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# One-Dimensional Model Predictions of Carbonaceous Biological Oxygen Demand and Dissolved Oxygen for Hilla River Water Quality, Iraq

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## ABSTRACT

The water quality of the Hilla River, located in Iraq, has been varying due to the presence of different illegal point and non-points sources along the river stream. This study highlighted the carbonaceous biological oxygen demand (CBOD) and dissolved oxygen (DO) levels for safe usage by applying the river and stream water quality model called QUẠL2K model, depending on the hydraulic and water quality data collected along 6.8 km passing through the main city (Hilla City) on October 2022 (low flow season) and January 2023 (high flow season). The modeling results showed that the simulated predictions are in good agreement with field data. The outputs revealed the two parameters (CBOD and DO) ranged between (1.425–3.075) mg/L and (9.5–10.65) mg/L, respectively, during low flow season and between (0.745–2) mg/L and (9.5–10.5) mg/L, respectively, during high flow season. The river CBOD levels along the river follow same pattern during the high and low flow seasons, but the DO levels behaved inversely. However, both parameters were within the acceptable limits. Thus, the river health can be considered good for basic human usage.

**Keywords:** CBOD, DO, QUẠL2K, Hilla River, water quality modeling.

## INTRODUCTION

Rivers and streams provide water for municipal and industrial applications in addition to recreation (such as for swimming and fishing), transportation, and waste disposal. The quantity of outfalls dumped into the waterway and its ability to be integrated have a direct influence on the river water quality. It is often useful to utilize water quality models to improve the performance and river management (Mohamed, 2003). Environmental contamination is thought to be a very important concern for humanity. Iraqi rivers have been widely polluted by rapid population increase, industrialization, urbanization, and land development (Al Kindi et al., 2021). Due to its significance as a basic and essential source for water supply, the quality of river water has been subjected to intensive studies. However, it has become increasingly clear that the portable water is less safe and more hazardous; it is also apparent from the observation of medical data that many people suffer from water-borne illnesses on a daily basis. The unfavorable side effects of low-quality water also include the disappearance of aquatic life and vegetation (Obais & Al-Fatlawi, 2012). On the basis of its biological, chemical, and physical features in rivers, water quality can be identified. It is crucial to evaluate its quality before employing it for all of its intended uses, such as drinking water, agriculture, pleasure, or industrial water consumption. Prevention of contamination in rivers has become highly important in Iraq (Mustafa et al., 2017). On the basis of the required constituents concentration in river water, the strategy to monitor water quality may involve a number of complex, multi-disciplinary decisions (McIntyre & Wheater, 2004). Numerical representations are created because there are complex interactions between amounts of waste from areas and the quality of the recipient waterways (Deksissa et al., 2004). QUAL2E is the preferred and frequently applied numerical model that may be used for conventional contamination impact evaluation, established by USEPA, and then this model version was developed more to be QUAL2K model. The QUAL2K model is a constant-flow, one-dimensional streams quality of water estimator. It entails the modeling of novel interactions among water constituents that have an impact on river water quality, mainly BOD and DO. This beneficial program is free for modeling river management scenarios where there is no enough field data (Mustafa et al., 2017). The most important parameters that impact the river ecological health are Dissolved Oxygen and Carbonaceous Biological Oxygen Demand, which are regulated by several physical, chemical, and biological processes (Thomann & Mueller, 1987). DO is the amount of oxygen that has been dissolved in water. Aquatic plants use photosynthesis to push oxygen into the water, or oxygen passes from the air to the water through (waves, turbulence, currents, etc) (Al-Dhamin et al., 2012). CBOD is the amount of dissolved oxygen necessary for the oxidation of some inorganic materials (e.g., iron and sulfites) and the biochemical decomposition of organic parts.

Rafiee et al. (2014) employed the QUAL2K model to simulate the water quality of the Gargar River as well as the main sources of wastewater that run into it. The model accuracy is demonstrated by simulating values for DO, CBOD, $NH_4$-N, and $NO_3$-N. An analysis for the flow and water quality parameters across 18 dischargers was conducted. The variability of fast CBOD and DO concentrations in water was 3.47 to 5.77 mg/L. The river flow, point source flow, fast CBOD oxidation rate, and nitrification rate were the main variables used in the model. Results showed that water quality parameters such as fast CBOD and DO varied between 3.47 and 5.77 mg/L and 6.66 and 9.34 mg/L, respectively, at the five locations along the river based on the rates of ammonium nitrification, fast CBOD oxidation, and nitrate denitrification of 0.3, 2.0, and 0.2 day$^{-1}$, respectively. Ashwani et al. (2017) used the QUAL2K model for a 22.63 km section of the Pamba River. Samplings taken during the study period showed how the river water quality changed. The results showed the model predicted and measured values are in agreement, and the water quality is within reasonable limits. In addition, the study gave future possibilities to involve determining the allowable levels of pollution for the considered reach. Bui et al. (2019) simulated water quality with a focus on organic and nutrient pollution in the Cau River basin, in absence of data. This study sought to combine the outputs from a hydrological model (SWAT) with a water quality model (QUAL2K). While the QUAL2K model was used to simulate water quality processes in the downstream river network, the SWAT model was used to capture relevant hydrological processes in the upland watershed and tiny river tributaries. Using the two models, PBIAS and NSE, the model was able to accurately mimic the vast majority of water quality variables. Results showed that the model calibration and validation for the Cau River water quality model led to "very good" simulated water quality variables. Al-Dalimy & Al-Zubaidi (2023) applied the QUAL2K model to simulate the river water quality parameters, such as CBOD and DO in Hilla River, Iraq, utilizing river and point-source flow rates in addition to the water quality recorded throughout the river. The calibration of the model was established by the simulated results for DO, BOD5, and temperature during October, 2022. The two parameters (CBOD and DO) varied between (9.5 and 10.65) mg/L and (1.425 and 3.075) mg/L, respectively. The model predictions and field data showed good agreement.

In this paper, two parameters (CBOD and DO) were simulated along the Hilla River (Iraq) study area using the QUAL2K model to reveal their concentration distribution and the possible spill locations that impact the river water quality.

## METHODS AND MATERIALS

### Study area background

In Hilla City, Iraq, the Hilla River is considered the primary source of water (Figure 1). In the city center, where the study was done, the river flows from the Bata Bridge in the upstream direction to the Al-Farsi District in the downstream direction, forming a reach of around 6.8 km located between latitudes (32°27'54.35" and 32°30'56.39") and longitudes (44°26'02.09" and 44°26'27.08"). The river width ranges from 40 to 60 meters, with an average of 50 meters. The river depth is from 7 to 15 meters, and its flow velocity ranges between 0.3 and 0.5 m/sec. It has been used for farming, drinking, and tourist visits along this reach. In winter, the air temperatures are less than 13 degrees Celsius. The precipitation season is from January through March. Recently, this has impacted the river water quality. Therefore, river management is essential. Figure 1 shows the Hilla River and various locations where the quality of water was investigated.

Nine sampling sites on the river were chosen for the model calibration and verification for the study periods (October – 2022) and (January – 2023), see Figure 1. The study area was covered from Bata Bridge (S1) to Al Faris (S9), passing through Marjan Hospital (S2), Babel Passport Department (S3), First Bab Al-Hussein Bridge (S4), Second Bab Al-Hussein Bridge (S5), Old Governorate (S6), Al-Atiq Bridge (S7), and Al-Hunud Bridge (S8). Samples were taken from sampling stations based on the Iraqi ministry of water resources for testing the target water quality constituents, see Table 1 for the water quality parameters, units, and testing methods (Apha) (Rice et al., 2012).

## QUAL2K model

The QUAL2K model was used to model the water quality distribution along the river, it requires that the river length is divided into reaches and each reach is segmented into equally spaced elements. On the basis of the available data, the entire length of the study area along the Hilla River, which is 6.8 km, was divided into five reaches. Figure 2 shows the segmentation of the river system starting from Reach 1 to 5. The necessary model input data include: geographic characteristics (elevation, geographical longitude, and latitude); meteorological characteristics (air temperature, wind speed, dew point, shade, and cloud cover); hydraulic characteristics (morphological elements, Manning roughness coefficient, flow

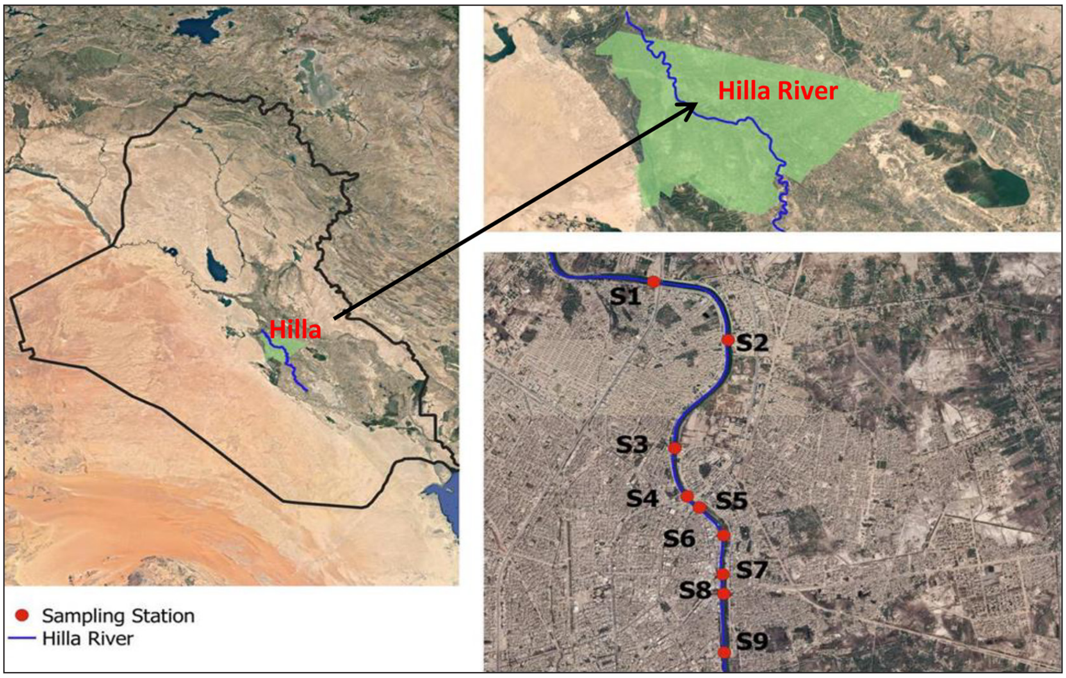


**Figure 1.** The study area

**Table 1.** Water quality parameters used in this study

| Parameter | Units | Methods |
|---|---|---|
| pH | - | Digital pH meter |
| Electrical conductivity | μs/cm | Conductivity meter |
| Temperature | °C | Mercury thermometer |
| Total alkalinity | mg/L | Titration method |
| Bio-chemical oxygen demand | mg/L | Winklers method, 5-day BOD test at 20 °C |
| Dissolved oxygen | mg/L | Azide modification |

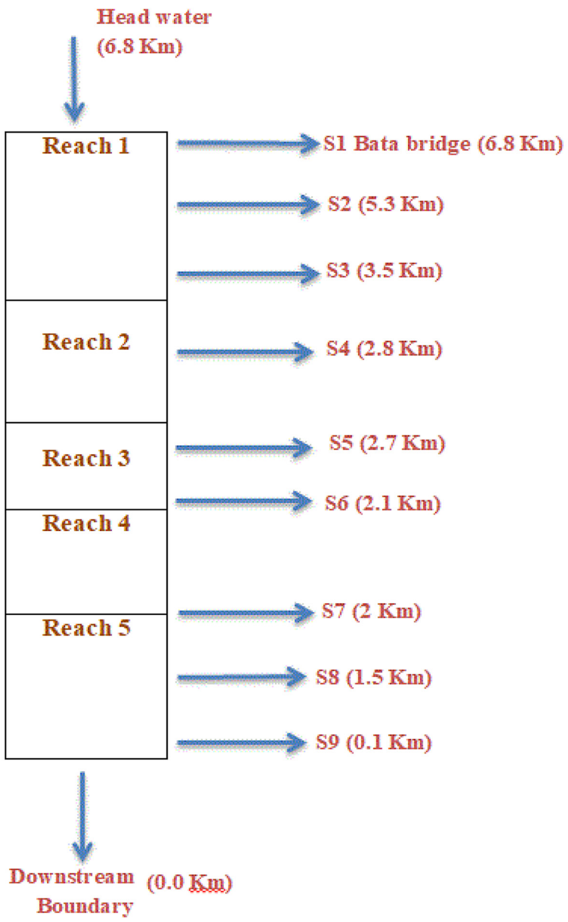


**Figure 2.** The model segmentation along the Hilla River study area

curve); as well as physical-chemical and biological parameters of rivers and point sources. Google Earth has been used in this study to calculate the reach segment lengths and geographical longitude and latitude. Table 2 shows the input model segmentation, location, and length of each reach.

Before being employed for simulating the water quality, the QUAL2K model was calibrated and validated using field data and changing the model coefficients during subsequent or repeated model run. In general, the model was calibrated to reduce the error for BOD and DO. The model input parameters of water quality used for the calibration process are temperatures, DO, pH, alkaline levels, and electric conduction. Hydraulic constants can impact the model simulation in the water system (Paliwal et al., 2007). Manning equation expresses the relationship between flows and depths. Because the Hilla River is a natural stream channel, with some portions becoming straight and clean and others appearing distinct, pivoting, and weed-filled, Manning's coefficient is thus taken to be between 0.022 and 0.03 (Chapra, 2008).

The observed 5-day CBOD (CBOD5) was converted to final CBOD (CBODu) using the following relationship (Kannel et al., 2007):

$$CBOD_U = \frac{CBOD_5}{1 - e^{-5k}} \qquad (1)$$

Field data during October 2022 and January 2023 was employed to calibrate the model. To increase the model stability, the calculation model time step was set to 0.03 h. The model ran repeatedly until the model properties were displayed correctly, and the match between the model outputs as well as field data was confirmed.

## RESULTS AND DISCUSSION

The QUAL2K model was calibrated using field observations in Table 3, 4, and 5 during October 2022 and January 2023 (dry and wet season, respectively). Two water quality constituents (CBOD and DO) were included in the model simulation, the target parameters of the present study. These variables serve as primary indicators for the river health. In addition, input parameters, built-in the model, were employed in this process. The calculation time step was adjusted to 0.03 hours in order to ensure the model stability. The model was executed until the field measurements and simulated results were matched with less statistics error.

**Table 2.** Model segmentation (length and location of each reach along the Hilla River, Iraq study area)

| Reach No. | Downstream Location (km) | Elevation | | Downstream | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Latitude | | | Longitude | | |
| | | Upstream | Downstream | Deg. | Min. | Sec. | Deg. | Min. | Sec. |
| 1 | 1.5 | 31 | 31 | 32 | 30 | 56.39 | 44 | 26 | 02.09 |
| 2 | 2.4 | 31 | 31 | 32 | 30 | 34.53 | 44 | 26 | 14.81 |
| 3 | 0.9 | 31 | 30 | 32 | 29 | 16 | 44 | 26 | 02.64 |
| 4 | 0.5 | 30 | 30 | 32 | 29 | 43.1 | 44 | 26 | 23.21 |
| 5 | 1.5 | 30 | 29 | 32 | 28 | 49.37 | 44 | 26 | 22.67 |

**Table 3.** Input field data for head water (Batta Bridge station)

| Parameters | Unit | Head water data (October 2022) | Head water data (January 2023) |
|---|---|---|---|
| Temperature | °C | 23.40 | 14.50 |
| pH | - | 7.58 | 8.16 |
| Electrical conductivity | μs/cm | 1316.00 | 1558.80 |
| Dissolved oxygen | mg/L | 10.40 | 9.10 |
| BOD | mg/L | 1.47 | 1.22 |
| Total alkalinity | mg/L | 122.50 | 142.00 |

**Table 4.** Input field data along Hilla River, Iraq (October 2022)

| Station | Parameter | |
|---|---|---|
| | CBODu (mg/L) | DO (mg/L) |
| S1 | 1.47 | 10.4 |
| S2 | 1.45 | 10.11 |
| S3 | 1.53 | 10.08 |
| S4 | 2.23 | 9.91 |
| S5 | 2.31 | 9.88 |
| S6 | 2.40 | 9.85 |
| S7 | 2.48 | 9.82 |
| S8 | 2.54 | 9.80 |
| S9 | 2.73 | 9.75 |

**Table 5.** Input field data along Hilla River, Iraq (January 2023)

| Station | Parameter | |
|---|---|---|
| | CBODu (mg/L) | DO (mg/L) |
| S1 | 1.23 | 9.1 |
| S2 | 1.12 | 9.9 |
| S3 | 2.35 | 10.5 |
| S4 | 3 | 10.2 |
| S5 | 1.97 | 10.13 |
| S6 | 2.055 | 10.195 |
| S7 | 2.25 | 9.95 |
| S8 | 2.53 | 9.99 |
| S9 | 2.055 | 9.8 |

Table 6 displays the mean absolute error (MAE) and root mean square error (RMSE) for the model predictions compared to the field measurements for the considered water quality parameters at the nine stations after the model calibration and validation. The MAE and RMS values indicate that there is good agreement between the model results and measurements. In developing countries with very poor data measurements, simple consistent standard models are accepted (Hadgu et al., 2014). Thus, the QUAL2K model can be used as an excellent estimation tool for the water quality of the Hilla River because the repeated management processes need a lot of study and financial resources to aid decision-making different water quality management scenarios. This reduces the time and cost required to periodically check of the river status.

Figure 3 shows the model simulated and observed CBODu concentrations output along the selected river length on October 2022, the dry season. The simulated CBODu values have good agreement with field data, highlighting the strong robustness of the model as well. The highest values of CBODu are found at stations (S4, S5, S6, S7, S8 and S9). Starting from S4, the CBODu level rises in the river. These high values were not observed at the other stations upstream the river. This occurs as a result of different point sources contaminating the river with organic materials. Also, it is suspected that there are unmonitored discharges from various industries at these stations, causing this level of CBODu. However, still the river BOD levels are considered acceptable. Figure 4 displays the simulated DO values during the same period (October 2022). The values are

**Table 6.** Statistics error for the predicted and measured water quality parameters

| Parameter | MAE (mg/L) | | RMSE (mg/L) | |
|---|---|---|---|---|
| | October 2022 | January 2023 | October 2022 | January 2023 |
| DO | 0.442 | 0.436 | 0.55 | 0.956 |
| CBODu | 0.426 | 0.382 | 0.549 | 0.53 |

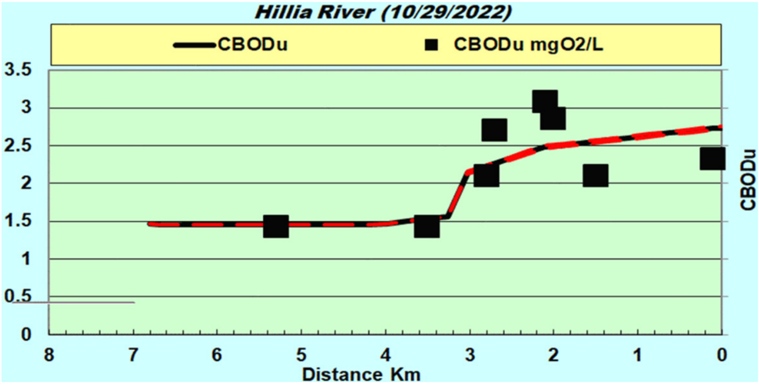


**Figure 3.** Simulated CBODu concentration along Hilla River, Iraq (October 2022)

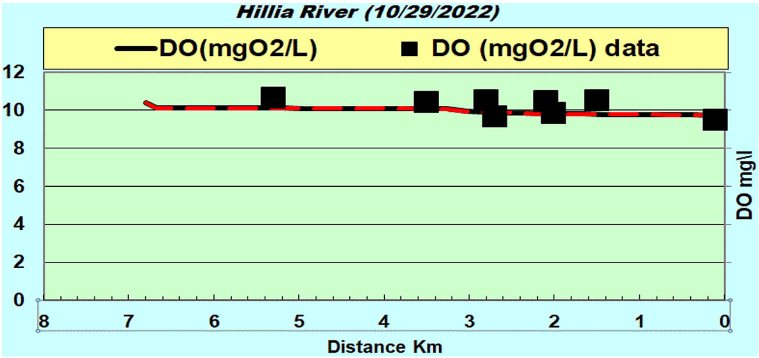


**Figure 4.** Simulated DO concentration along Hilla River, Iraq (October 2022)

approximately equal at all stations, but DO level dropped down starting from S4, reflecting the model predictions of CBODu as shown in Figure 3 as well as demonstrating a clear and good catch to the field conditions. The river DO level range is from 9 to 10 mg/L. As a result, the model outputs have shown that the dissolved oxygen levels in the river are higher than the minimum level of 4 mg/L (Kannel et al., 2007; Chapra, 2008).

Figures 5 and 6 are the model outputs of CBODu and DO during the high flow seasons (January 2023), respectively. The river CBODu levels behaved similar to the low flow season (October 2022) with lower values. On the other hand, the river DO levels behaved inversely to those levels of October 2022. The increased river discharge, enhancing aeration in the river, causes lower CBODu concentrations during high-flow seasons by mixing. It was found that the level of dissolved oxygen in the study area is above the limit of 4 mg/L too. Nevertheless, while simulating the river, a number of constraints might arise, such as the inability to anticipate the effectiveness of extraction from non-point sources like

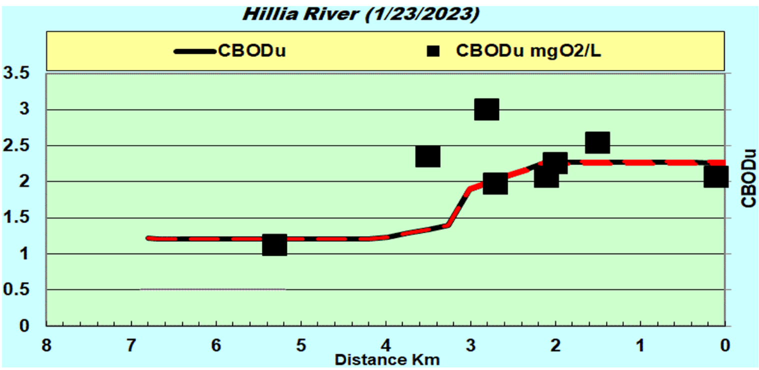


**Figure 5.** Simulated CBODu concentration along Hilla River, Iraq (January 2023)

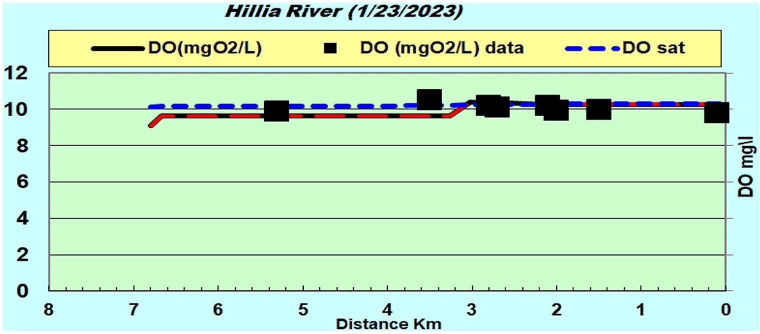


**Figure 6.** Simulated DO concentration along Hilla River, Iraq (January 2023)

livestock and agricultural operation discharges. Under many situations, the model was therefore capable of predicting the quality of water during the study period (Vieira et al., 2013). Thus, it has obvious that the Hilla River water quality is within the permissible levels for CBODu and DO. The level of CBOD has increased in some river stations as a result of different municipal and industrial wastewater spills at many parts of the river and from some sources of different types of waste dumps. Therefore, it is possible to conclude that the expected Hilla River water quality is safe to use as a source of drinking water or for other purposes and is within the permissible level of the drinking water standard.

## CONCLUSIONS

Different point and non-point spills are located along Hilla River (Iraq) illegally. To measure the river health, two parameters were chosen (CBOD and DO) along the river length that passes through Hilla City, where the river water is the only source for drinking water. By applying the QUẠL2K model based on field data, the CBOD and DO levels were acceptable (low flow CBOD values of (0.745–2) mg/L and DO values of (9.5–10.65) mg/L, respectively, and high flow values of (0.745–2) mg/L and (9.5–10.5) mg/L, respectively). Similar CBOD patterns were revealed along the river during both the high and low flow seasons. The maximum concentrations were at the Hilla City center due to many municipal and industrial discharges. In addition, it was clear that DO was impacted by these spills but it is still within the permissible values. The QUẠL2K model was capable of picking up the locations of spills, and this feature can help decision-makers find the best management scenarios for future purposes.

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