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International Journal of Engineering, Science and Technology
Vol. 15, No. 3, 2023, pp. 43-57

INTERNATIONAL
JOURNAL OF
ENGINEERING,
SCIENCE AND
TECHNOLOGY

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Stream water quality modelling for pollution load capacity in Roshi river- rural Nepal

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Abstract

A rural catchment stream, Roshi (Nepal), is experiencing pollution loads from non-point pollution sources: agricultural runoffs and stone quarry sediment loads requiring immediate concern. This study is focused on developing a well-calibrated and validated water quality model to determine the pollution load capacity of Roshi River at peak rainfall periods using software QUAL2kW concerning pH, Temperature, DO, FSS, NO3-, NH4+, TP, BOD, and Turbidity. A pollution-dominant stretch of 1.95km was selected and segmented into three segments. RMSE values showed the model satisfactory in predicting actual in-field scenarios. Scenario analysis showed that in the existing pollution source flow and streamflow, the pollution load capacity is 275 mg/L for BOD, 33 mg/L for NH4+, 1250 mg/L for NO3-, 10 mg/L for TP, and 0 mg/L for DO. The FSS in the Headwater must be limited to 55 mg/L to maintain the stream water quality within standards signifying the immediate need to reduce the upstream stone quarry load. Policymakers are urged to implement stringent regulations on upstream quarries concerning sediment load discharge into the stream. The developed model can be a valuable tool for predicting the stream's response to potential emissions from future development activities during the monsoon period.

Keywords: Roshi river, QUAL2kW, water quality modelling, scenario analysis, stream pollution

DOI: http://dx.doi.org/10.4314/ijest.v15i3.5

Cite this article as:
Karki S., Bhattarai M., Kharel H.L., Karki B.K. 2023. Stream water quality modelling for pollution load capacity in Roshi river- rural Nepal. *International Journal of Engineering, Science and Technology*, Vol. 15, No. 3, pp. 43-57. doi: 10.4314/ijest.v15i3.5

Received: July 25, 2023; Accepted: August 3, 2023; Final acceptance in revised form: August 6, 2023

1. Introduction

Water pollution poses a grave threat to surface waterbodies, degrading their water quality, harming aquatic life, and undermining the vital ecosystems they support. Surface water bodies i.e., rivers and streams, hold a significant value in nature for objectives such as transportation, hydroelectric power generation, sustaining ecosystems, recreational activities, and disposal of treated and untreated sewage (Ghorbani et al., 2020). Human activities can accelerate the negative impacts on the ecological well-being of these surface waterbodies (Ustaoğlu et al., 2021). In a developing country like Nepal, where people have always depended on streams to fulfill their primary water needs, they face water insecurity problems due to stream pollution. The synergistic impact of anthropogenic and climatic factors has led to the drying out of numerous perennial springs and streams, creating water scarcity and poverty in various regions (Dass et al., 2021). A typical example of surface water pollution in Nepal is the Bagmati River. A study by Karn and Harada (2001) revealed that the dissolved oxygen (DO) levels in the Bagmati River were decreasing at a rate of 0.3 mg/L/year due to unplanned urbanization and industrialization, resulting in a dire situation for stream health. Despite infrastructural improvements, awareness-raising initiatives, and policy measures, water pollution remains a persistent problem for Kathmandu (Mishra et al., 2017). The Roshi River faces similar challenges, with significant pollution loads from agricultural runoff and sediment. Elevated nutrient levels in the river can lead to algal blooms and eutrophication, contributing to the emission of greenhouse gases, particularly nitrous oxide, from streams (Wurtsbaugh et al., 2019).

Given that water is a critical resource, knowing a river's capacity can aid in predicting and planning for future developments that may negatively impact water quality (Dewata & Adri, 2018). Moreover, conducting frequent water quality monitoring in less developed rural areas is financially and logistically challenging. Due to such difficulty, understanding a rural river's capacity is crucial as it identifies the amount of pollution that can be tolerated without contamination (Poedjiastoeti & Indrawati, 2015). Therefore, there is a need to focus on determining the pollution load capacities of rural rivers like Roshi under various scenarios and proposing strategies to limit pollution through mathematical modeling. Managing stream water quality will help to prevent the Roshi River from facing a situation similar to the heavily polluted Bagmati River. On the depiction of actual stream behavior in a well-developed water quality mathematical model, water quality management strategies can be proposed. Initially developed to predict simple oxygen depletion, river water quality models are now being used for research and designing management plans (Rauch et al., 1998). Accurately calibrated water quality models can be valuable choices for assessing and managing receiving waterbodies (Mannina & Viviani, 2010). Water quality modeling can be advantageous when continuous monitoring of water quality parameters is challenging, allowing for predicting various water quality scenarios and suggesting suitable management strategies (Loucks & Van Beek, 2017).

Thereupon, various stream-quality modeling softwares are available, namely Water Quality Analysis Simulation Program (WASP), QUAL2Kw, AQUATOX, Branched Lagrangian Transport Model (BLTM), One Dimensional Riverine Hydrodynamic and Water Quality Model (EPD-RIV1) and Water Quality for River-Reservoir Systems (WQRRS) (Sharma&Kansal, 2013). Among them, QUAL2kw and WASP are comparatively advantageous regarding the number of water quality parameters that can be modeled and easiness in calibration (Sharma&Kansal, 2013). QUALs are favored for their ease of use in the following conditions: the extensive specialization of the modeler is not required, input data are low, and they have a short simulation time (Burigato Costa et al.,2019). The advantage of QUAL2K is its greater flexibility in performing tasks depending on various user-set parameter values and water quality simulations (Hadgu et al., 2014). QUAL2kw uses a Visual Basic for Application (VBA) interface within Ms. Excel interface to display the contents input and running operations of modeling (Aliffia & Karnaningroem, 2019b). interface and efficient computation make the use of QUAL2kW favored for water quality modeling of Roshi.

The selection of modeling parameters for Roshi depends on the purpose served by the stream and the properties of the pollution source. For modeling in Roshi, the parameters chosen are pH, temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrate (NO3), ammonia (NH4), total phosphorus (TP), turbidity, and fixed suspended solids (FSS). DO, and BOD are modeled to represent the minimum oxygen content, while nitrate, ammonia, and phosphorus are modeled to represent nutrient loads from agricultural runoff. Turbidity and FSS are used to indicate the sediment load from upstream stone quarries.

Most studies in Nepal regarding water quality have been conducted in the urban rivers, with only a few studies focusing on the Western Nepal watersheds; most studies have examined its suitability for drinking water only (Singh et al., 2021). Moreover, studies regarding agricultural pollution in streams are minimal. Therefore, this study attempts to integrate the concept of modeling into stream management strategies for a rural stream in Nepal, focusing on agricultural nutrient and sediment pollution.

2. Material and Methods

2.1 Study Area

The Roshi River flows through Panauti Municipality, a historic town in Kavrepalanchok, Nepal. The river originates in the Mahabharat mountain range and flows through the Panauti valley before merging with the Sunkoshi River, eventually joining the Ganges in India. Roshi River intersects with the Punyamata River at the Tribeni Ghat area of Panauti Municipality [Figure 1]. Major causes of pollution are visually seen in the region considered. The considered stretch of the stream for river water quality modeling is 2 km stretch of Roshi River lying in Panauti Municipality, a semi-urban type catchment. The design and construction of interceptor drains for catching the incoming sewage from settlements have already started in the Punyamata River. Water quality management methods in the Punyamata River are actively going on, whereas the Khopasi hydropower diversion headworks-Tribeni ghat section of the Roshi River is neglected as the level of pollution noted in this region is relatively lower. Major pollution in this stretch is from the agricultural runoff and stone quarry sediment loads. This study is themed on the assumption that water quality management strategies, if applied in the diversion headwork -Tribeni ghat stretch of Roshi River, overall water quality can be maintained down to acceptable limits. Hence, this study is concentrated on the Khopasi Hydropower diversion headwork – Tribeni ghat stretch. The principal focus of this study is the analysis of the effects of agricultural runoff and stone quarry sediment load in the rural stream of Nepal Roshi.

The pollution sources in the stretch can be identified, and stream modeling can be done for further analysis to determine the carrying capacity. For the water quality management of the Roshi River, the diversion headwork to the Tribeni Ghat region has to be considered. The water from the Roshi River is primarily used for irrigation. Agricultural land use along the catchment of Roshi highly depends upon Roshi for fulfilling irrigational requirements.

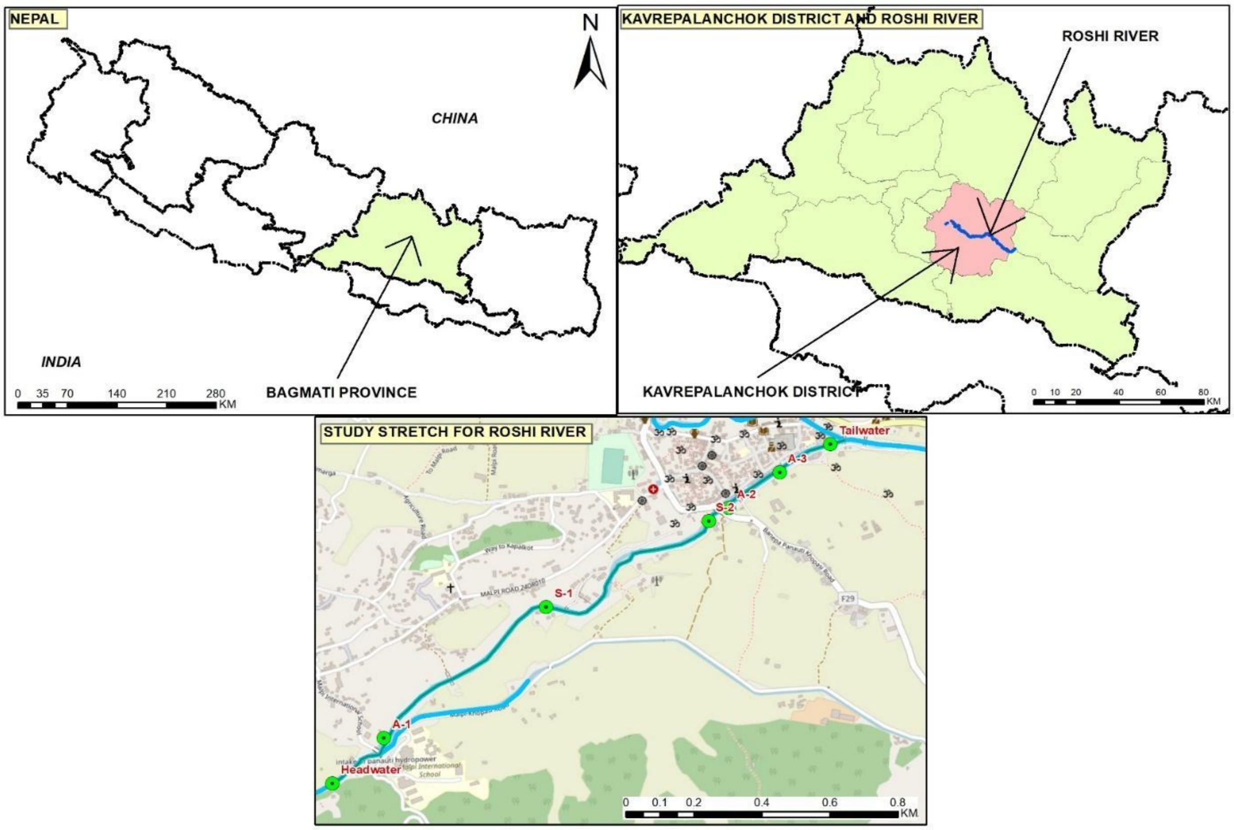


Figure 1 Location Map, Stream Segment Under Consideration, and Sampling Stations

2.2 Stream Segmentation

The stretch of the studied stream has been divided into three sections [Table 1], and sampling stations have been set up accordingly. The headwater section is located near the Khopasi hydropower diversion headwork region. Section S1 is situated in an area used for agriculture, while section S2 marks the transition from agricultural to residential land use. The tailwater section is located where the Punyamata River joins the main Roshi River segment at the Tribeni Ghat region. Two sources of pollution, A1 and A2, are identified at the points where the stream intersects with agricultural runoff from the catchment area [Figure 2]. Figure 3 shows the study methodology diagram.

Table 1. Location of Sampling Stations

Station Name	Location	Descriptions
Headwater	0m Region	Region of Khopasi Hydropower Headwork
A1	220m from Headwater	Agricultural runoff addition into the main river stream
S1	860m from Headwater	Sampling Station
S2	1475m from Headwater	Sampling Station
A2	1550m from Headwater	Agricultural runoff addition into the main river stream
Tailwater	1950m from Headwater	The intersection of the Punyamata River with the main Roshi River stretch

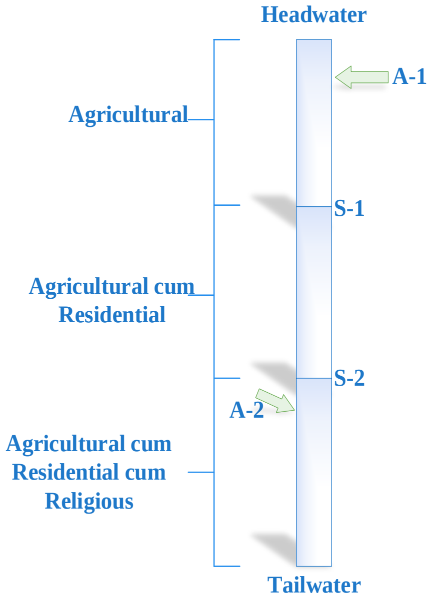
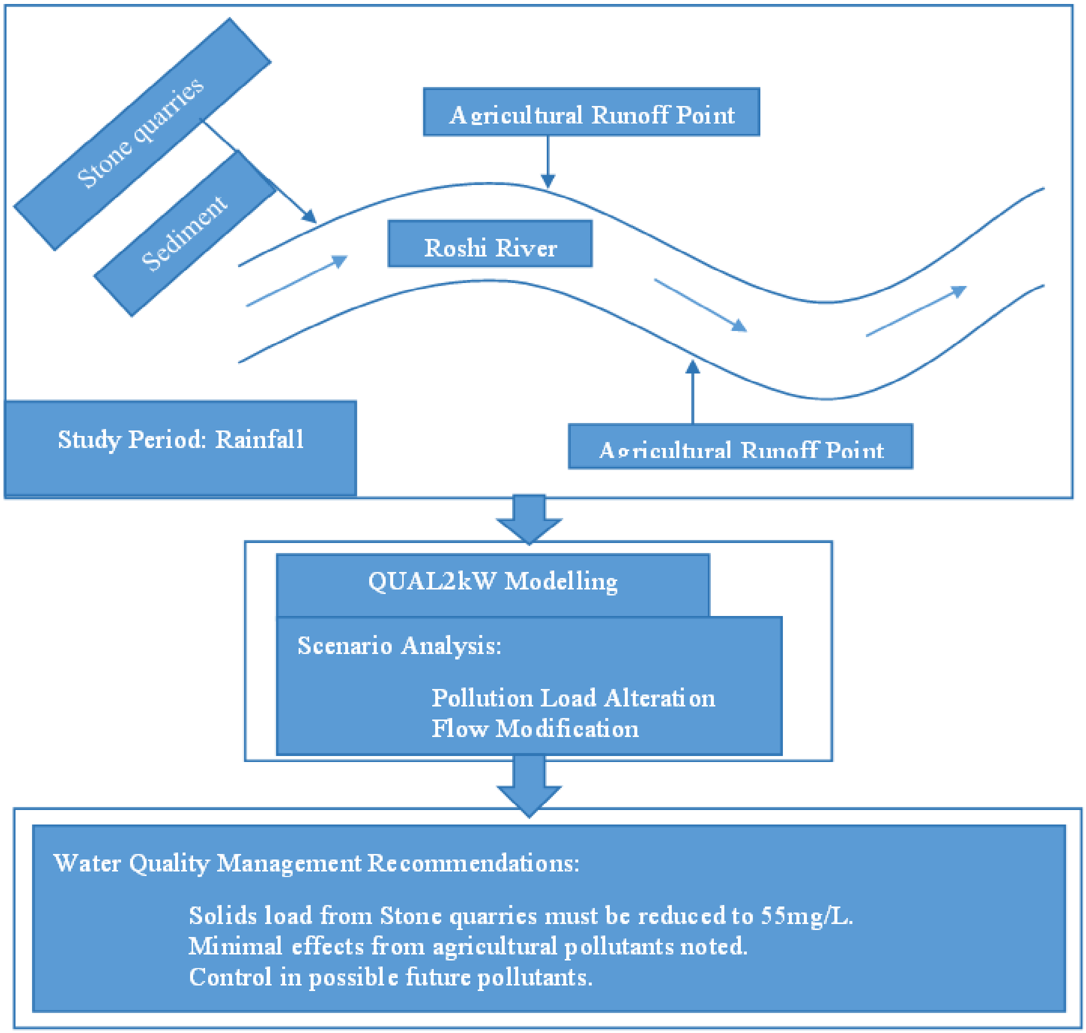


Figure 2 Stream Segmentation and Sampling Stations



Solids load from Stone quarries must be reduced to 55mg/L.
Minimal effects from agricultural pollutants noted.
Control in possible future pollutants.

Figure 3. Study methodology diagram

2.3 Data Collection

The calibration stage of the water quality data collection was conducted during the peak rainfall period in July 2022 [from 24th to 26th July]. On the other hand, the validation stage was performed towards the end of the monsoon season, with the sampling period running from 27th to 31st August 2022. The rainy season is considered the critical time for sampling non-point source pollution because nitrogen and phosphorus export from agricultural lands are highly dependent on rainfall volume. Studies conducted by Chen and Hong (2010) and Camargo et al. (2010) show that the amount of TN and TP is proportional to the flow during base-flow and storm runoff conditions. The concentration of solutes is high during rainfall in the rising limb of the rainfall hydrograph because water particles displace nitrogen and phosphorus from the soil voids. Conversely, lower rainfall is experienced during dry periods in the study area. Therefore, the maximum pollution driven from non-point sources occurs during the monsoon season in the Roshi River, with significant sources of pollution as agricultural runoff and sediment load from the quarry site.

At each sampling station, one sample per day was collected. On-site measurements of temperature and dissolved oxygen were taken. Grab samples were obtained using clear plastic bottles rinsed three times with river water before collection. The samples were then kept refrigerated at 4°C and transported to the Environmental Engineering Laboratory of IOE Pulchok Campus. The samples were kept at -20°C in the laboratory and tested within 10 days. Each sample was thoroughly investigated for pH, BOD, turbidity, FSS, Nitrate-N, Ammonia-N, and TP using the methods described in APHA,1998. In-field discharge measurement was conducted using the Velocity-Area method. The flow velocity was determined by measuring the time taken for a float to travel 30 meters, and the cross-sectional area was determined by measuring the water depths at intervals of 1m from the bank using a measuring tape. The cross-sectional area was then plotted to obtain accurate measurements.

Table 2. Sampling Analysis Method

Parameter	**Mode of Measurement**	**Referred Laboratory Analysis Procedure**
Temperature	On-Site Measurement using a thermometer	
pH	Standard pH meter	
Turbidity	Standard Turbidity Meter, UR Biocoction	
Dissolved Oxygen (DO)	On-Site Measurement using DO probes	Standard Methods for the Examination of Water and Wastewater (APHA)
Fixed Suspended Solids (FSS)	Solid analysis in the laboratory	Standard Methods for the Examination of Water and Wastewater (APHA)
Nitrate (NO_3^-)	UV Spectrophotometric Measurements, UV Spectrophotometer	Standard Methods for the Examination of Water and Wastewater (APHA)
Ammonia (NH_4^+)	Phenate Method using UV Spectrophotometer	Standard Methods for the Examination of Water and Wastewater (APHA)
Total Phosphorus (TP)	Persulphate Digestion Method	Standard Methods for the Examination of Water and Wastewater (APHA)
Biological Oxygen Demand	Winklers Method for DO determination post 5 days incubation @ 20°C	Standard Methods for the Examination of Water and Wastewater (APHA)

2.4 Modeling Software under Consideration

The basic working principle of QUAL2kW is the general mass balance [Figure 4]. QUAL2kW uses a method of steady-state numerical integration of the concentration of each constituent over space and time, considering the one-dimensional advection-dispersion mass transport of constituents (Ye et al., 2013c). The concentration of a particular pollutant in the downstream region is obtained with the help of the concentration of the parameter in the upstream region with the inducement of various driving force parameters and atmospheric parameters.

General Mass-balance equation adopted by QUAL2kW is,

$$\frac{dC_i}{dt} = \frac{Q_{i-1}}{V_i}C_{i-1} - \frac{Q_i}{V_i}C_i - \frac{Q_{ab,i}}{V_i}C_i + \frac{E_{i-1}}{V_i}(C_{i-1} - C_i) + \frac{E_i^r}{V_i}(C_{i+1} - C_i) + \frac{W_i}{V_i} + S_i \qquad (1)$$

Where,

Q_i = flow ($\frac{m^3}{d}$), ab = abstraction

V_i = Volume (m^3)

$E_i^{'}$ = the bulk dispersion coefficient between reaches i and i+1 ($\frac{m^3}{d}$)

W_i = the external loading of the constituent to reach i (g/d or mg/d)

S_i = sources and sinks of the constituent due to the reactions and mass transfer mechanisms (g/m^3/d or mg/ m^3/d) (Pelletier et al., 2006)

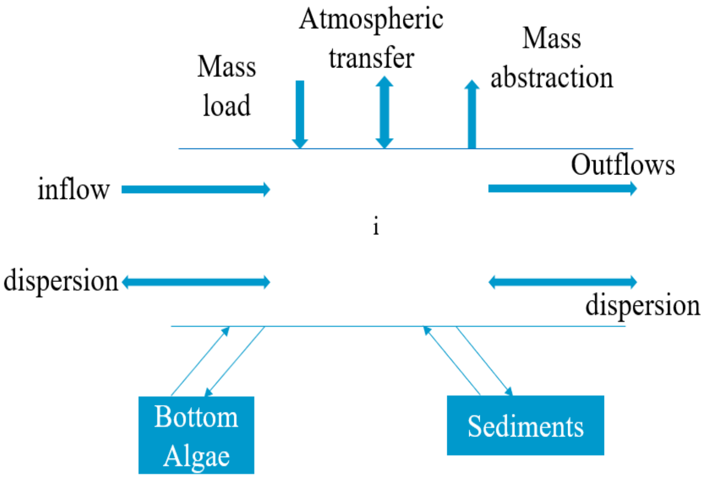


Figure 4. General Mass-flow diagram for a considered section

QUAL2kw has the property of auto-calibration. For auto-calibration, the model uses a genetic algorithm (GA) to maximize the goodness of fit of the model results compared with measured data by adjusting many parameters (Kannel et al., 2007). Calibration using trial and error can also be done. Trial and error can be made until the simulated result aligns with the observed data. Trial and error is a method in which the errors are reduced until a satisfactory result is obtained by performing trials of the various model parameters (Zhang et al., 2012).

$$f(x)=\left[\sum_{i=1}^{N}(W_i)\right]\left[\sum_{i=1}^{N}\left(\frac{1}{W_i}\right)\left[\frac{\sum_{j=1}^{m}\left(\frac{O_{ij}}{m}\right)}{\left(\sum\left(P_{ij}-O_{ij}\right)^2/m\right)^2}\right]\right] \qquad (2)$$

Where,O_{ij} = observed values

P_{ij} = Predicted values

M = number of pairs of measured and predicted values

W_i = weighting factors

n= number of different state variables included in the reciprocal of weighted normalized RMSE

2.5 Model Calibration

The analysis of various scenarios was based on model calibration using the three-day datasets obtained during the peak rainfall period of July 2022. Various inputs provided for the model are:

- Headwater flow and water quality properties: Done with the help of field sampling and measurements. Laboratory analysis of samples for parameters except DO and temperature.
- Reach geometry: Obtained from field measurements.
- Climatological dataset: Air temperature, Dew point temperature, Wind speed, Cloud cover, Shade, and Solar radiation were gathered from the Pachkhal climatological station provided by the Department of Hydrology and Meteorology and fed into the model.
- Point source pollution properties: For pollution sources, A1 and A2, flow values and water quality parameters are fed.

The concentration of any chemical ion at a given point in the stream depends upon the hydrological parameters and inflow pollution loads, which can be estimated through chemical mass balance studies (Purandara et al., 2004). In a similar study done by Jain et al. (1998), the concept of mass balance is used for the assessment of point and non-point sources of pollution in the river Kali to determine the non-point source pollution load as per the upstream water quality, point source of pollution load and downstream water quality. The various processes simulated by QUAL2kW are represented by various equations which contain many parameters that can be fed from QUAL2kW user-manual and similar research (Kannel et al., 2007). A compelling feature of QUAL2kW is that it includes an option for auto-calibration. In this option, the fed rate constants are iterated until the maximum possible goodness of fit is established between the observed and predicted datasets.

During the modeling operation, some of the constant rate parameters are fed manually, and the auto-calibration is turned off by selecting "No" whereas some of the rate constants are left for auto-calibration by turning the auto-calibration feature "Yes" for the respective parameter. Once fixed during the calibration stage, these rate constants are kept unchanged at the stage of validation and analysis. The calculation time step was set at 5.625 min to avoid instability in the model.

2.6 Model Validation

Validation of the model is crucial to demonstrate its efficacy and applicability in various stream-related projects. During the period of 27th August 2022 to 31st August 2022, additional field samples were collected for model validation. The rate constants derived during the calibration stage using data from the peak rainfall period were also utilized in the validation stage. Root Mean Square Error (RMSE) values were obtained between the in-field observed and model-predicted value to check the model predictability for various parameters.

2.7 Scenario Analysis

The carrying capacity of the stream was analyzed using scenario analysis in the model. The stream's carrying capacity was determined by altering various input values and studying the simulated model's response. The scenarios used in the study were pollution load modification and flow augmentation, where pollution load and flow were altered until the stream water quality remained just within the water quality standard requirements for DO, BOD, NO3, NH4, TP, and FSS.

The water quality parameter levels set for the analysis were based on various Water Quality Guidelines for Nepal, including Nepal Drinking Water Quality Standards (2022), water quality guidelines for irrigation water, water quality guidelines for aquaculture, water quality guidelines for recreation, and water quality guidelines for aquatic ecosystems (CBS, 2019). The values used for the analysis can be summarized in Table 3.

Table 3. Water quality standards and permissible values used for analysis

SN.	Parameter	Permissible Range	Referred Standard
1	Dissolved Oxygen (DO)	>5 mg/L	Nepal Water Quality Guidelines for the Protection of Aquatic Ecosystem, Department of Irrigation, Ground Water Project (Nepal Gazette (Number 10, 16 June 2008)
2	Biological Oxygen Demand (BOD)	<15 mg/L	Nepal Water Quality Guidelines for Aquaculture Department of Irrigation, Ground Water Project (Nepal Gazette (Number 10, 16 June 2008)
3	Nitrate	<50 mg/L	Nepal's Drinking Water Quality Standards, 2022
4	Ammonia	<1.5mg/L	Nepal's Drinking Water Quality Standards, 2022
5	FSS	<50 mg/L	Nepal Water Quality Guidelines for Irrigation Water Department of Irrigation, Ground Water Project (Nepal Gazette (Number 10.16 June 2008))
6	Total Phosphorus	<0.6 mg/L	Nepal Water Quality Guidelines for Aquaculture

Various scenarios assumed in the study are:

- Pollution Load Alteration at A1
    - Average discharge of A1 + Alteration in water quality parameters of A1
    - Maximum possible Discharge of A1 + Alteration in water quality parameters of A1
    - Discharge covering half the depth of Hume pipe A1 +\\ Alteration in inflow water quality parameters of A1

-Sediment load alteration in Headwater
-Flow Augmentation
-Flow Augmentation + Pollution load modification at A1

- Headwater discharge (-20%) + alteration in inflow parameters of A1
- Headwater discharge (-40%) + alteration in inflow parameters of A1

3. Results and Discussion

3.1 Current Water Quality Situation in the Stream

From sample analysis done at the calibration and validation stages, it was found that the pollution levels in the stream are high in terms of turbidity and FSS [Table 4 and Table 5]. Other parameters show a varying trend. Observed pollution loads from the agricultural runoff into the stream are Ammonia and Phosphorus, and those from stone quarries are FSS and turbidity.

pH, temperature, DO, and nitrate were observed to be within the acceptable limit [as listed in Table 3]. Every section had a DO value greater than 5 mg/L, representing that the stream can support the aquatic system well. Slightly lower DO values were observed at the agricultural input points.

Looking at the trend of ammonia concentration, a higher ammonia concentration is seen in the inflow of agricultural runoff, indicating agrochemical interaction. The values are greater than mentioned in the maximum permissible standards for protecting aquatic systems, i.e., 7 µg/L and within the allowable range for drinking water purposes.

The maximum ammonia concentration is observed during the sampling period in which a very high rainfall is experienced (i.e., day 3 of the calibration sampling period), which is 0.936 mg/L. The phosphorus concentration is higher from the agricultural runoff inflows but within permissible limits. Likewise, FSS concentration and turbidity at various sections are found to be higher than the permissible range. A maximum turbidity of 282.67NTU and FSS concentration of 867 mg/L was observed at sampling station S1 and a turbidity of 112NTU and FSS concentration of 780 mg/L was observed in Headwater. Higher turbidity and FSS in Headwater are due to sediment load from upstream stone quarries. Higher turbidity and FSS in S1 are due to agitation raised by streamflow properties. It can be marked that the water turbidity and solid concentration are high during the high rainfall sampling period.

3.2 Calibration and Validation

The calibration and validation results are presented in graphs [section 3.3 and section 3.4], where actual in-field values are depicted as dots and model-predicted values are represented as lines. Root mean square error (RMSE) is calculated between the observed and simulated values for both calibration and validation periods [Table 6]. A lower RMSE value indicates that the model is performing well. The RMSE values obtained during both stages are within an acceptable range, showing that the model can accurately predict actual in-field scenarios and is suitable for further analysis.

Table 4. Calibration stage data results: (Peak rainfall period July,2022), (Mean +/- sd)

Section Code	**Q, m^3/s**	**T(°C)**	**DO (mg/L)**	**pH**	**Turbidity (NTU)**	**FSS**	**NH3(μg/L)**	**NO3(μg/L)**	**TP(μg/L)**	**BOD (mg/L)**
HW	7.033 +/- 1.412	21.033 +/- 1.619	8.1 +/- 0.173	8.1 +/- 0.1	112.333 +/- 65.01	780 +/- 242.487	171 +/- 48.607	127 +/- 658.423	201 +/- 20.083	5.549 +/- 0.649
A1	0.297 +/- 0.05	23.033 +/- 0.611	7.166 +/- 0.416	7.766 +/- 0.152	86.666 +/- 83.032	326.666 +/- 190.087	635 +/- 296.312	150 +/- 478.61	657 +/- 166.223	5.725 +/- 0.736
S1	6.587 +/- 1.347	20.933 +/- 1.53	7.866 +/- 0.585	8.066 +/- .0577	268.333 +/- 92.354	866.666 +/- 190.087	169 +/- 28.787	131 +/- 449.43	285 +/- 79.077	4.872 +/- 0.58
S2	6.362 +/- 0.907	20.666 +/- 1.747	7.866 +/- 0.493	7.966 +/-0.0577	282.666 +/- 73.799	706.666 +/- 190.087	180 +/- 35.131	139 +/- 351.07	249 +/- 10.925	5.094 +/- 0.977
A2	0.0054 +/- 0.001	23.566 +/-1.861	6.933 +/- 0.115	7.9 +/- 1.087	43.666 +/- 19.139	200 +/- 34.641	143 +/-33.237	860 +/- 114.88	105 +/- 433.743	4.05 +/- 0.269
TW	6.274 +/- 0.745	21.433 +/- 1.274	7.966 +/- 0.251	7.9 +/-0.173	163.333 +/- 17.243	660 +/- 170.88	184 +/- 56.195	161 +/- 276.83	192 +/- 54.013	5.416 +/- 0.566

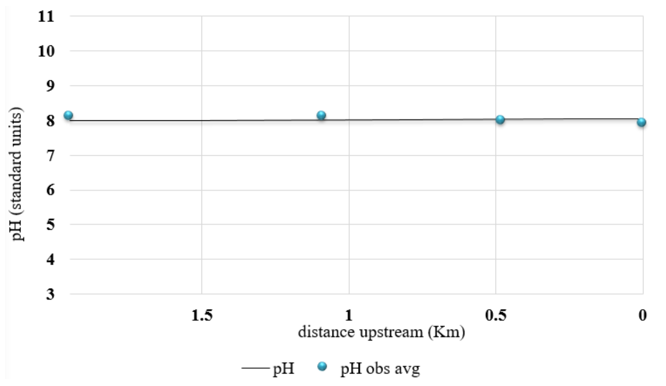
Table 5. Validation stage data results: (End of the monsoon, August 2022), (Mean +/- sd)

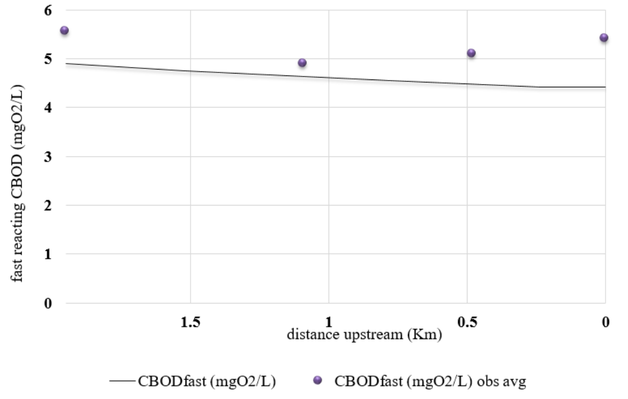
Section Code	**Q, m^3/sec**	**T(°C)**	**DO (mg/L)**	**pH**	**Turbidity (NTU)**	**FSS**	**NH3(μg/L)**	**NO3(μg/L)**	**TP(μg/L)**	**BOD (mg/L)**
HW	4.775 +/- 0.522	18.88 +/-1.275	8.5 +/- 0.244	8.2 +/- 0.234	45 +/- 48.734	472 +/- 231.775	472.21 +/- 92.878	1671.857 +/- 122.354	147.207 +/- 33.569	2.155 +/- 0.345
A1	0.0608 +/- 0.0186	21.62 +/-1.304	7.52 +/- 0.396	8.02 +/- 0.443	15 +/- 10.464	136 +/- 66.932	1071.89 +/-630.225	2071.474 +/- 123.616	753.376 +/- 261.509	4.609 +/- 1.195
S1	4.0587 +/- 0.934	19.22 +/-1.531	8.6 +/- 0.234	8.16 +/- 0.371	42.2 +/- 37.319	316 +/- 267.357	473.952 +/- 25.57	1684.365 +/- 116.717	180.649 +/- 96.402	3.315 +/- 0.573
S2	3.586 +/- 0.167	19.4 +/- 1.369	8.46 +/- 0.25	8.1 +/- 0.353	40.4 +/- 38.122	304 +/- 243.885	472.119 +/- 44.966	1646.075 +/-158.503	177.402 +/- 104.017	3.148 +/- 0.489
A2	0.0035 +/- 0.0017	20.66 +/-1.273	7.66 +/- 0.27	8 +/- 0.441	33.8 +/- 17.383	120 +/- 67.823	485.269 +/- 55.858	1364.39 +/-120.997	777.272 +/- 243.389	2.428 +/- 0.182
TW	3.783 +/- 0.761	19.74 +/-1.209	8.34 +/- 0.23	8.08 +/- 0.327	34.6 +/-25.608	272 +/- 217.531	475.647 +/- 29.611	1618.506 +/-148.025	175.324 +/- 109.302	2.692 +/- 0.725

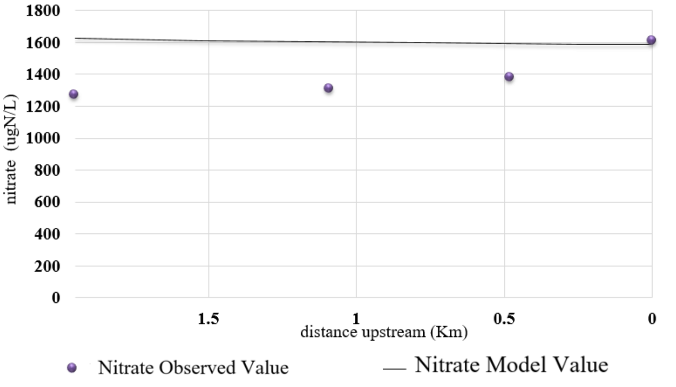
Table 6. RMSE Values for Calibration and Validation Stages

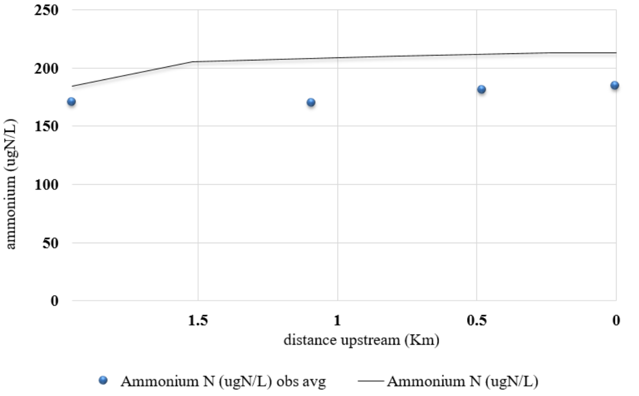
SN.	Parameter	RMSE Calibration	RMSE Validation
1	pH	0.669	1.54
2	Temperature	4.378	3.564
3	DO	2.903	4.484
4	BOD	5.48	11.869
5	FSS	16.005	15.215
6	Ammonia	6.913	0.281
7	Nitrate	9.679	1.466
8	Total Phosphorus	7.793	5.852

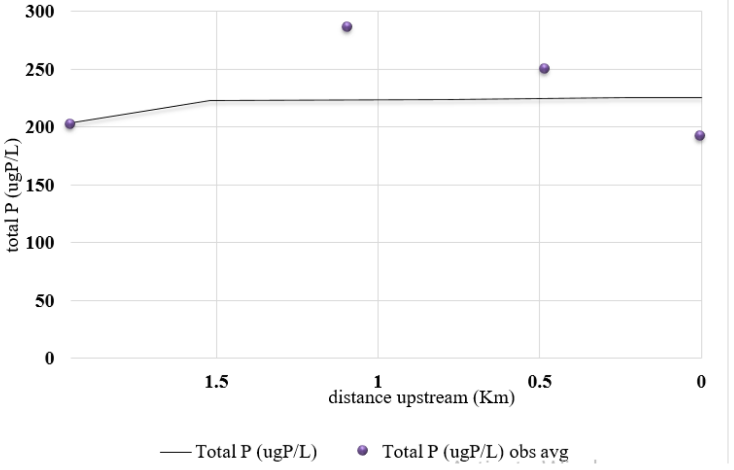
3.3 Calibration Stage Graphs

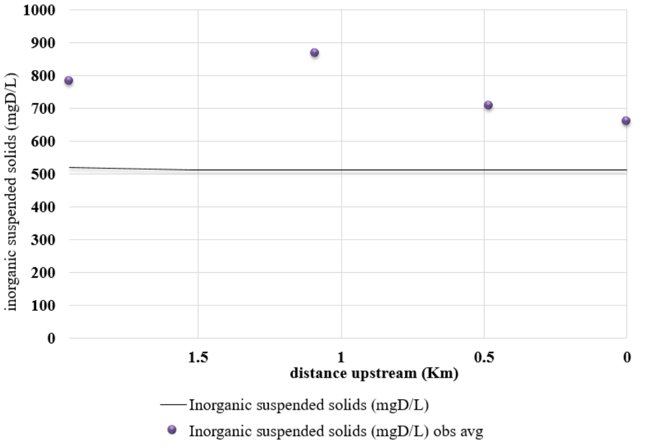


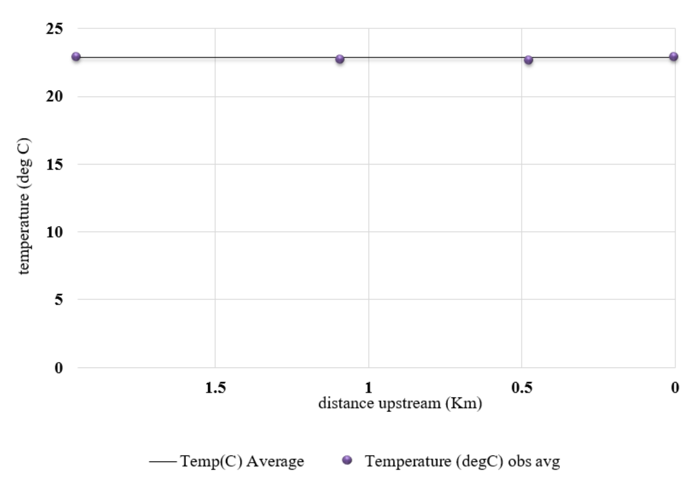


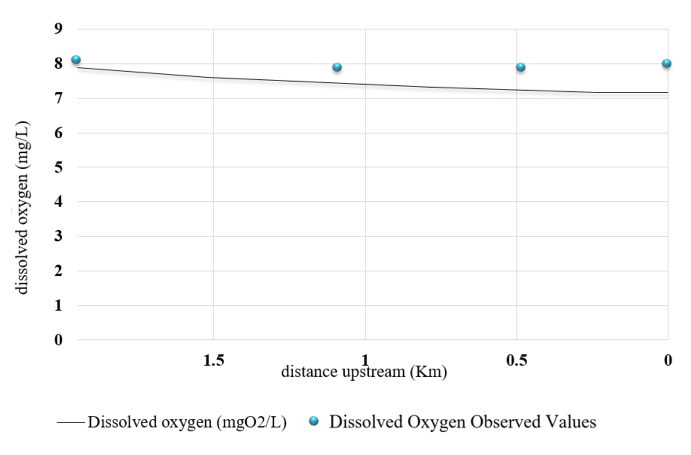




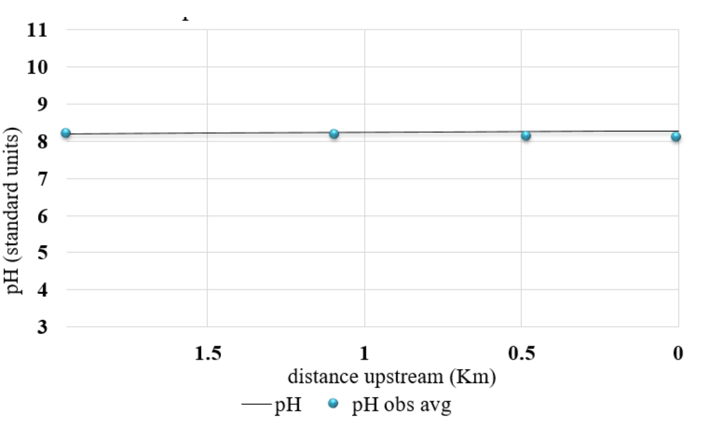


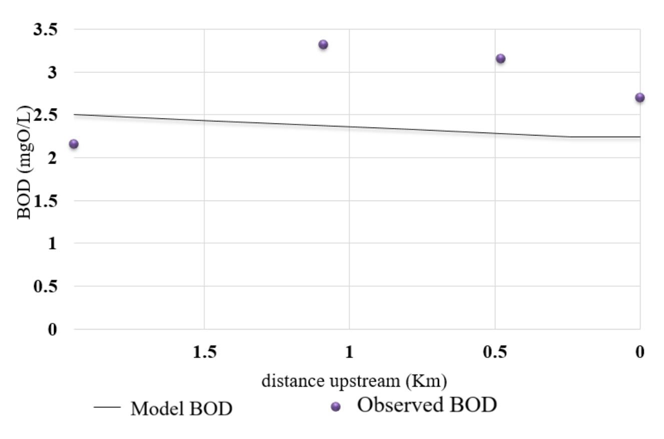


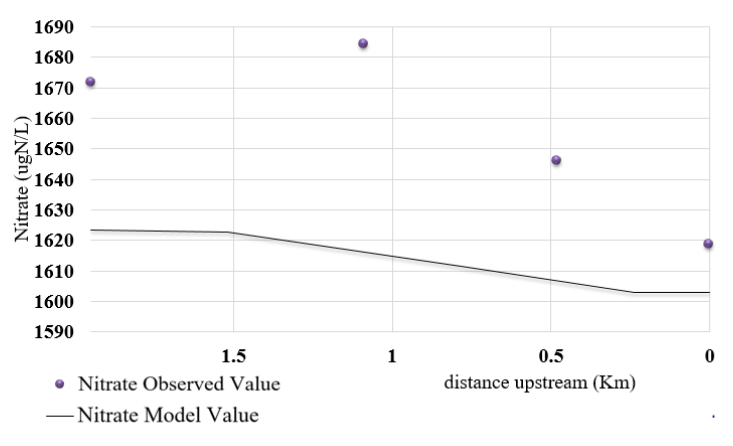


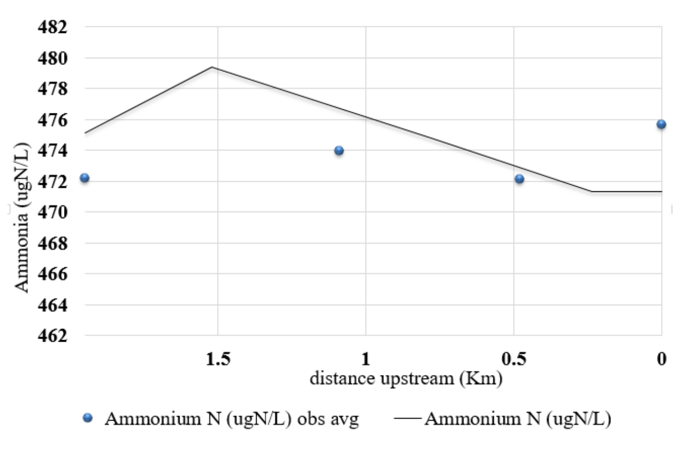


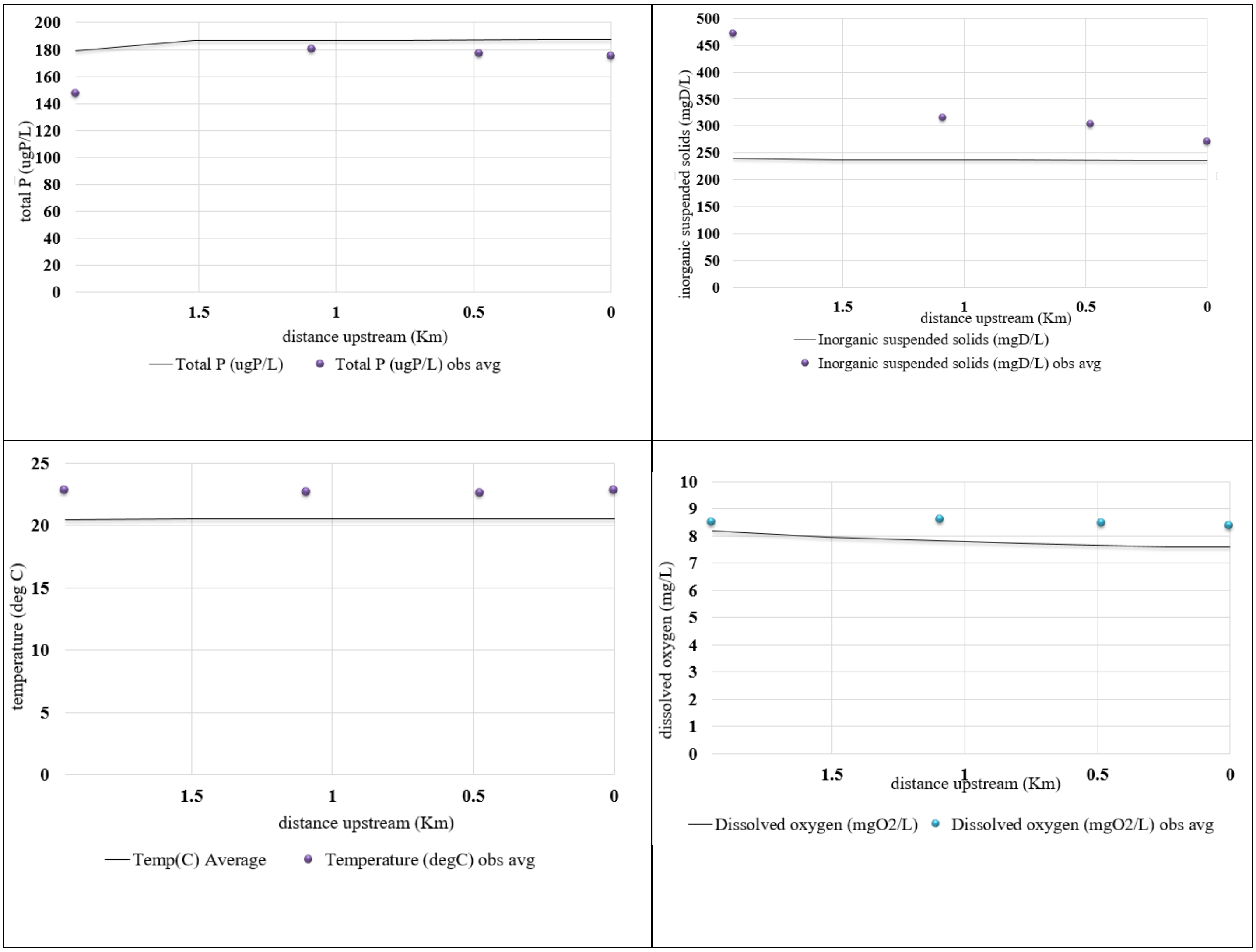
3.4 Validation Stage Graphs











3.5 Carrying Capacity Analysis

The determination of carrying capacity is based on scenario analysis. Four different scenarios were analyzed. The scenario parameters were altered continuously, and the model response was noted. Alteration of the parameters was done until the water quality degraded upto the point where they lay just within the permissible level. This point is considered as the carrying capacity for the scenario.

3.5.1 Scenario: Pollution source A1 alteration

In the scenario of Average discharge of A1 + Alteration in water quality parameters of A1, the pollution load capacity regarding the parameters BOD, Ammonia, Nitrate, TP and DO are 275mg/L, 33 mg/L, 1250 mg/L, 10 mg/L, and 0 mg/L respectively. Similarly, in the scenario of Maximum possible Discharge of A1 + Alteration in water quality parameters of A1, the pollution load capacity regarding the parameters BOD, Ammonia, Nitrate, TP and DO are 35 mg/L, 4.25 mg/L, 150mg/L, 1.34 mg/l and 0mg/L respectively. Moreover, the scenario of discharge covering half the depth of Hume pipe A1 + Alteration in inflow water quality parameters of A1: shows 60 mg/L,7.55 mg/L,260 mg/l, 2.5 mg/L, and 0mg/L of BOD, Ammonia, Nitrate, TP and DO respectively. These values are the maximum limiting level of pollution that can be allowed to be imparted through A1.

Scenario 1: Pollution Capacity at Pollution Source A1 alteration

Scenario 1.1: Average discharge of A1 + alteration in water quality parameters of A1

BOD (mg/L)	Ammonia(mg/L)	Nitrate(mg/L)	Total Phosphorus(mg/L)	DO (mg/L)
275	33	1250	10	0

Scenario 1.2: Maximum possible Discharge of A1 + alteration in water quality parameters of A1

BOD (mg/L)	Ammonia(mg/L)	Nitrate(mg/L)	Total Phosphorus(mg/L)	DO (mg/L)
35	4.25	150	1.34	0

Scenario 1.3. Discharge covering half the depth of Hume pipe A1 + Alteration in inflow water quality parameters of A1

BOD (mg/L)	Ammonia(mg/L)	Nitrate(mg/L)	Total Phosphorus(mg/L)	DO (mg/L)
60	7.55	260	2.5	0

3.5.2 Scenario: FSS load Alteration at Headwater

It is observed that the maximum permissible pollution load through the Headwater regarding the FSS is 55 mg/L.

3.5.3 Scenario: Flow Augmentation

The headwater flow values were altered by +10 percent, +20 percent, -10 percent, -20 percent, and -40 percent, respectively. At a 40 percent decrease in flow, the percentage of increase in BOD, Ammonia, Nitrate, TP, and DO are 2.82 percent, 8.6064 percent, 1.115 percent, 5.682 percent, and 2.446 percent, respectively. It is observed that flow augmentation does not have much significant effect on the Alteration of the stream water quality as even a high decrement in discharge shows a low increase in pollutant parameter concentration.

Scenario 3: Pollution Capacity on Flow Augmentation

Augmentation by	BOD (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Total Phosphorus (mg/L)	DO (mg/L)
-40%	+2.82%	+8.6064%	+1.115%	+5.682%	+2.446%

3.5.4 Scenario: Flow augmentation + Pollution source A1 alteration

In the scenario of flow Augmentation (-20%) + Pollution load modification at A1, pollution load capacities in terms of BOD, Ammonia, Nitrate, TP, and DO are found to be 210mg/L, 275 mg/L,1000mg/L,8.1mg/L, and 0 mg/L, respectively.

In the scenario of Headwater discharge (-40%) + Alteration in inflow parameters of A1, the pollution load capacity regarding parameters BOD, Ammonia, Nitrate, Total Phosphorus, and DO are 175 mg/L, 21mg/L, 750mg/L, 6.2 mg/L, and 0 mg/L respectively.

Scenario 4: Pollution Capacity on Flow augmentation + Pollution source A1 Alteration

Scenario 4.1: Flow augmentation of -20% + Pollution source A1 alteration

BOD (mg/L)	Ammonia(mg/L)	Nitrate(mg/L)	Total Phosphorus(mg/L)	DO (mg/L)
210	275	1000	8.1	0

Scenario 4.2: Flow augmentation of -40% + Pollution source A1 alteration

BOD (mg/L)	Ammonia(mg/L)	Nitrate(mg/L)	Total Phosphorus(mg/L)	DO (mg/L)
175	21	750	6.2	0

As per data observations and analysis, the stream is critical regarding the FSS loading. Existing headwater properties regarding the solid concentration must be reduced to a greater extent to bring the water quality within standards. The findings align with those of Kannel et al. (2007), who suggested a cumulative pollution load reduction of 30 mg/L CBOD, 5 mg/L TN, 0.25 mg/L TP, along with a flow augmentation of 1 cumec, and the addition of 3 weirs in critical locations based on scenario analysis. Similarly, in the current study, the critical identified pollutant of FSS has to be reduced to 55mg/L in the headwater region to maintain the stream water quality within permissible limits. Formulation of regulations regarding permissible sediment load imparted by the stone quarries is necessary. The inflow load from agricultural pollution sources is found to be impacting the stream water quality very minimally. It is recommended to prevent any possibility of mixing sewage from pollution source A1 into the stream.

4. Conclusion

Stream water quality model QUAL2kw was calibrated and validated using the data of peak monsoon and end of monsoons of 2022. The stream's agricultural runoff from the catchment and sediment load from upstream stone quarries are the primary sources of pollution. Obtained RMSE between the field observed and model-predicted values show that the model-predicted values represent the actual in-field condition quite well. Pollution from agricultural runoff affecting the stream has a specific concentration of Ammonia, Nitrate, and TP. The DO content of the stream and pollution sources are in a healthy range. Four scenarios were analyzed using the model to obtain the carrying capacity of the river Roshi. It was found that the pollution load capacity of the stream at existing pollution sources and existing flow condition is 275 mg/L for BOD, 33 mg/L for ammonia, 1250 mg/L for nitrate, 10 mg/L of phosphorus, and 0mg/L for DO. It can be concluded that the stream is critical in terms of FSS concentration. The Headwater's FSS must be limited to 55 mg/L to maintain the stream water quality. Scenario analysis shows that pollution due to agricultural runoff is less significant. This model is limited to its use in peak diffuse pollution periods of monsoon. Headwater quality enhancement by reducing the upstream stone quarry load is the utmost requirement for Roshi River. Regulation regarding pollution effluent in the stream has to be developed. This model can be a tool to predict the resultant pollution imparted into the waterbody due to possible emissions by the future development activity in the monsoon period. Possible future pollution load can be applied to the model to observe the response of stream, thus, helping in setting emission standards for the pollution load.

Nomenclature

BOD	Biological Oxygen Demand
CBS	Central Bureau of Statistics
DO	Dissolved Oxygen
CBOD	Bio-Chemical Oxygen demand
FSS	Fixed Suspended Solids
ISS	Inorganic Suspended Solids
NTU	Nephelometric Turbidity unit
RMSE	Root Mean Square Error
TN	Total Nitrogen
TP	Total Phosphorus

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