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Water Quality Calibration of Bagmati River Using QUAL2Kw

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Abstract
Qual2Kw, a one-dimensional water quality modeling software, was used for calibration of water quality in Bagmati River. The study was done for river stretch of 9.5 km from Khokanaa to Katuwal Daha. DO, CBOD, pH and Temperature were calibrated for data in 27 October 2021 and validated for data in 14 February 2022. The variation in DO and CBOD of four selected stations from khokana to katuwal daha were very high. DO increased significantly in the downstream reach. The measured data and model predictions were in reasonable agreement. In validation, the coefficient of determination (R^2) for temperature, pH, DO, and CBODs, were 0.82, 0.73, 0.75, and 0.42 respectively.

Keywords
Water Quality, Qual2K, Calibration, Bagmati River

1. Introduction

Water is an essential natural resource for every living thing on Earth. Water is necessary for all forms of life to survive, and most living organisms can only survive for a short time without it. As a matter of fact, any change in natural water quality or distribution has the potential to have disastrous environmental consequences [1]. A large amount of nutrients and organic materials are released into rivers and streams as a result of human's municipal, agricultural, and industrial activities. Dissolved oxygen concentrations in rivers and streams are low as a result of organic waste discharges [2].

Water pollution remains a problematic issue for the long-term development of Kathmandu valley, despite several infrastructures, awareness-raising, and policy measures. The Bagmati River's pollution is a major concern for the Kathmandu valley's long-term development. During the dry season, the quantity and quality of river water are at very alarming levels mostly along the river's course through the valley. Water quality issues in the Bagmati river include low dissolved oxygen concentrations and bacterial contamination. The primary causes of pollution in the Bagmati river are uncontrolled urbanization and population growth, inadequate wastewater treatment facilities, low awareness, lack of regulations, and inadequate ability to adhere to laws of industrial and municipal wastewater generation [3].The Bagmati River and its tributaries are served by some sewer lines. Only a few kilometers of the uppermost section are fit for drinking water. The valley's wastewater management system involves collecting wastewater from a number of sources through open and subsurface sewer lines and discharging it into rivers untreated. Despite the fact that several wastewater treatment plants have been built, only the Guheshwori wastewater treatment plant is currently operational, and only a few new wastewater treatment plants are being built [3]. In Nepal's rivers, there have been very few studies on river water quality modeling. Modeling of the Bagmati river has been done in particular, and these studies are limited to the Bagmati river and its tributaries within the valley.

In this study, Chapra and Pelletier's QUAL2Kw, a widely used mathematical one-dimensional, steady-flow river water quality model, is used. In this model, auto-calibration using a genetic algorithm can be used. Temperature, pH, carbonaceous biochemical demand, sediment oxygen demand, dissolved oxygen, organic nitrogen, ammonia nitrogen, nitrite and nitrate nitrogens, organic phosphorus, inorganic phosphorus, total nitrogen, total phosphorus, phytoplankton, and bottom algae are the constituents it can simulate [4, 5]. Thus, QUAL2Kw was selected to study and understand the water quality of Bagmati river.

1.1 Literature Review

Water quality modelling of Bagmati river has been done by [6] for year 2004 using QUAL2Kw where the model was calibrated and validated for the river and the observed and predicted water quality parameters had minor exceptions. The research showed that the wastewater management strategies can increase the DO levels and local oxygenation was effective in increasing levels of DO. Similarly, the water quality model of Bagmati river using QUAL2Kw was calibrated and confirmed from the data in 2000 by [5]. The model was found to be highly sensitive to water depth and moderately sensitive to point sources flow, TN, CBOD, and nitrification rate, according to the study. This study also showed that the water quality management strategies such as wastewater modification, flow augmentation and local oxygenation were effective to maintain the acceptable limits of water quality criteria. In the research done by [7], QUAL2Kw model was developed for river Yamuna in Delhi and the variation in modeled and predicted water quality parameter were satisfactory and predicted DO, CBODf, TN and TC were highly sensitive for headwater flow, point source flow and quality. Dissolved oxygen modeling in Silver Bow creek was done using QUAL2K by [8] , the model satisfactorily predicted DO swings and longitudinal oxygen profiles.

1.2 Objectives

The objectives of this study are:

1. To calibrate the water quality parameters DO, CBOD, pH and Temperature.
2. To understand the variation in DO, CBOD, pH and Temperature along the selected stretch of the river.

2. Research Methodology

2.1 Study Area

The Bagmati River basin is situated approximately in the central part of Nepal. The river has 650 km2 of drainage area within Kathmandu valley [5]. The river escapes from valley from Chobar gorge and flows through steep mountain valleys towards terai region of Nepal. In this study, the initial point is taken from Khokana suspension bridge which is downstream from Chobar gorge. River stretch between Khokana suspension bridge and Katwal Daha was selected for the study. The study covered a 9.5 kilometer stretch of the Bagmati river. The river is often straight and follows meandering path in this stretch. The population is sparingly distributed near the selected stretch. The elevation of the stretch varies from 1254 m to 1195 m and width of the river is in decreasing order as it flows from Khokana to Katwal daha. The selected river has mild slope till its half portion and remaining stretch has steep slope with boulders in the river. The study area with monitoring station in main stem of river is shown in Figure 1. In the selected stretch, following streams flow into the Bagmati river: Kharpa Khola, Kabhre Khola, Seshnarayan Khola, and two small streams. Flow through these streams were very less as compared to the Bagmati river.

2.2 Data Collection

In the study, the primary data contains hydraulic data measurements from the main river and its tributaries to determine the river flow as input data for the QUAL2K model. The primary data additionally contains water sample collection, in-situ measurements and water quality measurements in lab for QUAL2K model result evaluation. Secondary data for this research was gathered from various sources and agencies like the Department of Hydrology and Meteorology (DHM), literature, survey department, Google Earth etc.

2.3 Water Quality Monitoring Data

The monitoring stations taken for this study covered four stations along the main stem of the river and five tributaries. The data were collected on 27 October 2021 (post-monsoon season) for calibration and 14 February 2022 (pre-monsoon season) for validation. The Department of Hydrology and Meteorology provided meteorological data such as air temperature, wind speed, and relative humidity. The field work consisted of measuring discharges, and collecting a single sample for each station. Water quality parameters measured in this study include: flow, water temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), total suspended solids (TSS), total alkalinity as $CaCO_3$ (alkalinity), total phosphorous (TP), ammonium nitrogen (NH_4N), nitrate as nitrogen (sum of NO_3N and NO_2N), total kjeldahl nitrogen (TKN), 5 days biochemical oxygen demand as O_2 (CBOD or BOD) and chemical oxygen

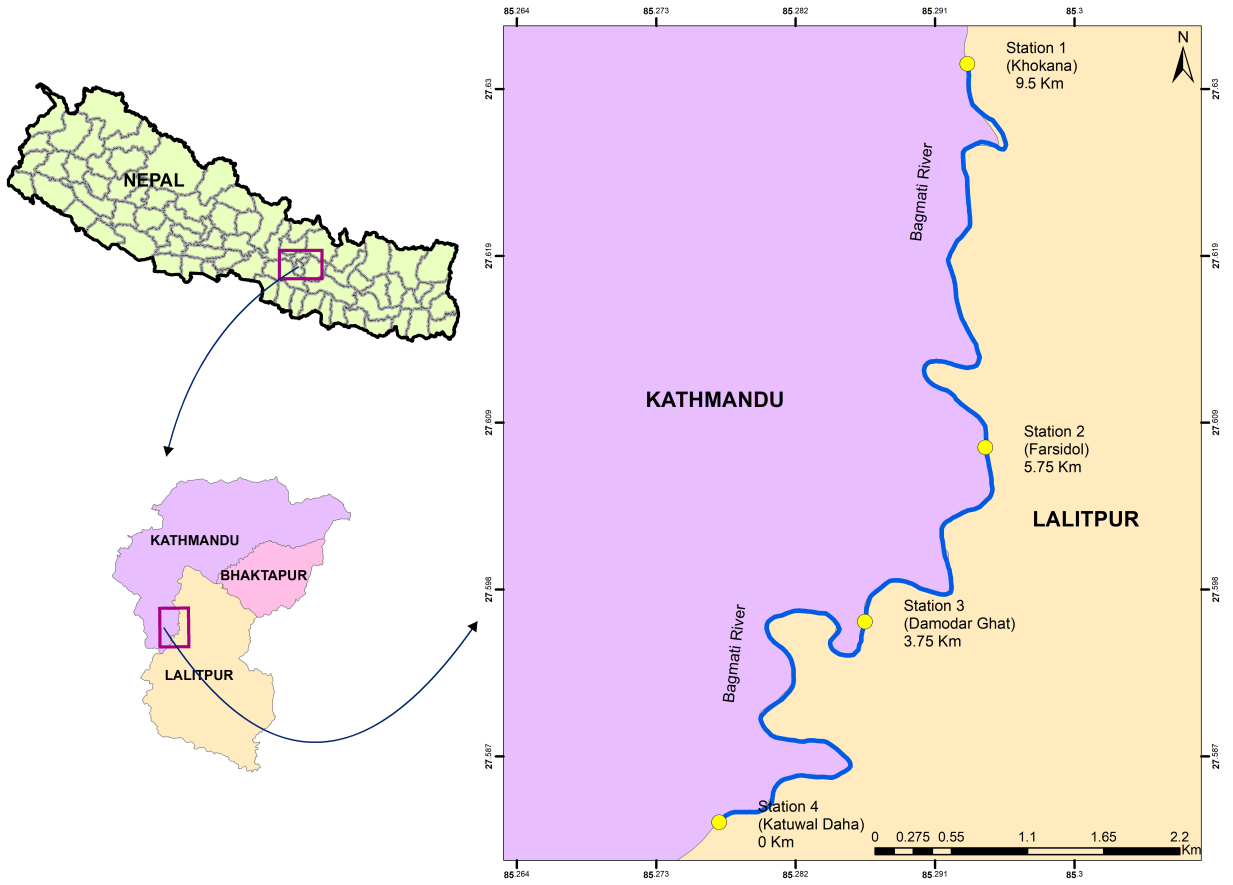

Figure 1: Monitoring stations along the main stem of Bagmati river

demand as O_2 (COD).The parameters for in-situ measurements were pH, temperature and DO, while the other parameters were collected for laboratory analysis. The water quality of tributaries of the Bagmati river other than Kabhre khola and kharpa khola were not measured and considered to be similar to Kabhre Khola and Kharpa Khola.

2.4 Model Calibration

In model calibration, river segmentation is the first step of water quality model development in Qual2K.The 9.5 kilometer Bagmati river was divided into 20 reaches with lengths ranging from 0.25 to 1.25 meters based on the hydraulic geometry.The headwater section of the river, which includes monitoring station 1, was used to define upstream boundary conditions in the model. For the downstream boundary condition, the internal calculation option was chosen. River geometries obtained from DEM, Google earth and DHM were used to determine the hydraulic characteristics at each sampling locations. The model allows the use of manning's equation to define the river hydraulics. The water quality input parameters included in the model were flow, temperature, pH, DO, BOD, electrical conductivity, alkalinity, suspended solids, organic nitrogen, ammonia nitrogen, nitrite+nitrate nitrogen, organic phosphorus and inorganic phosphorus. The ranges of model rate parameters were obtained from various literatures including Environment Protection Agency (EPA) guidance document [9], QUAL2Kw user manual [4] and Documentation for the enhanced stream water quality model QUAL2E and QUAL2E-UNCAS [9].

2.5 Model Implementation

The calibration was performed using data collected on October 27, 2021. For model stability, the calculation time step was set to 0.703125 minutes. Euler's method was used to solve the integration problem. The goodness of fit was determined by assigning different weights to different parameters. Different weights were applied to trials to reduce the error between measured and modeled water quality values.

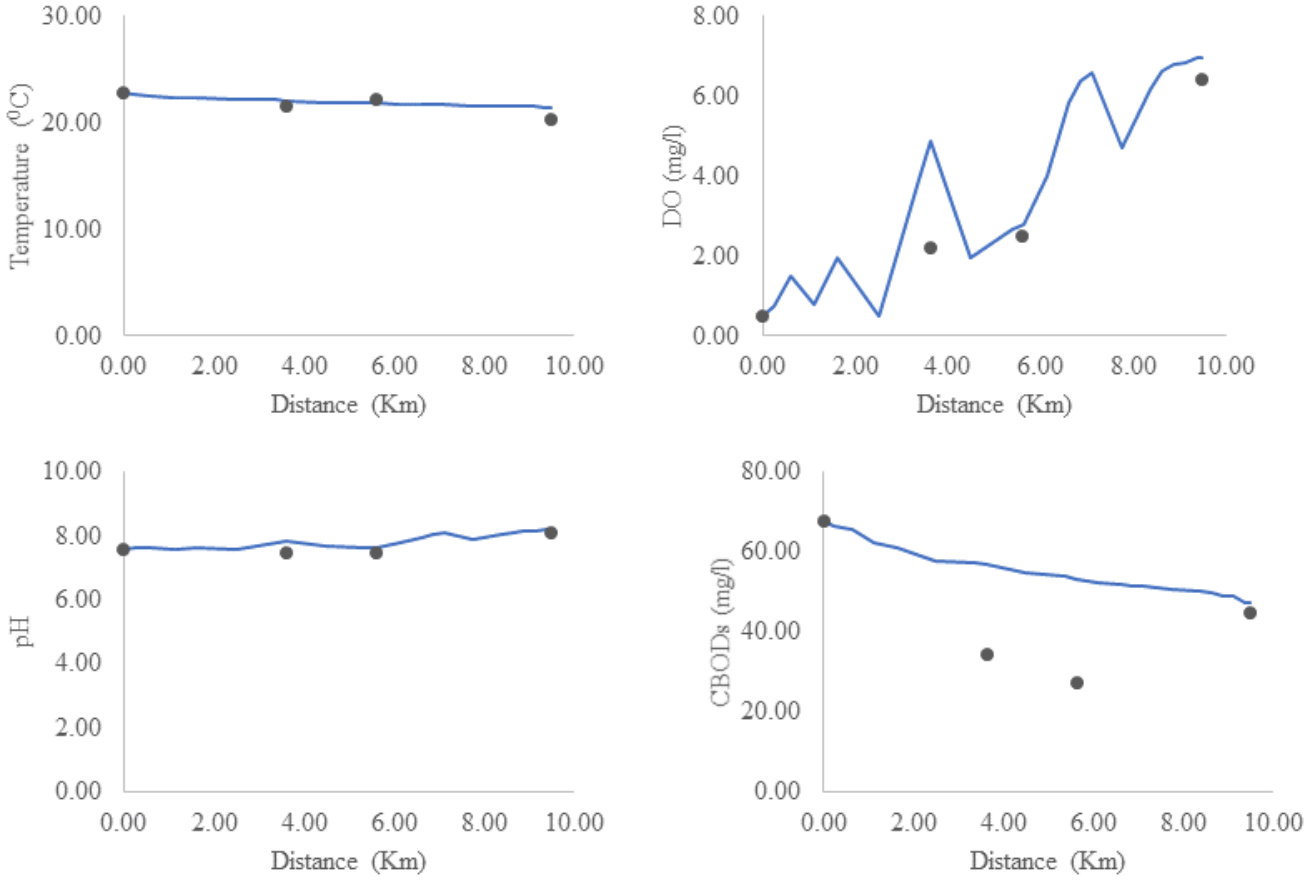

Figure 2: Calibration of water qualities in Bagmati river

The system parameters were automatically calibrated using a genetic algorithm available in Qual2kw version 6. The model was run until the system parameters were properly calibrated and the model results and field measurements were in good correlation. For automatic calibration, population size and generation were set to 100 and 50 respectively. A population size of 100 generates better results compared to a size of 500 and lower values [4]. All other parameters in genetic algorithm table were left as default.

3. Conclusion And Discussion

Qual2K simulates several hydraulic and water quality parameters. Initially, hydraulic calibration was done to obtain manning's roughness coefficient (n) then calibration followed by validation was done. In water quality parameters, DO, slow reacting CBOD (CBODs), temperature, and pH were selected for calibration and validation. The measured data and model predictions were in reasonable agreement. The coefficient of determination (R^2) between the simulated and observed values for temperature, pH, DO, and CBODs, were 0.73, 0.72, 0.80, and 0.46 respectively in calibration. In validation, The coefficient of determination (R^2) between the simulated and observed values for temperature, pH, DO, and CBODs, were 0.82, 0.73, 0.75, and 0.42 respectively Due to fund and time limits, the fieldwork consisted of collecting a single sample at each station so some errors in the modeling were unavoidable. The model predicted the daily average value but the sampling time may not represented the average values as DO,pH and temperature varies with time. Despite the limitations, the model calibration and validation results were satisfactory. Monitoring various inputs on a regular basis and using 2D or 3D models better accuracy could be achieved. The calibration and validation graph obtained from Qual2Kw are shown in Figure 2 and Figure 3 where continuous solid lines and the points represent predicted and observed values respectively.

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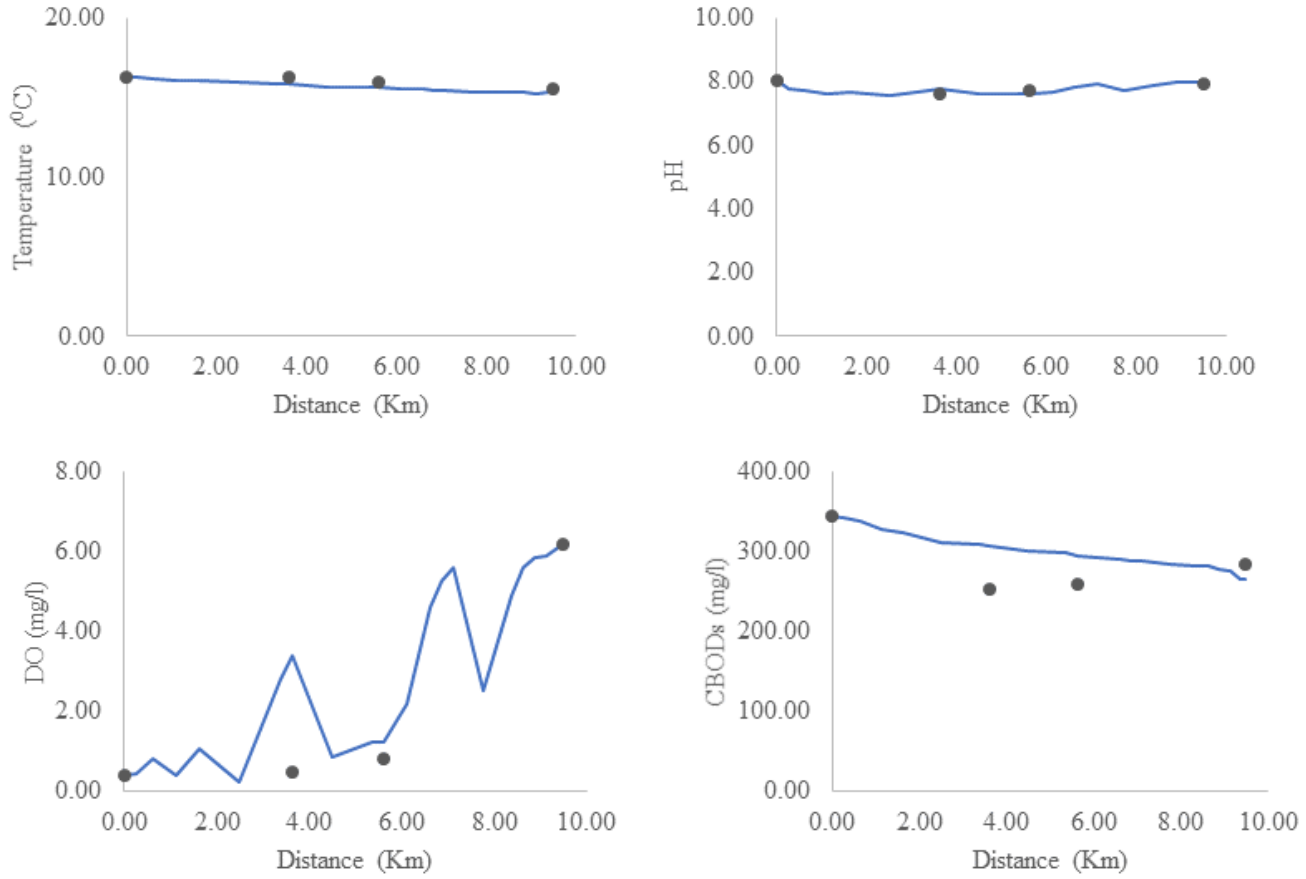

Figure 3: Validation of water qualities in Bagmati river

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