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Analysis of Pollutant Load Carrying Capacity of the River Tapi Using QUAL2Kw for Surat City

Hiralkumari B. Patel*, Namrata D. Jariwala

Department of Civil Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India
Email: *hiralkumari.patel@ckpcet.ac.in

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Abstract

River Tapi is the prime water body for Surat city, Gujarat, India. On a long stretch of 22.39 km in Surat city (Kamrej to Causeway) of the Tapi river, there are many identified and non-identified discharge points available. Excessive discharge from these points restricts the efficiency of the self-purification process which ultimately degrades the river water quality. In this paper, an attempt has been made to estimate the pollutant load-carrying capacity at different segments of the river Tapi using the QUAL2Kw tool. The study has been undertaken with different scenarios: First, the QUAL2Kw model was trained with available river water quality and hydraulic data of the Tapi river in which the complete river segment was divided into 21 reaches. The model was calibrated and validated with the actual concentrations of the pollutants entering. In the second phase, all the point source, non-point source, and headwater characteristics were considered and the pollutant load-carrying capacity of the river in terms of BOD, ISS, and N-nitrate was found. In the third phase, all the sources of pollutants entering the river have been removed and only headwater characteristics were considered for the study. The results indicate that reach no. 21 (21.23˚N, 72.82˚E) has the maximum load-carrying capacity of Biochemical Oxygen Demand (BOD) up to 2057.7 kg/day, Inorganic Suspended Solids (ISS) up to 85633.8 kg/day, and Nitrate (NO_3) up to 31688.8 kg/day. However, reach no. 4 has the minimum load carrying capacity of BOD up to 1088.1 kg/day, reach 8 carries a minimum of ISS 205341.6 kg/day and NO_3 10215.57 kg/day.

Keywords

Load Carrying Capacity, River Water Quality, QUAL2Kw, Tapi River

1. Introduction

Water pollution has created a significant impact on human and natural ecosystems in current decades therefore recognition of fluctuations in water quality is the most challenging issue [1]. Land use and human actions have a substantial influence on the water quality of the river. The effluent of various urban, industrial, and agricultural pollutants that exceeds the river capacity of the self-purification process causes the river ecosystem to deteriorate [2] [3]. The high concentration of sediments in water negatively affects the country's economy, and polluted water harms people and adversely affects aquatic life [4]. An increase in population, agricultural and industrial activities, and disturbed climate are threats to the global hydrologic cycle and the world's water quality is under threat [5]. The many settlements along the river course mainly depend on the main source of drinking water. So, the efficient control and management of the contaminated segment of the river are significant to protect human health and aquatic life [6]. The increasing scarcity of pure water as a result of degraded quality is exerting pressure on developing countries to improve the water quality of rivers [7]. The urban reach of the river channel is a premier overstrained environmental resource since it receives treated, partially treated, and untreated wastewater, stormwater, and combined sewage [8] River topography and rapid urbanization influence water quality, which is measured using physical, and biological, and chemical parameters [9]. Evaluation impact of human activities on surface water quality has become a top priority for urban reach management systems [10]. The quality of surface water is determined by numerous complex physical and biochemical processes [9]. Wastewater discharge has undesirable effects on physical, chemical, and biological parameters [11]. The nonlinear and complex relationship between many variables influences water quality parameters, so common methods cannot efficiently manage water resource quality [12]. Forecasting the concentration of pollutant loads in a river is a critical issue in determining the influence of various anthropogenic activities on river systems [13]. According to statistics many river conditions, the concentration of pollutants exceeds the river's self-purification capacity, disrupting the balance of water bodies to improve water quality. Hence, techniques of simulations may be helpful [14].

With a mathematical model tool, it is easy for estimating a river's pollutant load-carrying capacity. Greg Pelletier and Steve Chapra developed the QUAL2Kw water quality model, which is utilized to simulate the quality of water in rivers and streams. The model can simulate various pollutants like temperatures, pH, Dissolved oxygen, Inorganic suspended solids, carbonaceous biochemical oxygen demand, sediment oxygen demand, ammonia, organic and nitrate nitrogen, and organic and inorganic phosphorous along the stretch of the river. QUAL2Kw is used globally and can deliver basic information for assessing water quality with restricted datasets [8] [15] [16].

Tapi is facing an influx of pollutants, which is causing its water quality to deteriorate. Increasing human settlement and uncontrolled anthropogenic activities are major causes of changes in water quality. The few pollutants are extremely persistent in the water and can accumulate posing significant threats

[17]. The Tapi River Water Quality Index suggests water quality of the river is not suitable for drinking and irrigation purposes [18]. According to a study [19] more than 15km of the stagnant, upstream of the weir passes through Surat city and receives approximately 5200 m^3 of effluents every day, in addition to non-point waste loads such as open defecation, dairy farm waste, laundry waste, which increases nutrient content in the river system. When the high pollutant enters in river system, it interferes self-purification process of the river. The analysis of the pollution load-carrying capacity of the river is a very complicated process because river water quality parameters fluctuate within the stretch of the river drastically [20]. The situation of the Tapi river is also becoming complex as it receives various pollutants from identified and non -identified sources. The main objective of this research determines the pollutant load-carrying capacity of the river Tapi using QUAL2Kw.

2. Materials and Methods

2.1. Study Area

The current study was conducted on the river Tapi shown in **Figure 1** flowing from Surat city. Surat is one of the fastest-growing smart cities in the Indian state of Gujarat. The Tapi river originates from the Saputara hills of the Betul district of Madhya Pradesh and finally meets the Gulf of Khambhat (Arabian Sea) after flowing through Madhya Pradesh, Maharashtra, and Gujarat [21]. Tapi river is the main source of the drinking water of Surat city and is subjected to multiple uses. Tapi river enters Surat city near Kamrej and across a stretch of it receives partially treated and untreated sewage from the point, non-point source discharge, and various activities like agriculture runoff, bathing, washing of clothes, and crematorium waste. The discharge locations from the upstream side of the river are mentioned with their distance in **Table 1** and the monitoring stations are mentioned in **Table 2**.

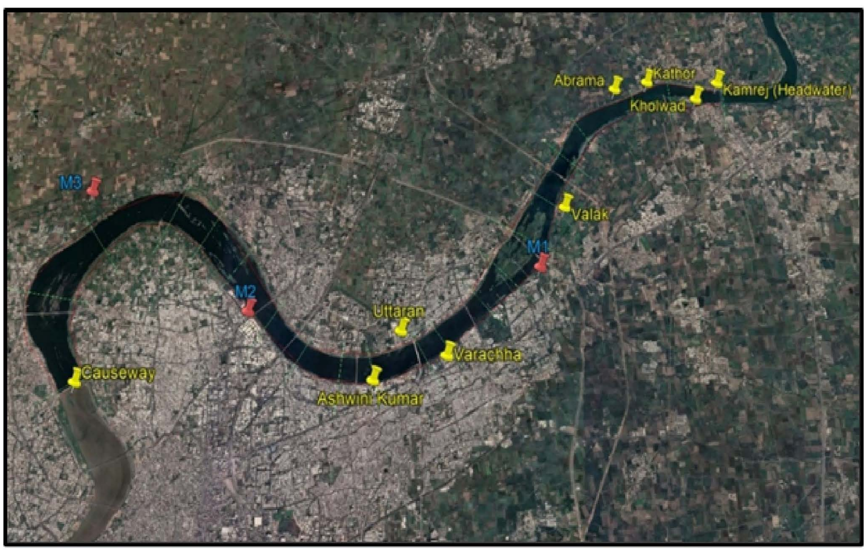


Figure 1. Map of river Tapi with discharge locations and monitoring locations.

Table 1. Description of pollution load discharge location.

Indications	Stations	Distance from upstream (km)
W1	Kholawad village	1.58
W2	Kathor village	2.05
W3	Abrama village	4.82
W4	Valak drain	6.96
W5	Uttaran	13.83
W6	Varacha drain	11.08
W7	Ashwini Kumar	15.03

Table 2. Water quality monitoring stations.

Indications	Stations	Distance from upstream (km)
M1	Sarthana	7.77
M2	Katargam	15.15
M3	Jahangirpura	19.89

2.2. River Segmentation

In a QUAL2Kw model entire stretch of 22.39 km of the river, Tapi was divided into 21 unequal reaches according to the cross-section of the area. The river segmentation detail is shown in **Table 3**. The hydraulic load of the river was calculated using manning's equation [22].

$$Q = \frac{1}{n} \times \frac{S^{\frac{1}{2}} \times A^{\frac{5}{3}}}{p^{\frac{2}{3}}} \tag{1}$$

where, Q = flow of the river (m^3/s), S = bottom slope (m/m), n = coefficient of the Manning roughness, A = cross-sectional area (m^2), and p = wetted perimeter (m).

Observed data were considered and the model has been calibrated using an average of inflow, dissolved oxygen, temperature, BOD, inorganic solids, pH, organic nitrogen, and ammoniacal nitrogen. The samples were collected and analyzed according to APHA Method 4500-F: Standard Methods for the examination of water and wastewater. Climatic data for the water quality modeling were acquired from the Magdala meteorological station of Surat city. From the data, the mean temperature of 2˚C, dew temperature at 9˚C, and 8.1 m/s wind speed were considered for the study. At the same 5%, cloud cover was also considered for the study. Shade values were considered as zero percentage as the adjoining river areas were cleared of all vegetation.

The entire data were fed into the QUAL2Kw water quality model as it is a 1 – D computer-based model that is utilized to simulate the water quality of rivers and streams [23]. QUAL2Kw runs in a Microsoft Windows environment. It is

Table 3. River segmentation with their geographical coordinates.

Reach Number	Length (km)	Latitude (N)	Longitude (E)
1	0.20	21.29	72.93
2	0.85	21.28	72.94
3	1.64	21.29	72.93
4	1.04	21.29	72.92
5	0.75	21.27	72.91
6	0.89	21.25	72.90
7	1.02	21.27	72.90
8	1.09	21.25	72.90
9	1.15	21.24	72.90
10	1.75	21.24	72.88
11	1.15	21.24	72.87
12	0.65	21.23	72.87
13	0.75	21.24	72.85
14	0.74	21.23	72.84
15	1.99	21.25	72.83
16	0.90	21.26	72.84
17	0.86	21.26	72.84
18	0.74	21.23	72.81
19	1.39	21.22	72.81
20	1.45	21.23	72.83
21	1.39	21.23	72.82

programmed in Visual Basic for Applications, a Windows macro language (VBA) [24]. Any reach can accept multiple loadings and abstractions [25]. The model can be used to simulate pollutants along a stretch of river and can be used to simulate parameters of dissolved oxygen, temperature, inorganic suspended solids, pH, carbonaceous biochemical oxygen demand, ammonia, organic nitrogen, nitrate nitrogen, sediment oxygen demand, and organic and inorganic phosphorous [22] [25]. It assumes the river as part of various reaches. To create model geometric properties of the river like channel slope and width, side slope, and manning roughness coefficient are also required. River flow rate, pollutant loads and their characteristics, and meteorological data are also required for simulation. The model executes hydrologic, thermal, and mass balances for each reach, assuming one-dimensional steady flow and vertical and horizontal mixture completion for each reach. It includes an automatic calibration system for hyporheic metabolism using genetic algorithms (GA) as well as a simulation of heterotrophic bacteria metabolism in the hyporheic zone [8]. The genetic algorithm is utilized to calculate the best combination of kinetic rate parameters and constants for a model application when compared to observed data. The model calibration was performed by trial-and-error techniques repetitively running until the model resembled the real situation of the river. The validation of the model was done by different datasets of water quality keeping co-efficient parameters constant.

Calibrated models were utilized to simulate various scenarios of river conditions. The simulation was performed in three scenarios. First, the QUAL2Kw model was trained with available river water quality and hydraulic data of the Tapi river in which the complete river segment was divided into 21 reaches. The river reach has been considered as per the available data of the river cross-section. The Tapi river cross section details were collected from Irrigation circle Surat city. The model was calibrated and validated with the actual concentrations of the pollutants entering. In the second phase all the point source, non-point source, and headwater characteristics were considered and the pollutant load-carrying capacity of the river in terms of BOD, ISS, and N-nitrate was found. The point and non-point source flow, and water characteristics have been collected from the hydraulic department of Surat Municipal corporation. The headwater characteristics are considered as per the CPCB river water quality criteria. In the third phase, all the sources of pollutants entering the river has been removed and only headwater characteristics were considered for the study.

Simulations second and third scenarios were used to calculate the pollution load capacity of the Tapi river. The data on pollutant concentration was debited from the Sources Summary worksheet for each scenario. The pollution load is calculated by multiplying the large concentration of pollutants in the river by the river flow discharge. The following formula is utilized to calculate pollution load [1] [26].

$$\text{Pollution Load (kg/day)} = \text{Flow (m}^3\text{/s)} \times \text{Concentration of pollutant (mg/l)} \times 86. \tag{2}$$

3. Results and Discussion

The results of model calibration and validation have a better correlation with field-monitored data which represents in **Figure 2**, concerning parameters like DO, BOD, ISS, pH, organic nitrogen, and NH4. The mean absolute errors (MAEs), and The RMSEs between the observed and simulated values of the water quality are shown in **Table 4**. The water quality QUAL2Kw model was calibrated and validated with summer and post-monsoon seasons. The model calibration and simulation results are well in agreement with the measured data with some expectations.

The pollution load-carrying capacity of the river was obtained considering the difference between simulation results 2 (full pollution load) and simulation 3 (without pollution load). The model results showed the complete stretch of the study area did not meet drinking water quality standards.

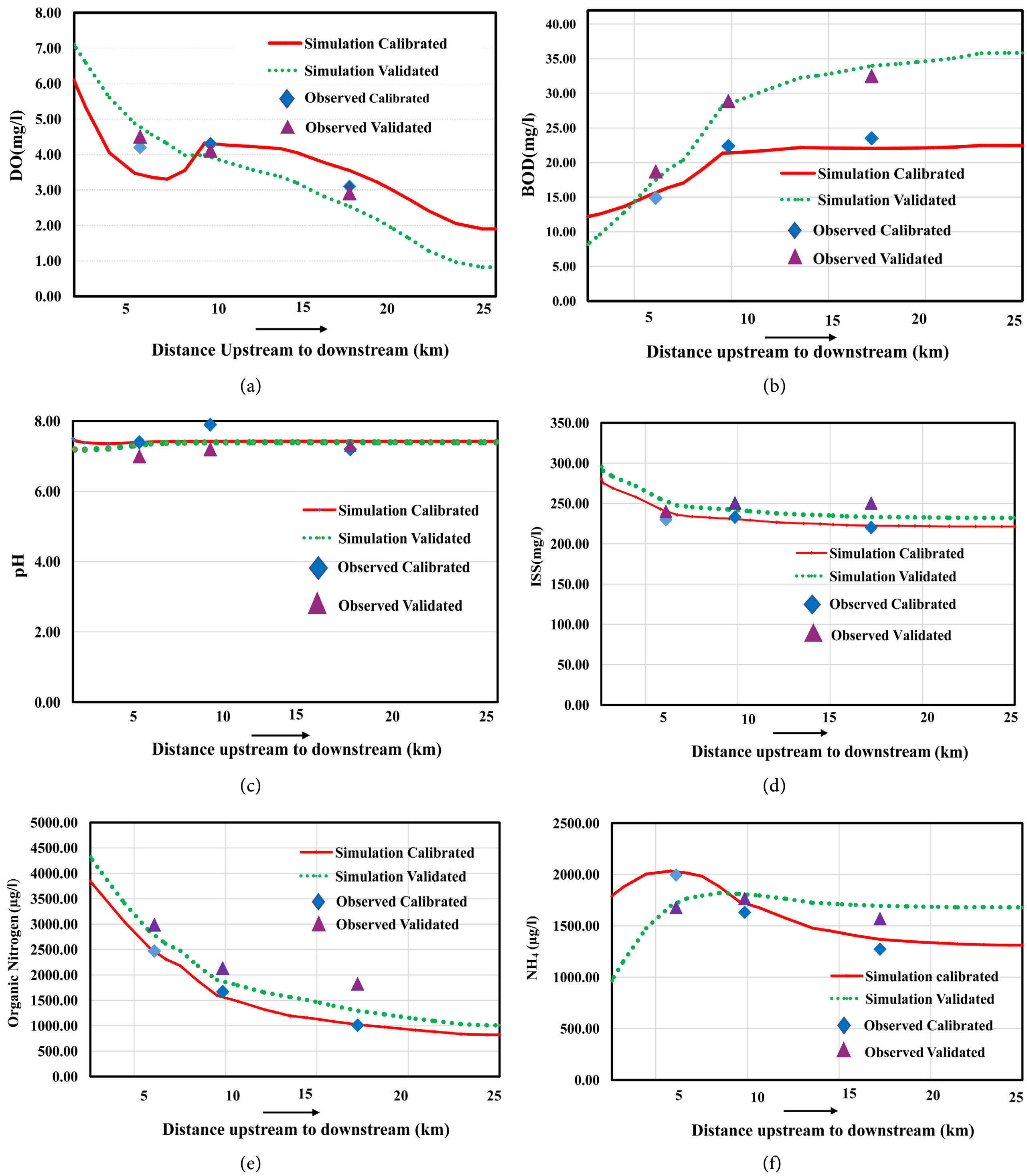


Figure 2. Simulation results of calibration and validation for (a) DO, (b) BOD, (c) pH, (d) ISS, (e) Organic Nitrogen, (f) NH_4.

The QUAL2Kw program model generates source summary, hydraulic summary, and water quality worksheet by using its magnitude of concentration of pollution load calculated which is in Table 5. The pollutant load capacity of river Tapi from upstream Kamrej to Causeway in different reach sections represents in Figure 3.

Table 4. Results of model calibration and validation.

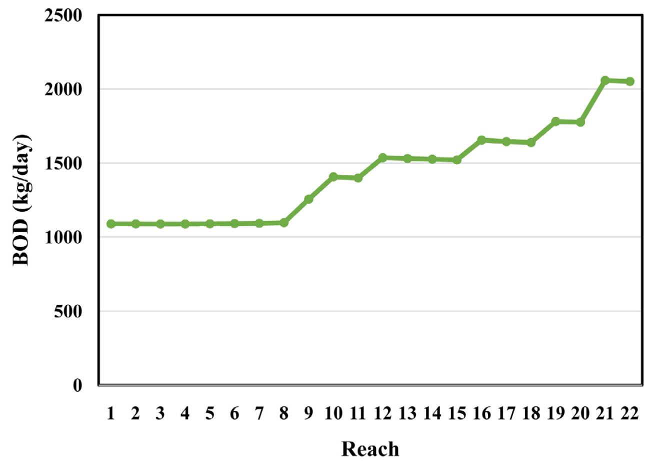
Parameters	Statistics	Calibration	Validation
DO (mg/l)	MAE	0.12	0.05
	RMSE	0.46	0.37
BOD (mg/l)	MAE	0.78	0.06
	RMSE	0.98	1.06
pH	MAE	0.43	0.06
	RMSE	0.53	0.41
ISS (mg/l)	MAE	0.23	0.63
	RMSE	0.40	13.2
Organic Nitrogen (mg/l)	MAE	0.32	0.13
	RMSE	0.57	0.29
NH_4 (mg/l)	MAE	0.06	0.03
	RMSE	0.08	0.13

Table 5. The pollutant load-carrying capacity of the Tapi river.

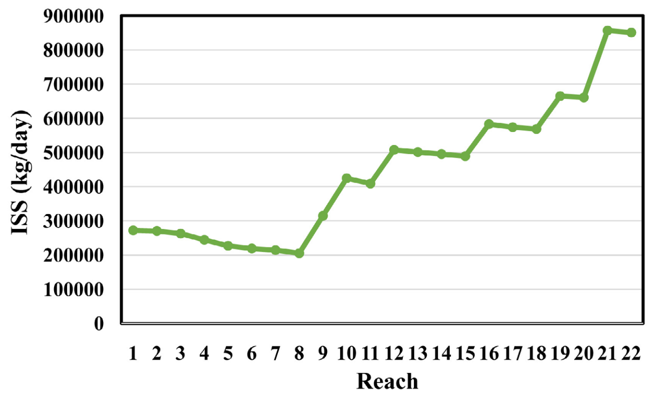
Reach	BOD (kg/day)	ISS (kg/day)	NO_3 (kg/day)
1	1088.6	272160.0	18144.00
2	1088.5	270469.5	17951.64
3	1088.2	262885.4	17092.13
4	1088.1	244501.7	15027.32
5	1089.5	226981.6	13013.2
6	1090.9	219063.8	12059.72
7	1092.3	214575.2	11491.49
8	1097.0	205341.6	10215.57
9	1255.3	314790.8	14241.37
10	1406.2	424412.3	18651.18
11	1398.4	408941.5	17325.02
12	1535.7	507688.9	20771.93
13	1530.3	501189.5	20309.29
14	1525.7	495295.5	19868.37
15	1521.0	489210	19378.3
16	1654.8	582911.6	22559.43
17	1644.7	573888.9	22027.31
18	1638.7	568744.6	21,698
19	1780.3	664795.7	25222.62

Continued

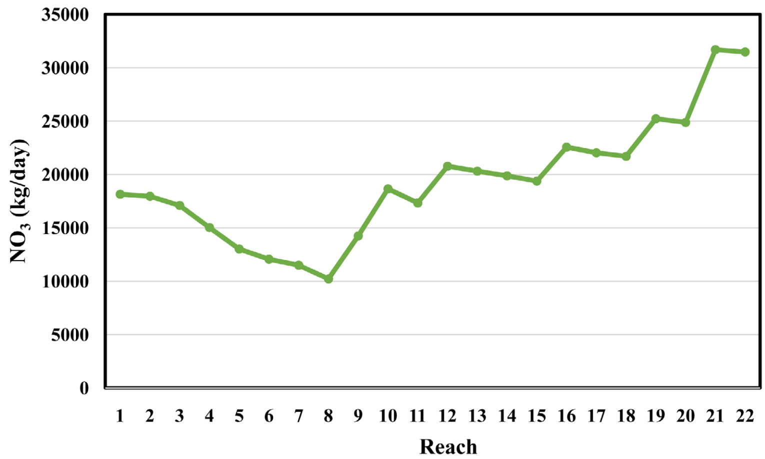
20	1775.6	660812.6	24875.58
21	2057.7	856633.8	31688.78
22	2050.7	850819.2	31475.57



(a)



(b)



(c)

Figure 3. Pollutant load capacity parameters (a) BOD, (b) ISS, (c) NO_3.

4. Conclusion

The river Tapi was found significantly contaminated owing to heavy untreated and partially treated discharge from different sources. The water quality parameters like DO, BOD, ISS, pH, organic nitrogen, and ammoniacal nitrogen were calibrated and simulated with the monitored data. The load-carrying capacity of the BOD load for upstream of the river and mid-segment of the river was observed low, whereas the downstream side's slightly higher capacity was observed. With different simulation conditions with the QUAL2Kw model, we can determine the water quality of the Tapi river at different segments. At the same time calculations of load carrying, capacity/assimilative capacity of the river can effectively be studied with the QUAL2Kw model. The result obtained with this type of study can be helpful for planners of urban authority to look out which sections of the river require improvement.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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