreme discharge of pollutants into the river decreases the dissolved oxygen (DO) concentration. At the same time due to the increase in temperature, the process of transformation of atmospheric O_2 gas into dissolved form also becomes very slow. In this study, the QUAL2Kw one - dimension water quality model was applied to assess the DO and BOD at various locations. The QUAL2Kw model was calibrated and validated with observed data. The calibrated model was applied to evaluate the effects of temperature on the DO and BOD of the Tapi river. The conditions of maximum, minimum, and average temperature for March, April, and May from the year 1991 to 2021 were considered. The result revealed that the full stretch of 22.39 km was not able to maintain minimum dissolved oxygen (DO) concentration, hence biochemical oxygen demand (BOD) has subsequently increased downstream of the river stretch. It was also observed that DO and BOD levels tremendously fluctuate ambient temperature.***

Keywords: ***BOD, Dissolved Oxygen, QUAL2Kw, Tapi River, Water Quality***

I. INTRODUCTION

The temperature of steam water is one of the most significant parameters as it influences many chemical processes in the river [1]. The availability of dissolved oxygen (DO) and biological oxygen demand (BOD) in water is influenced by temperature and pollutants present in the river water. Due to various activities, significant pollutants enter into rivers and streams which lower dissolved oxygen below a critical point which results in adversely affecting the ecosystem, odor problems, and aesthetic nuisances [2,3].

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The deterioration in water quality can be assessed by measuring DO and BOD [4,5] Hence, BOD becomes an essential factor in determining organic substances present in a river [6,7]. The analysis of the effects of temperature on pollutants in river systems is a very challenging task [8, 9,10]. Expanding water scarcity coupled with declining quality is pressuring developing countries to explore river water quality restoration options. As an outcome, it has become essential to consider river water quality and forecast future changes in water quality [11]. Mathematical modeling is an effective tool for load estimation in aquatic environments, establishing cause-and-effect relationships between water quality and pollution sources. It also evaluates how the aquatic environment will respond to various circumstances. The simulation results are an effective management tool that can help decision-makers to develop realistic strategies. It considers the unique conditions of the river and forecasts the impact of accidental discharges or additional pollutant loads [1]. The QUAL2Kw model is effectively used to simulate various pollutants regarding varying climatic conditions. High stream water temperatures can harm the aquatic system by restricting fish habitation and in some cases causing fish mortality. It has been reported that a higher river water temperature of 23°C to 25°C can be responsible for trout mortality [12]. The significant differences in stream water temperature increase during the summer season also affect other factors like solar radiation, low flows, depth of water, cloud cover, etc. Generally, the higher difference is observed in the summer season whereas minor differences have been noticed in the winter [12]. The main aim of this research work is to assess the effects of temperature on the concentration level of DO and BOD in the stretch of the Tapi river using the QUAL2Kw model.

II. METHODOLOGY

A. About The Qual2kew Model

The QUAL2Kw is a one-dimensional stream water quality model developed in 2006 by Pelletier and Chapra [5] which considers the river to be divided into several segments [13]. It can simulate water quality parameters like pH, temperature, electrical conductivity, DO, carbonaceous biochemical oxygen demand, inorganic suspended solids, organic Nitrogen, NH4-N, NO3-N, organic and inorganic phosphorus, alkalinity, phytoplankton, and bottom algae [14]. It facilitates an automatic genetic algorithm for the calibration process. The QUAL2Kw considers the various climatic conditions as it can influence the heat balance which influences the water quality conditions.

The following equation (1) shows heat equilibrium in elements [15,16].

$$\frac{dT_i}{dt} = \frac{Q_{i-1}}{Vi}T_{i-1} - \frac{Qi}{Vi}Ti - \frac{Q_{ab,i}}{Vi}Ti + \frac{E'_{i-1}}{Vi}(T_{i-1} - Ti) + \frac{E'_i}{V_i}(T_{i+1} - T_i) + \frac{W_{h,i}}{\rho_\omega C_{p\omega V_i}}\left(\frac{m^3}{10^6\ cm^3}\right) + \frac{J_{h,i}}{\rho_\omega C_{p\omega H_i}}\left(\frac{m}{100cm}\right) + \frac{J_{s,i}}{\rho_\omega C_{p\omega H_i}}\left(\frac{m}{100cm}\right) \quad (1)$$

where T_i = temperature in reach i (°C)

t = time in days

E'_i = the bulk dispersion coefficient between reaches i and $i + 1$ (m^3/d)

W_h, i = the net heat load into reach from point and non-point sources i (cal/d)

ρω water density (g/cm^3)

C_{pw} = the specific heat of water [cal/(g °C)]

$J_{h,i}$ = the heat flux in air-water [cal/(cm^2 d)]

Js ,i = the heat flux in sediment-water [cal/(cm^2 d)] [15].

B. Study Area

The present work was undertaken for Surat city which is one of the fastest-growing smart cities in Gujarat, India. The study area includes the 22.39 km long stretch of the Tapi river, flowing between Kamrej to Causeway. This segment of the river is the most affected as it receives waste discharge from various point sources and non-point sources. The activities that influence the quality of river Tapi are mainly agricultural runoff, washing clothes, religious activities waste discharge, cattle farming, open defecation, cremation, etc. The discharge of untreated/partially treated wastewater from Kathor, Valak, Varacha, Kholwad, Abrama, Uttaran, and Aswini Kumar villages is mainly contributing to the deterioration of river water quality.

C. Model Input, Calibration, and Validation

Considering the cross-section of the study area, the entire 22.39-kilometer stretch of the Tapi River from Kamrej to the causeway was divided into 21 unequal sub-reaches. Manning's equation was used to create the river's hydraulic model [17]. The average monthly water flow, temperature, pH, BOD, organic-N, ammonium (NH_4), and inorganic suspended solids (ISS) have been considered in the model. The model was calibrated and validated with available data. Multiple trial-and-error approaches were used with various rate coefficient combinations. The model performance was evaluated in terms of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE).

D. Scenario Evaluation

The calibrated model was used to analyze the effect of temperature on DO and BOD. As the water quality is maximum affected in the summer seasons the study has been carried out for March, April, and May. The average value of maximum, minimum, and average temperature of summer from 1991 to 2021 was used to assess the effects of temperature on DO and BOD which is shown in Table 1.

Table 1. Maximum, Minimum, and Average Temperature Data

Seasons	Month	Maximum Temp. (°C)	Minimum Temp. (°C)	Average Temp. (°C)
Summer	March	33	21.6	27.3
	April	34.9	24.9	29.6
	May	34.2	27.2	30.2

Source:https://en.climatedata.org/asia/india/gujarat/surat-959693/#climate-table

III. RESULT AND DISCUSSION

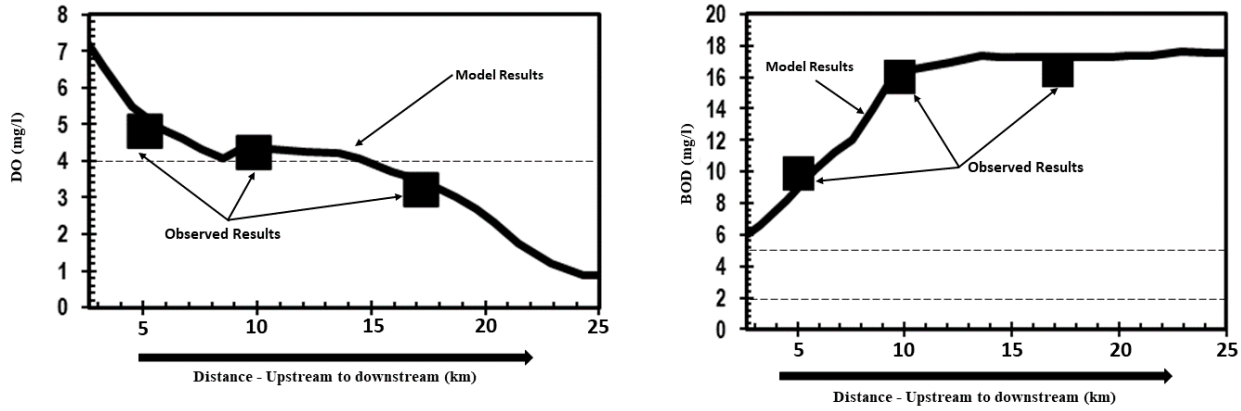
A. Model Calibration and Validation

Figure 1 depicts the calibration results, while Figure 2 depicts the modeling validation results of DO and BOD. The model result was evaluated with mean absolute error and root mean square error. The results show a good correlation between observed and predicted values of DO and BOD which is shown in Table 2.

Table 2. Statistics of DO and BOD for Calibration and Validation

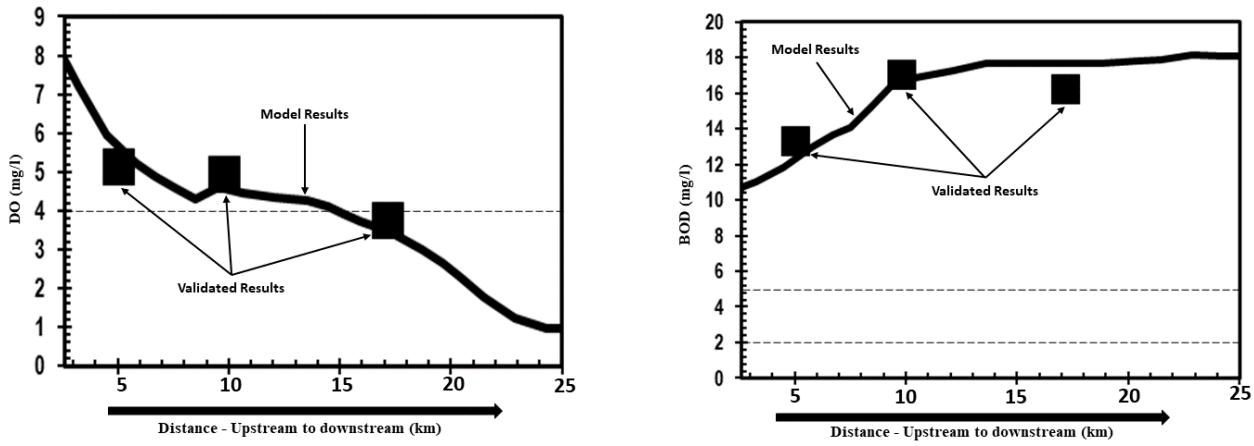
Particular	DO	BOD
Calibration of model		
Mean Absolute Error (MAE)	0.03	0.36
Root Mean Square Error (RMSE)	0.016	0.24
Validation of model		
Mean Absolute Error (MAE)	0.13	0.42
Root Mean Square Error (RMSE)	0.026	0.72

The model has been calibrated with available results of DO and BOD along the stretch of Tapi which indicates a good correlation with observed and calibrated results. The available point and non-point sources data have been further used to validate the results stretch of Tapi. From the validation has been observed that the entire stretch of 22.39 km failed to meet the river water quality standards. In the stretch of the river from the upstream side up to 15 km, river water quality was significantly good as in most of the locations DO was observed greater than 4 mg/l. However, after 15 km there was a significant reduction in DO value. From the study, it has been observed that the downside of 9 km in most of the stretches DO level has been observed as less than 4 mg/l which indicated a significant deterioration of water quality. Figure 2(b) shows BOD value is increasing from upstream to downstream. To meet drinking water quality standards BOD value ≤ 2mg/l but it was observed in the range of 6 mg/l to 17.5mg/l it indicating river water quality is very poor.



(a) (b)

Figure 1. Model Calibration results of river Tapi (a) DO, (b) BOD



(a) (b)

Figure 2. Model Validation results of river Tapi (a) DO, (b) BOD

B. Effects of Maximum, Minimum, And Average Temperature on Do and Bod

The rate of chemical reactions in water, the interaction of pollutants, the rate of photosynthesis in aquatic plants, and the rate of metabolism, parasites, and other pathogens with water are affected by temperature. The chemical reaction accelerates the rate of BOD degradation by microbes during the deoxygenation reaction [18]. It was observed that variations in DO and BOD concentrations were influenced by variations in ambient and water temperature.

As the temperature is influencing parameters for DO and BOD, the temperature data from 1991 to 2021 were considered for the study. In Surat city month of March, April and May are recorded as the hottest month. So, in the study maximum, minimum, and average temperatures of March, April and May have been considered. The average maximum, minimum, and average temperature from 1991 to 2021 is as per table 1. Is used in model results. The variation in a DO and BOD concerning maximum, minimum, and the average temperature is represented in figure 3(a) & (b), figure 4(a) & (b), and figure 5(a) & (b) respectively. The baseline temperature is considered as 22 °C as per the model calibration and validation conditions.

From the graph, it has been observed that as temperature increases beyond 33°C in most of the stretches of the river DO has been observed as less than 4mg/l. Considering the minimum temperature criteria at least the river can maintain 4 mg/l DO at most of the point. However, the river water quality was deteriorating downstream at 9 km.

As the average temperature is reported as higher than the minimum temperature in the case of average temperature DO has been dropped significantly lower. However, in the case of BOD similar increasing trend has been observed irrespective of maximum, minimum, and average temperature.

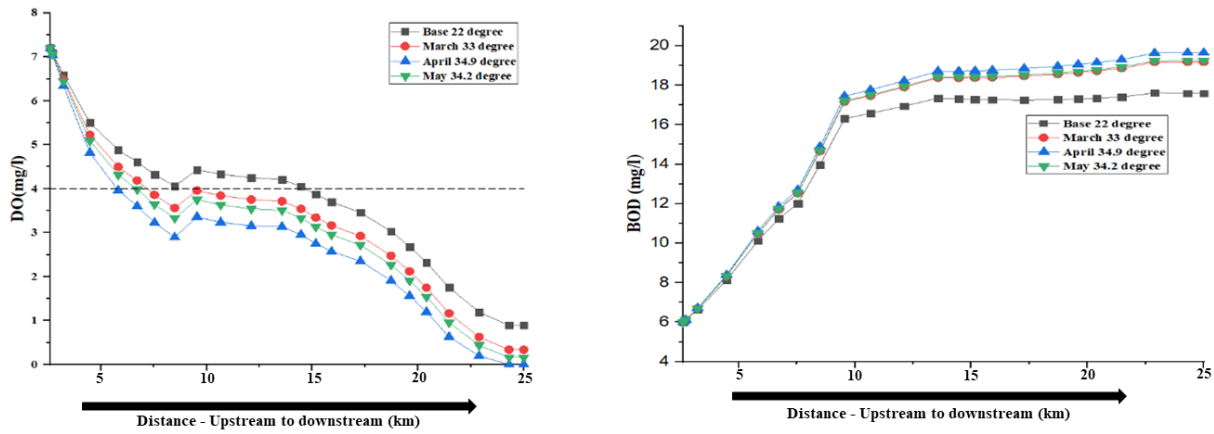
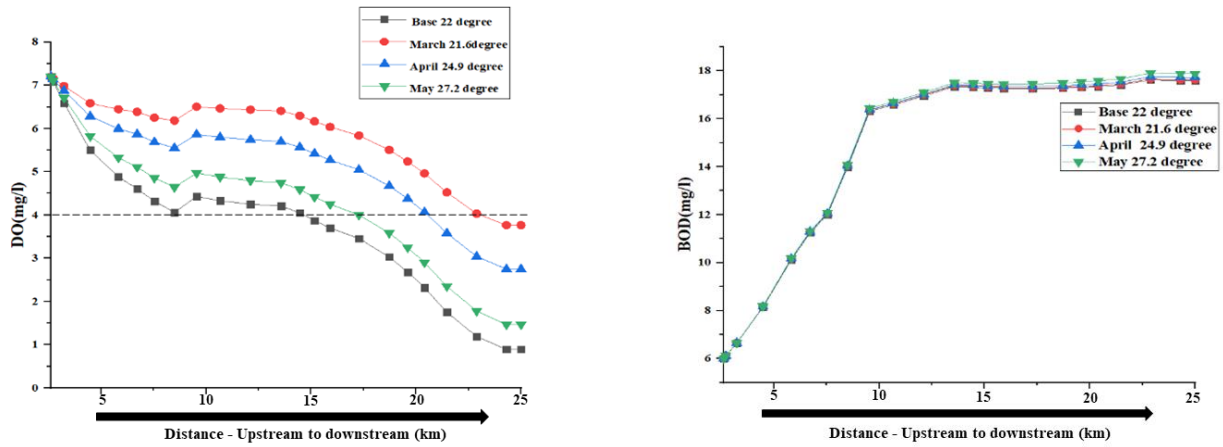
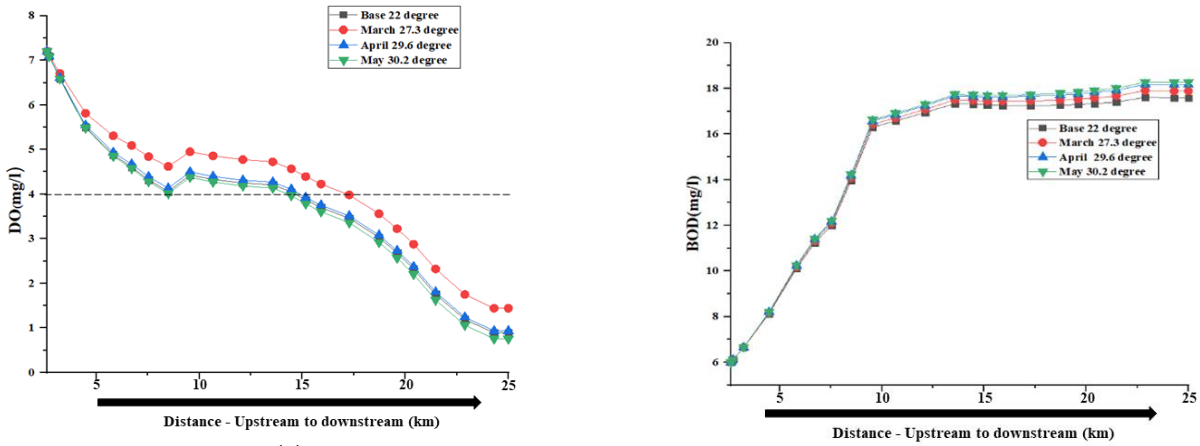


Figure 3. Results of maximum temperature condition for the months March, April and May (a) DO, (b) BOD



(a) **(b)**

Figure 4. Results of minimum temperature conditions for March, April, and May (a) DO, (b) BOD



(a) **(b)**

Figure 5. Results of average temperature conditions for March, April, and May (a) DO, (b) BOD

IV. CONCLUSION

In this research work QUAL2Kw, a modal is utilized to simulate water quality. This model shows a strong correlation between calibrated and validated values of the DO and BOD table. The Tapi river was most influenced by various point and non-point sources and anthropogenic activities. The calibrated model can also be used to simulate the effects of temperature on water quality parameters. During March, April, and May the river water quality was most significantly deteriorating as in most of the stretches the minimum DO level obtained was 4 mg/l. In some of the stretches, DO was observed to be enriched because of the growth of microalgae as shown in figure 4(a). BOD throughout the stretch was observed as an incremental increase up to some extent with a constant value of less than 18 mg/l.

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Thus, the condition of the Tapi river is having worst water quality during the summer season. This research would be urban planners to make decisions to control pollutants entering the river and to evaluate the different conditions to maintain.

DECLARATION

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Ethics Approval	Not relevant.
Consent to Participate	Not applicable.
Consent for Publication	Not applicable.
Availability of Data and Material	The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.
Authors Contributions	HP has done a detailed literature survey for this study. She also collected samples, conducted all the experiments, along with data interpretation, and generates the result using QUAL2KW software. NJ provided administrative and technical support in addition to critical comments and revisions in the manuscript as the supervisor for the study. The experimental study was conducted under her supervision. Both authors read and approved the final manuscript.
Code Availability	Not applicable.

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