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A Numerical Modeling Framework for Water Quality Monitoring in Hilla River, Iraq: Simulation and Management Senarios

A Thesis

Submitted to the Council of the College of Engineering, University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master in Engineering / Environmental Engineering

By

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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

﴿أَوَلَمْ يَرَ الَّذِينَ كَفَرُوا أَنَّ السَّمَاوَاتِ وَالْأَرْضَ كَانَتَا رَتْقًا فَفَتَقْنَاهُمَا ۖ وَجَعَلْنَا مِنَ الْمَاءِ كُلَّ شَيْءٍ حَيٍّ ۖ أَفَلَا يُؤْمِنُونَ﴾

صَدَقَ اللّهُ العَلِيُّ العَظِيم

سورة الأنبياء الاية (٣٠)

SUPERVISOR CERTIFICATION

I certify that the preparation of this thesis entitled " **A Numerical Modeling Framework for Water Quality Monitoring in Hilla River, Iraq: Simulation and Management Senarios"** was presented by **" Shahad Zaman Ayyed Aldalimy** " under my supervision at the Department of Environmental Engineering / College of Engineering/ University of Babylon, as partial fulfillment of the requirements for the degree of master in Engineering/ Environmental Engineering.

Signature:

Name : **Asst. Prof. Dr. Hussein A. M. Al-Zubaidi**

Date : / / 2024

DEDICATIONS

To

First and foremost, I have to thank my parents for their love and support throughout my life. Thank you both for giving me strength to reach for the stars and chase my dreams.

*Sought and suffered to enjoy comfort and contentment and did not skimp on anything to push me on the path of success that taught me to climb the ladder of life with wisdom and patience ..... **my dad**.*

*nurtured me with love and tenderness, the symbol of love and healing, the balm of the heart ,the brightest white called out to her successful secret ..... **my mam**.*

I ask god to protect and save them for us.

*To those who love my veins and their seeds to support me on my jour ..... **my brothers and sisters.***

To everyone who has stood by me during this journey.

Shahad

2024

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"In the Name of Allah, the Most Gracious, the Most Merciful" *Praise to Allah his Majesty before anything and after anything and to the prophet " Mohammed and Ahl-Al-Bait " for the strength ، courage, and wisdom that Allah gave me to complete this humble work and lengthy journey this degree.*

To my godfather and supervisor who made me like the success and responsibility, to my teacher. I would like to express my deepest gratitude and respect to my thesis supervisor Asst. Prof. Dr. Hussein Ali Al-Zubaidi. I am very grateful for his precious time spent and useful suggestions which provided valuable guidance and important role in the completion of thesis as well as the moral support continued for the duration of the search, calling God richly rewarded him.

Shahad

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Abstract

Since industrial and human activities have been developed in different ways in Iraq, water quality has been declining along Hilla River, the only water resource in Hilla City for drinking water. In this research, the water quality was explored and simulated for the Hilla River length passing through the Hilla City center by using a model called “QUAL2K model”, a numerical modeling framework for water quality monitoring in rivers, depending on the hydraulic and water quality data collected along 6.8 km to be used as inputs by the model. Water quality constituents including dissolved oxygen (DO), carbonaceous biological oxygen demand (CBOD), pH, electrical conductivity (EC), alkalinity (ALK), and temperature (Temp) were measured at nine sampling stations located along this river length on October 2022 (low flow season) and January 2023 (high flow season). The model was calibrated and validated for both seasons to ensure the robustness, first. Statistical errors for the model predictions of (DO, CBODu, pH, EC, ALK, and Temp) compared to field measurements indicated that there is a good agreement during both dry and wet seasons.

The results showed that the Hilla River flow rate affects the model simulation of DO by reducing its level along the river slightly, because the flow reaches the city with high sediment demand and nutrients from agricultural areas upstream the river. However, this behavior of reduction depends mainly on the river hydraulic and water quality conditions such as pollution source discharge, absent algae, bacterial activity, decomposition of organic matter, and bottom sediments. As result, the model output showed are adductions behavior to the CBODu distribution in which the high flow decreases the CBODu values. EC model simulation results showed that in case of increase the flow rate of water, the conductivity of the water increased due to increase the ions in the river water. For pH and Alk model simulation, increasing the river flow rate led to increase them too.

Model sensitivity analysis was performed to explore the river water quality and to highlight how some factors can impact the model simulation, second. In order to

investigate the influence of changing the river conditions on the model simulation, the main inputs of the calibrated and validated model were varied significantly. This was performed by changing one model input and keeping the others without changing. Then, the model simulation results were displayed to be explored for this specific change outcomes. This analysis is important because it gives an indication to the user on how some variable can influence the model simulation and stability. The effect of CBOD oxidation rate coefficient was examined for both dry and wet seasons. It can be employed to calibrate the model. For CBODu, the effect of the CBOD oxidation rate was slight due to the low CBODu concentration in the river. However, the river suffered a reduction in the DO values when the CBOD oxidation rate increased to 0.2 day^{-1} and became more for 0.5 day^{-1}. This oxidation rate may increase due to chemical reactions; for example, the oxidation of inorganic compounds such as iron or sulfur can also consume dissolved oxygen. In addition, the reaeration rate coefficient is important to run the model, generally. It can be employed to calibrate the model. Most of these equations are based on field studies of selected streams or laboratory channels. The effect of manning roughness coefficient is significant on the river water velocity. As a result, the increase of roughness coefficient from 0.08 to 0.09, and 0.1 reduced the average velocity by 7.41% and 12.96%, respectively.

Finally, analysis of QUAL2K model management capability was performed to investigate the effect of pollution point sources on the Hilla River DO level since the presence of pollution point sources along the river can have several negative effects on the river ecosystem and its water quality. Results indicated the existence of these pollution point sources decreased the dissolved oxygen level downstream the outfall locations, depending on the source pollutant concentration and discharge. The presence of one BOD_5 polluted source at a point 2.8 km with pollutant concentration of 100, 150, and 200 mg/l and discharge of 1 m^3/s decreased the dissolved oxygen in the river but the decrease in case of 200 mg/l was huge and larger than those of 100 and 150 mg/l. The additional more point sources reduced the dissolved oxygen more than the case of one point source.

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List of Abbreviations and Symbols

Abbreviation	Descriptions
A	The Cross-Section Area
A_c	The Cross-Sectional Area
AN	Ammoniakal Nitrogen
ALK	Alkalinity
B_o	Bottom Width
BOD_5	Biochemical oxygen demand
$CBOD_U$	Ultimate carbonaceous Biochemical oxygen demand
CBOD	Carbonaceous Biochemical oxygen demand
CE	Electric conductivity
Cs	Slowly Reacting CBOD
Cf	Fast Reacting CBOD
COD	Chemical oxygen demand
DO	Dissolved oxygen
EPA	Environmental Protection Agency
GIS	Geographic Information System
H	Element Depth
HW	Head Water
HSPF	Hydrological Simulation Program Fortran
K_{dc}	Oxidation Rate coefficient
Ka	Reaeration Rate
Km	Kilometers
L	Liter
MSE	Mean Square Error
MOE	Ministry of the Environment
Mi	Inorganic Suspended Solids
NTU	Nephelometric Turbidity Unit
NO_3-N	Nitrate nitrogen
NH_3-N	NO3-N Nitrate nitrogen NH3-N
N	The Manning Roughness Coefficient
N	The Number Of The Data Points
Ni	Number of iterations
PCs	Personal Computers
pH	Hydrogen Ions
Q	The Discharge
Q2E	QUAL2E Model
Q2K	QUAL2K Model
Qi	outflow from element i into the downstream element i + 1
Qi–1	inflow from the upstream element i – 1
Qin,i	the total inflow into the element from point and nonpoint sources

Qout,i	the total outflow from the element due to point and nonpoint withdrawals
RMSE	Root Mean Squared Error
S	Station
S1	Bata Bridge
S2	Marjan Hospital
S3	Babel Passport Department
S4	First Bab Al-Hussein Bridge
S5	Second Bab Al-Hussein Bridge
S6	Old Governorate
S7	Al-Atiq Bridge
S8	Al-Hunud Bridge
S9	Al Faris
SS	Suspended Solids
S	The Simulation Data
S_o	Bottom Slope
SOD	Sediment oxygen demand
TMD	Maximum daily load
TSS	Total suspended solids
Temp	Water Temperature
TDS	Total dissolved solids
TP	Total phosphorus
TN	Total nitrogen
TMDL	Total Maximum Daily Load
VBA	Visual Basic for Applications
WHO	World Health Organization
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant
W	Width
WASP	Water Quality Analysis Simulation Program
USEPA	United States Environmental Protection Agency
USACE	United States Army Corps of Engineers
C^o	Degrees Celsius
mg/l	Milligram per liter
%	Percent
µS/cm	Micro siemens per centimeter

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Water is the key to life and is considered the main component of the earth's life. More than 8 billion people on the planet use water at a rate ranging between 28-30% of the total earthly water, so it has become necessary to produce sterilized and high-quality drinking water, but much of the water on Earth is polluted and unfit for human use. Iraq is one of the countries with the most water pollution, even though it has large areas of arable land, the water quality needs great treatment. Iraq is a geographically and climatically diverse country. The average rainfall is three million cubic meters, and the average water storage rate is 1620 billion cubic meters. Hence, there is a growing global concern regarding water quality (Petrus, 1990). Thus, there is a lot of concern about its water quality, so it was necessary to direct researchers to find solutions to problems related to water quality in Iraq.

The Euphrates River is the main source of water for the Hilla River in Babylon Governorate, which has a length of 1910 km, of which more than 1400 km is inside Iraq. The Euphrates River serves as a primary resource for a range of purposes, including the irrigation of extensive agricultural regions, the water source for numerous water treatment facilities, and the water source for various industrial plants (Abu-Hamdeh 2000; AL-Janabi et al, 2011). The river' branches have a direct impact on the physio-chemical and biological properties of the surrounding areas, making Hilla River is the most important branch of the Euphrates River. The river water quality is the main component of human health and has a direct impact on human daily life and human activities in the Governorate. As a result, water quality assessment has become the most important topic and the main issue in recent years because of concern about the scarcity of fresh water in the future, which requires efforts to maintain water quality through laboratory testing of water, especially physical, biological, and chemical tests (Bakan and colleagues 2010). Because the control of environmental pollution of water has become one of the issues in developing countries, where pollution prevention has become the first precautionary act of water disposal by the authorities, the most important of which is the prevention of spills from reaching the waterways of rivers (Helmer and Hespanhol, 1997).

The importance of water pollution management comes as a result of the multiplicity of pollution sources that lead to the destruction of resources water and reduce their quality. Where water suffers from many sources of pollution and the most important of these sources (Lindesh et al, 2022): First, pollution from industries use and industrial activities; Second, pollution resulting from agricultural industries and this means nitrate and phosphate salts mainly; and Finally, pollution resulting from domestic use where it produces water from domestic uses, which are organic or inorganic solids. Thus, water quality parameters such as BOD and DO are very important for evaluating the ecology of aquatic life in rivers since they are the main impacted parameters by these water pollution sources.

Water quality models of surface water quality are crucial tools to manage surface water. Quantitative models control environmental management for a better understanding of how surface waters change as a result of pollution (Lindesh et al, 2022). Modeling stands as the primary dependable method for emulating alterations in water quality resulting from point and non-point source discharges. It assumes a pivotal role in forecasting the repercussions of pollution on water quality and establishes the foundation for water quality management (Kalburgi et.al, 2015). Typically, mathematical models tend to be intricate, requiring a qualification of the connections between pollution loads originating from diverse sources and the resulting water quality. The most effective way to describe these relationships is numerical modeling (Deksissa et al, 2004). In recent times, the widespread use of computer-based numerical models for studying the dynamics of river systems has become increasingly prevalent.

1.2 Research Problem and Significance

Hilla River water is used for various purposes, such as drinking water, irrigation, and other uses. Water pollution can be defined as a change in the quality of water directly or indirectly as a result of the presence of concentrations of pollutants, so that the water becomes unsuitable for human use. The increase in industrial, agricultural, and development activities in many respects has led to increased water pollution. Due to Iraq's expanding population, anthropogenic use, poor management, and low environmental awareness, it will be challenging to regulate, monitor, and assess the quality of water resources over time, which are frequently exposed to different pollutants as a result of discharges from point and non-point sources such as sewage, agricultural, and industrial effluents. Additionally, global warming seriously contributes to Iraq's acute freshwater scarcity, as recent studies show a marked decline in precipitation (Al-Ridah et al., 2020). Recently, the Hilla River basin has faced drought conditions due to the low amount of water reaching the basin. Therefore, surface water quality information is needed to manage the river and monitor global environmental changes. It is significant to understand the problem by using currently available data as input information along with the measured data to analyze the relationship between the predicted and measured data for best water quality movement scenarios. However, for monitoring and evaluating the quality of river, instead of the management strategies based on traditional in-situ measurements by only assembly of laboratory water samples for testing to determine the chemical, biological and physical features. This research will be used to determine and assess the surface water quality of the Hilla River by a computer model that requires simple field data.

1.3 Research objectives

The foremost purposes of this research are:

1. To model the water quality constituents using QUAL2K model, focusing primarily on CBODu, DO, EC, pH, and Alk in addition to temperature within the central stretch of the Hilla River in Iraq as it flows through the Hilla City.

2. To display the influence of possible spills on the river water quality distribution along the considered part of the river.

3. To perform sensitivity analysis, revealing the main water quality parameters that can impact the model performance and the river management.

4. To perform hypothetical management scenarios for the Hilla River water quality constituents.

1.4 Thesis layout

The Thesis includes five chapters as follows:

1. **First chapter** presents an introduction to the subject.
2. **Second chapter** presents a clarification of the previous studies executed on water quality models.
3. **Third chapter** presents analytical stage work, including formulation in addition to the modeling of water quality.
4. **Fourth chapter** The findings of the water quality analysis, and discusses the comparison between analytical and experimental data.
5. **Fifth chapter** offers conclusions and recommendations besides suggestions for future studies.

CHAPTER TWO

THEORETICAL CONCEPTS

AND

LITERATURE REVIEW

CHAPTER TWO

THEORETICAL CONCEPTS AND LITERATURE REVIEW

2.1 Introduction

This chapter explores the theories behind the methods used in this study to achieve its objectives. In this chapter, the water quality modeling and its components are explained. Also, previous studies related to the present river water quality model are reviewed.

2.2 Water quality modeling

(Pablo Picasso's simulated world as a model is a little like art. Although It was never entirely accurate, it is never quite possible. But it is best filled with reality and truth for the viewer to learn about the environmental system) (Agouridis, 2007) (Ji, 2012) ,(Chin, 2012). A water-quality model is simply an aspect of a more complex governance framework. The water-quality model was the result of a complex model development and application process. Figure (2.1) shows the general modeling process and how the model is fed by primary information sources. The first includes management objectives, alternatives for control, and limits, which may include real restrictions in addition to knowledge of the law, regulations, and economy. Data on the physics, chemistry, biology, and harvest basin of the water body make up the second source. Such details are frequently absent or nonexistent. Such scenarios could call for some preliminary modeling and the collection of information. The modeler should have a clear understanding of the issue objectives when this phase is complete, as well as the accompanying water-quality variables required to decide how the objectives will be reached (Chapra, 2008).

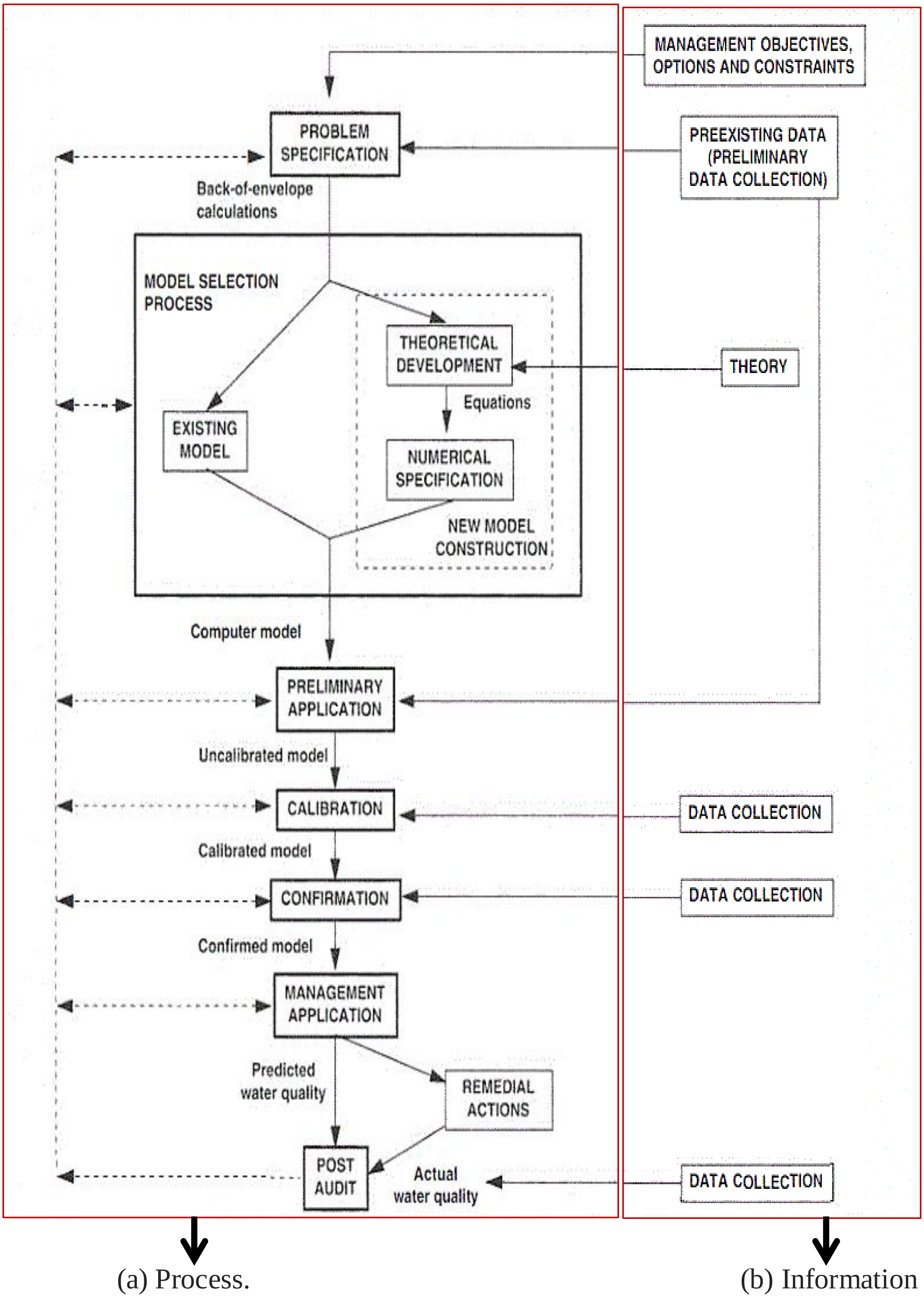

Fig. (2.1): (a) The water-quality modeling process along with (b) the necessary information needed for its effective implementation (Chapra, 2008).

Surface water quality modeling is a complex and variable process. As a result, there is no agreement among specialists on the best way to model different types of surface waters (rivers, estuaries, lakes, and coastal waterways) (Ambrose et al., 2009); (Wang et al., 2013).

2.3 River water quality models significance

Ji (2008) presented a study dealing with clarifying simplified description of a system that helps calculate and predict system conditions in a given situation. A water quality model is, in other words, "a mathematical representation of water quality processes that occur within a water body" (AEE, 2005). Increasingly, accurate modeling is essential for water quality management. By using water quality models, decision-makers can make more objective choices among several options to control water quality. To assess which of the possibilities will be best for solving a long-term water quality issue, water quality models are frequently employed. For leadership decisions and to predict calculated findings, it is essential to keep current events in consideration. Later modifications to a water system the models in these applications need to additionally describe the conditions that now exist and predict events that do not yet exist. The models also offer a foundation for economic analysis, enabling decision-makers to use the model results to assess a project's environmental importance in terms of cost-benefit analysis. Personal computers (PCs) have swiftly advanced and expanded as an essential platform for a variety of engineering applications. A computer-generated model may simply be shown to other computers. The modeling is cheaper to perform due to the low cost of PCs. Due to rapid developments in computer technology, surface water modeling studies are now often applied to PCs. Also, they function as an analyzing for the effects of various management choices to select one that has a minimal impact on the environment (Ji, 2008).

2.4 Types of river water quality models

Dispersion, advection, and sources/sinks processes typically control the transport of river constituents. Models across one, two, and three dimensions were developed to explain these processes. The study objectives, river characteristics, and data availability are the main drivers of a model's applicability.

Small rivers are mostly simulated by 1-D models; however, bigger rivers require the study of flow velocities and directions in more detail can be simulated by 2- and 3-D models. Also, 2D models are used where vertical stratification is an important river feature. Large river settings require the use of 3D models. Over the past several decades, different models of river water quality have been developed. There are many available models used for river water quality management. Here, some of them including the well-known model called QUAL2K or Q2K (Ji, 2008).

- **WASP, 1970**

In 1970, the Water Quality Analysis Simulation Program (WASP) is US Agency for Environmental Protection (USEPA). For several pollution management decisions, the tool helps users assess and make water quality responses to natural elements and human-caused pollution (Di Toro et al., 1983).

It enables the creation of 1D, 2D, and 3D models by designers. The model includes water columns and core bottoms and is dynamic compartment modeling software for hydroponic systems. Through several revisions, the USEPA has developed and modified the model over the years. While more recent, improved versions were created to be used under Windows with a graphical user interface for creating input files and output visual files for a simple look at simulation results, older versions were developed to run under the Disk Operating System (DOS). Geographic information system (GIS) tools and software for water quality statistics can distribute and use the outputs. The software interface may also read the results generated by the FORTRAN (HSPF) hydrological simulation software (Kannel et al., 2011). A heat balance model to simulate the water temperature is part of the model package. A particular set of water quality equations is defined by Booth's mass balance and chemical kinetic equations that were calculated on the input data set. As the simulation proceeds in time, the model numerically integrates these equations using an adaptive time-step Euler process. This model has been widely used to provide students with dissolved oxygen, bacteria, nutrients, suspended matter, and toxic compounds in a variety of water bodies (Thomann, 1975; Ambrose Jr, 1987; Wool et al., 2003; and Ambrose Jr et al., 2005).

- **CE-Qual-W2, 1975**

Developed by the United States Army Corps of Engineers (USACE) in 1975 (Edinger & Buchak, 1975; Norton & Bradford, 2009). The CE-Qual-W2 A hydrodynamic and water quality model for surface water systems is known as CE-Qual-W2. It is a 2D vertical longitudinal model (Deus et al., 2013). The model has been continually modified since 1975. The lateral homogeneous assumption of the model is particularly suitable for long, narrow bodies of water that include longitudinal and vertical water quality gradients. It uses a numerical method to directly correlate the hydrodynamics and water quality parameters of the model. It can be run across seasonal, annual, or multi-year cycles. Water quality parameters include temperature, longitudinal and vertical mixing, water transport, and a host of other applications. Similar to CE-Qual-W2 real-time simulations provided by hydrodynamic processes in model applications consist of a conservative tracker, speed, and temperature. CE-Qual-W2 can simulate about 21 water quality components, i.e., dissolved oxygen (DO), carbon biochemical oxygen demand (CBOD), pH, alkalinity, conservative tracer, coliform bacteria, total dissolved solids, algae, tailings, suspended soil, total phosphorus, ammonia, nitrates, thermally degradable dissolved oxygen matter, carbonates, sediments, total inorganic carbon dioxide, bicarbonates, and iron. Reservoirs, lakes, and lagoons are just a few of the stratified water systems to which the idea has been applied. For example (Kuo et al., 2006; Kurup et al., 2000; Martin, 1988)

- **QUASAR,1976**

A water quality and flow model titled QUASAR was developed to assess the impact of pollutants on the water quality of non-tidal rivers. It calculates the water chemistry in the river at places farther downstream as well as the water flow using upstream inputs from tributaries and point and non-point effluents. The model may be run in dynamic or planned modes (Ferrier et al., 1995; Kanel et al., 2011). Estimates of flow and quality are produced at each reach boundary over time using the time series data in the dynamic mode as model input. While in planning mode, a set of hydrological inputs and functions is used to develop a cumulative frequency distribution of some select water quality attributes. QUASAR could simulate temperature, algae blooms, dissolved oxygen, biochemical oxygen demand, ammonium, pH, E. coli, nitrate, and conservative pollutants Several studies utilized the model. The Pelenna River (in Wales, UK) was tested for heavy metal contamination by using it (Whitehead et al., 1995). In the Cuddalore District of Tamil Nadu, India, water samples from the Uppanar River were studied using the water quality and flow model QUASAR. The results show a one-to-one connection between the simulated and real values for DO, BOD, and pH, showing that the river was moderately dirty. To look into the parameters affecting the river's water quality, QUASAR can be used as a simulation model (Mullai et al., 2012).

- **QUAL2E, 1978**

The United States Environmental Protection Agency (USEPA) developed the one-dimensional water quality model Qual2E. In a river basin study, it has been granted as a planning tool (Ning et al., 2001). The model may also be used to assess the quality of flowing water. In addition to dissolved oxygen (DO), biochemical oxygen-demanding phosphorus, coliform, random non-conservative components, and three conservative components, it may simulate up to 15 various water quality parameters. Also necessary for flows of well-mixed factors, Qual2E simply considers the horizontal advection and dispersion of transport mechanisms to be essential along the longitudinal direction of the flow (Dai & Labadie, 1997). Also, the model includes the capacity to capture both steady-state and dynamic aspects of stream water quality. The model will simulate up to 20 compute objects with 25 access points, according to access. Qual2E has been applied since it was developed across various research areas and countries, such as Spain, Poland, the United States, Slovenia, Chile, and India (Walton & Webb, 1994); Chaudhury et al., 1998; Drolc & Konan, 1996; Drolc & Konan, 1999; Barnwell Jr. et al., 2004; Brown & Barnwell, 1987; Parveen & Singh, 2016).

- **QUAL2K or Q2K, 1979**

The elements of the QUAL2K buildings are similar to those of Qual2E. Provided this is a one-dimensional model, the channel's vertical and lateral mix is great. The system might contain a main river stem with branch tributaries. The QUAL2K model models steady flow and non-uniform. In addition, on a daily time scale, the computations of temperature and heat budget rely on meteorology. Also, daily time-scale simulations are carried out for all water quality indications. Simulated loads and withdrawals contain point and nonpoint types. Plenty of new features are in the novel QUAL2K elements. The numerical calculations were stored in Fortran90, and the model interface is a spreadsheet in Excel. Furthermore, all interface operations are programmed in the Microsoft Office macro language Visual Basic for applications (VBA). In contrast to Q2E, which divides the system into river reaches made up of similarly spaced elements, QUAL2K allows the element size to vary from reach to reach. Moreover, any component was capable of enduring repeated withdrawals and loadings. Furthermore, QUAL2K employs both a slowly oxidizing version (slow CBOD) and a rapidly oxidizing form (fast CBOD) of the carbonaceous form (BOD) to represent organic carbon. By reducing oxidation processes to zero at low oxygen levels, QUAL2K additionally accommodates anoxia. Denitrification is also depicted as a first-order system that develops at low oxygen levels. Rather than being prescribed, the dissolved oxygen and nutrient fluxes of sediment and water can be internally simulated. With factor stoichiometry, attached bottom algae were explicitly modeled in the QUAL2K model. The model assesses light extinction as an algae's function, trash, and inorganic solids. The pH of the river is then calculated based on alkalinity and total inorganic carbon, both of which may be simulated. The pathogen clearance is determined as a function of temperature, light, and settling, and the model permits simulation of the general pathogen. The QUAL2K allows users (or modelers) to specify an array of kinetic qualities on a reach-by-reach basis. The model framework additionally takes hydraulics and the impact of weirs and waterfalls on gas transport into account.

2.5 River segmentation in QUAL2K

The model of QUAL2K represents the river as a sequence of ranges in a system with only one river and no tributaries. In turn, these reaches signify river parts per hydraulic features (channel slope, bottom width, etc.). To allow for the placement of Sources, whether specific or diffuse, as withdrawals, At any point along the channel's extent, the reaches are labeled from the river's main stem headwater, as shown in Figure (2.2) (Chapra et al., 2012).

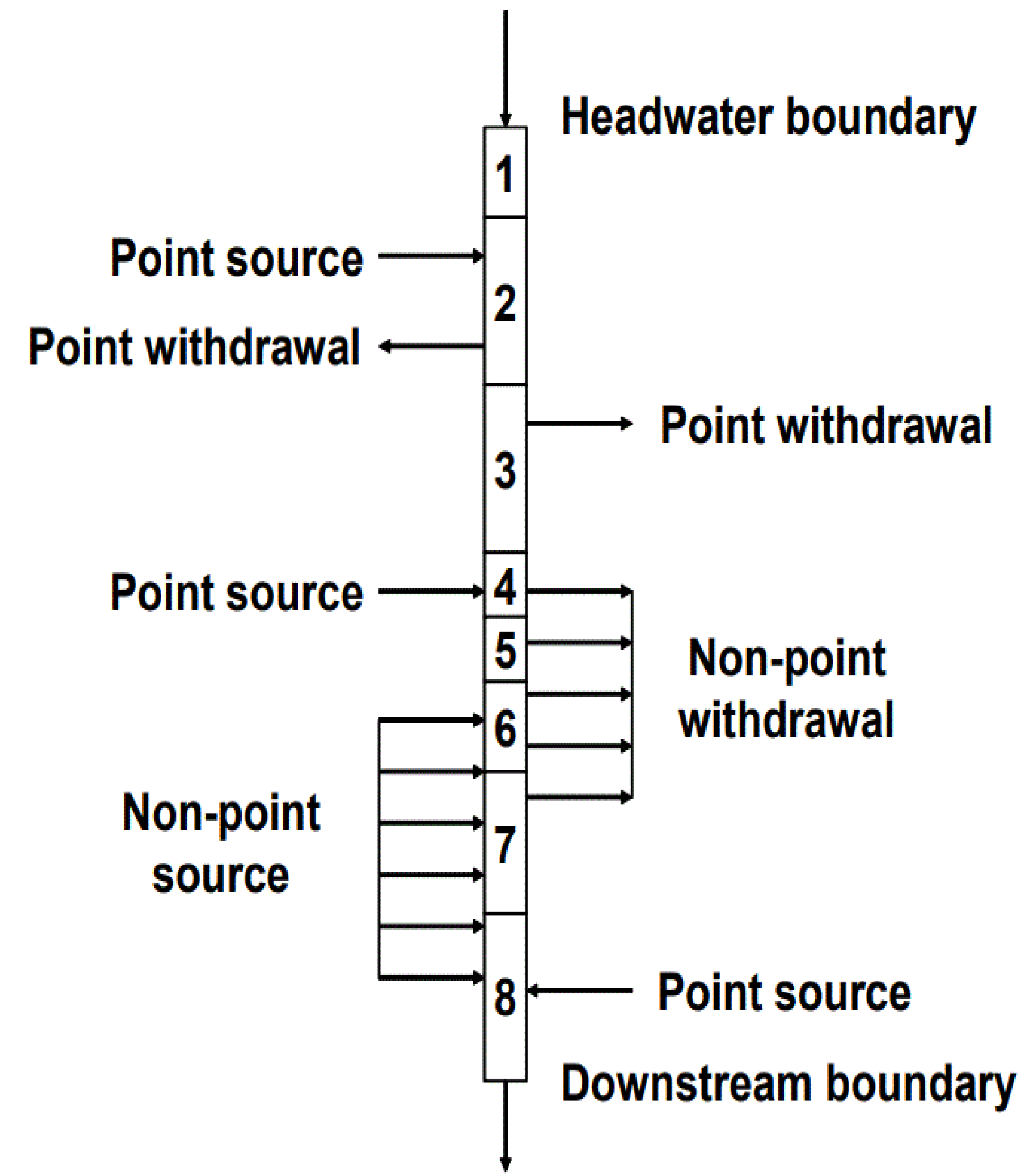

Fig. (2.2): A river with no tributaries and a QUAL2K segmentation scheme.

In the tributaries case, the reach is numbered starting with reach one at the water head which is the main step until it reaches a tributary, at which point the numbering continues to the tributary's headwater Figure (2.3). Numbered sequences are assigned to both headwaters and tributaries, following a sequencing strategy similar to that used for distances. Additionally, the primary river course and its tributaries within the system are collectively labeled as segments. On a segment-by-segment basis, QUAL2K shows graphics of model output. It generates individual plots for each of the main stems and tributaries. As a consequence, with the needed component numbers, and reach of the model may be divided into a sequence of several equally spaced elements. Figure (2.4) depicts an illustration of a reach divided into equal parts (Chapra et al., 2012).

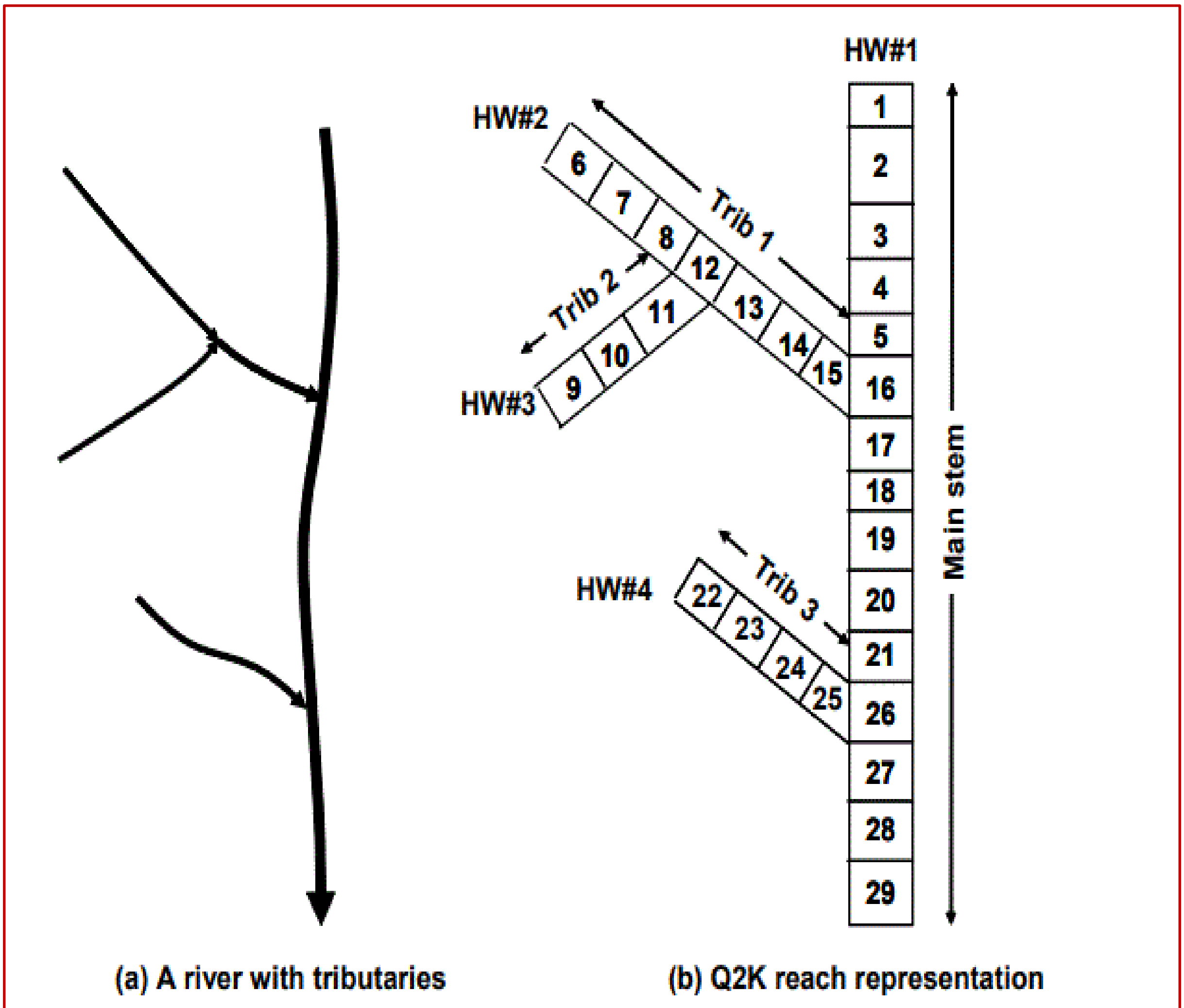

Fig. (2.3): River segmentation in QUAL2K; (a) A river featuring inflowing tributaries. (b) The representation of the QUAL2K reach (including the numbering systems for the reach, headwater, and tributaries).

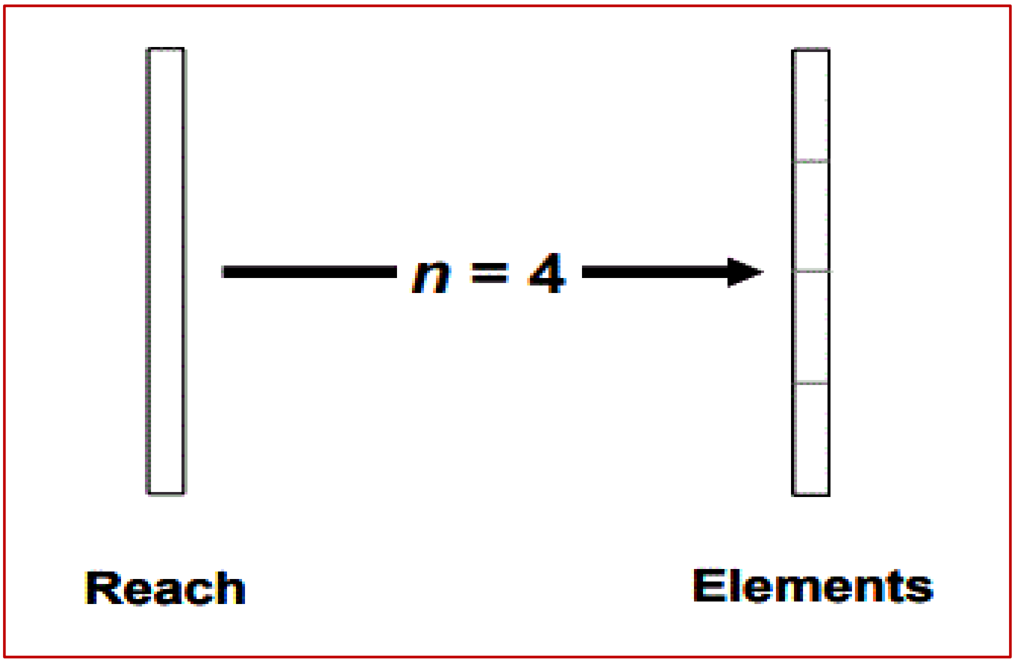

Fig. (2.4): A QUAL2K example of a reach divided into elements.

The following points are the terminology used to describe the QUAL2K arranges river topology:

- Reach: describes the river length at a constant hydraulic property.

- Element: The fundamental unit of the model involves equal-length units of a reach.

- Segment: reaches collection representative for system branch. These consist of the main stem as well as each tributary.

- Headwater: The top limit of a model section.

2.6 Geographic information system (GIS)

Given that QUAL2K is a one-dimensional model, it is considered necessary to provide a tool to explain and manage spatial data. The geographic information system (GIS) has been demonstrated by several previous studies to be a tool that can organize, analyze, and depict the spatial properties of soil, land use, and all-natural phenomena (Huang & Xia, 2001; Longley et al., 2005 ;Herrmann et al., 2014; Huda

M & Al-Ansari, 2018). An organized set of computer hardware, software, geographic data, and personnel called a GIS is used to efficiently collect, keep, change, analyze, and display all types of geographically linked information. In other words, it is a broad method for storing digitally formed geographic data (Alaa Eldin Mohamed Elamin, 2014). A tool called a Geographical Information System (GIS) makes it feasible to gather and use geographic data to promote improvements in the field of water quality. A digital map is typically better than a paper one since it has sources of data for data analysis and graphical presentation. By merging several information layers, users of GIS software may better organize and restore a lot of heterogeneous data (Huisman & de By, 2009).

2.7 Literature review: Previous related studies

River water quality assessment has been extensively studied in the literature. The water quality of rivers and streams has been the subject of a lot of research. Furthermore, multiple studies have estimated river water quality through simulation techniques. The most reliable strategy for understanding changes in water quality involves the application of mathematical models. The following are related previous studies that dealt with the subject of this study:

Zhang et al. (2012) investigated employing QUAL2K for water environmental capacity simulation to effectively manage the aquatic environment, the QUAL2K model was utilized to predict the water quality and environmental capacity of the Hongqi River. The study's objective was to offer a foundation for decision-making about water environmental management. Trial and error were used to regulate the model parameters until the simulated and observed data were in good agreement. Total phosphorus, dissolved oxygen, and petroleum-based chemicals do not fulfill the requirements for good water quality. Low flow velocity conditions were used for the monitoring. The monitoring period covered the winter months of September 2009 through December 2009 and the spring months of March 2010 through June 2010. along with other water quality and hydraulic data (TP). The Hongqi River's water environmental capacity was calculated using the calibrated QUAL2K model. Because of the significant amounts of dissolved oxygen required for the breakdown of contaminants, the DO is decreased. The Hongqo Paint Company's release of organic pollutants contributed to the decline in DO concentrations. The discharge of local wastewater and point-source contamination caused a small increase in COD, NH_3-N, TN, and TP concentrations at 0.9 km. With a few exceptions, the QUAL2K model's calibration findings matched the monitoring data. For instance, the dissolved oxygen (DO) and total phosphorus (TP) simulated curves differed somewhat from the measured values. COD, NH_3-N, TN, and TP have respective water environmental capabilities of 17.51 t, 1.52 t, 2.74 t, and 0.37 t. According to calculations, the headwater must reduce pollution loads of NH3-N, TN, and TP by 29.48%, 61.45%, and 44.07%, respectively, while the examined river reach must reduce pollution loads by 50.96%, 44.11%, and 22.92%. The main goal of this study was reached when the adjustment for simulating the Hongqo River water capacity (Zhang et al., 2012).

Ismail et al. (2013) examined the possibility of using the QUAL2K model to simulate and forecast the (DO) and (BOD_5) in the Tigris River's low flow period over a length of 49.97 kilometers. The majority of its municipal and industrial wastes were dumped directly into the river without any treatment, causing the river water to become contaminated, especially with organic materials. The longitudinal slope and precise location of the sample were two hydraulic factors for the Tigris River that were predicted using satellite images and DEM images. These hydraulic parameters were then interpolated into the QUAL2K model to get the result. To calibrate the QUAL2K stream water quality model for the Tigris River, physical-chemical parameters were assessed and data were gathered (Ismail et al., 2013).

Rafiee et al. (2014) used a one-dimensional QUAL2K water quality model to simulate the values of DO, pH, CBOD, NH_4-N, NO_3-N, and phosphorous data for the Gargar River in Iran. Five stations were created by the checking stations employed in this study to divide the river (S1, S2, S3, S4, S5). Data were gathered during the dry and wet seasons at these locations and from many sewage discharge devices. Clarifications regarding the wet season were made on May 3, 2011, while measurements regarding the dry season were made on October 13, 2010, with average monthly temperatures ranging between 14.7 and 37.5 ℃. The simulation results demonstrated that the model accurately captured the water quality profiles 20 km upstream and that they have a modest fitness. The dissolved oxygen and nitrite concentrations along the river gradually declined due to inadequate calibration that was obtained utilizing the local data that was available. Fast CBOD ranged from 3.47 to 5.77 mg/l and DO ranged from 6.66 to 9.34 mg/l in the samples that were analyzed (Rafiee et al., 2014).

Alaa Eldin. (2014) simulated the strain on Malaysia's urban centers to study the phenomena of increasing pollution from both point and non-point sources. Water quality was assessed by studying six variables such as DO, BOD, COD, SS, AN, & pH. The strategy for managing the water resources was decided upon in conjunction with the geographic information system (GIS) and water quality models. To forecast and assess the state of the water quality in the main stem of the River, the QUAL2K simulation model was employed. According to the simulation results for the current situation, outcomes revealed that DO ranges were between the first and second classes whereas BOD varies between classes II and III. According to the simulated results of the three scenarios, the Sewerage Treatment Plants (STPs) were the primary source of DO and BOD pollution in the river system. The absence of sewerage treatment plants (STPs) revealed meeting standards A and B which increased the DO quantities (from 0% to 40.5%) with reducing BOD amounts (from 0% to 49.4%) (**Alaa Eldin., 2014**).

Zhu et al. (2015) investigated the water quality in China's urban canals and rivers. In a laboratory-scale investigation, several environmental techniques were used to verify the water quality, the most important of which is activated carbon and plant treatment as the main variables of the study to evaluate the decomposition mechanism under varying water conditions. Then the QUAL2K model was used to simulate numerous speculative events and identify the the minimum ecological purification density and hydraulic retention time necessary to meet the Grade V or IV standards for China's surface water. Watershed pollutant control and water quality management both made extensive use of the adaptable and precise QUAL2K model. This model had been used to track the fate and movement of specific pollutants in medium-sized rivers with low width/depth ratios. Each day, samples were collected from the upper, middle, and lower sections of the water column in every tank during the time frame of 8:00 to 10:00 am. The TN, NH_4^+-N, NO_3-N, and TP samples were then thoroughly mixed in each tank and kept there until analysis at 4 ℃. The results showed that the ecological purification technique demonstrated constant N and P removal rates. Net removal rates for TN, NO_3-N, NH_4^+-N, TP across the entire system were 67.24%, 69.38%, 85.40%, 33.40%, and 47.54%, respectively (Zhu et al., 2015).

Mustafa & Sulaiman et al. (2017) applied the QUAL2K to measure the DO & BOD_5 at Diyala River over water quality data. To give some QUAL2K, Google Earth, and Arc-GIS methodologies were applied in this work. To calibrate and validate the model within the aforementioned period, Five discharge points were selected as pollution point sources. With further division into 26 segments, the Tigris-Diyala River confluence was partitioned into four distinct sections, each with a length of less than 1 km. Using input hydro-geometric data, Pollution load, and dissolved oxygen were the most important variables for assessing water quality. By trial and error, the model parameters were adjusted for the dry flow phase until the simulated and observed data coincided well. Different statistical metrics, including (MAE), (RMSE), and, were used to assess the model's performance (RE). The findings indicated a strong concurrence between the simulated and observed values. The (DO) (CBOD), spanning from 2.51 to 4.80 mg/l and 18.75 to 25.10 mg/l, respectively, exceeded permissible limits. Furthermore, it was noted that the interventions for pollution load reduction and localized oxygenation effectively improved DO levels. While for point sources, flow augmentation does not produce meaningful consequences in which the amount of DO falls despite a decrease in BOD5 (Mustafa et al., 2017).

Ismail & Robescu (2017) used QUAL2K to simulate the water quality in endless rivers. The lower stream of the Danube River was chosen for the study. Data from April 2008 (spring season) and September 2008 (fall season) were utilized separately to calibrate and validate the model of the water quality in endless rivers. To control the level of CBOD and DO in the river, four potential scenarios were looked at. The output of the model revealed that the calibration and validation results agreed with the observed values. Results showed that the DO exceeded the minimum dissolved oxygen levels of 4 mg/l, which suggests the river in the study's area is in excellent shape. CBODu simulation results were below 5 mg/l. Furthermore, the discharges had significant effects on the Danube River's water quality, with the Topolniţa tributary acting as the main source changing the river's water quality in the research area. QUAL2K may be used as a good tool to demonstrate the water quality in huge quantities of water, despite major constraints (Ismail & Robescu, 2017).

Chen et al. (2018) analyzed the impact of sediment oxidation, algal development, and nitrogen cycling on dissolved oxygen (DO). DO was chosen as the research index to move the analysis sensitivity along and to optimize the used parameters. A modified Morris screening approach was applied. The application of the model, which was used for water quality simulation, will be directly impacted by the determination of these parameters, which are contained in the QUAL2K model. As can be observed, oxygenation, CBOD, nitrification of ammonia nitrogen, beside river reoxygenation, are the four most significant processes affecting DO in the

QUAL2K. DO was also affected by the photosynthesis of algae at the bottom, but algae respiration has almost no effect on DO (Chen et al., 2018).

Abdovis Sabdovis et al. (2020) modeled the water quality of Iran's Dez River. There were five monitoring stations were utilized to investigate the water quality and fifteen at the sites where contaminants enter the river. To observe the Dez River's water quality changes throughout the last 10 years of development, the river's water quality was examined at various points in time. The QUAL2K Model then simulated the river's water quality state. The following parameters were simulated along the river in this model: electrical conductivity EC, pH, BOD, NO_3-N, DO, and NH_4^+-N. The model's findings demonstrated that the amount of DO parameter and the concentration of river pollutants are different in the rainy season (March). Additionally, the river's water quality is better during the rainy season than it is during times of low flow. The QUAL2K model's estimated electrical conductivity values, which were based on time series data from March to July 2013, are quite close to the actual value. Due to the river's natural self-purification and the decrease in input drainage, the DO value drops in the river downstream region over a distance of 80 to 160 kilometers before increasing. At this point in the river, the input density of industrial, agricultural, and urban drainage is very high. Due to the entry of a greater quantity of the linear pollutant, the NH_4 and NO_3 parameters increase in the river across a 140- 150 km. The pH along the river is typical **(Abdovis Sabdovis et al., 2020).**

Al Kindi et al. (**2021)**, Tigris River investigated the water quality based on the chemical and physical variables through the use of linear models. The study dealt with the evaluation of the quality of the stations for an estimated distance of 22 km along the Tigris River. Study variables were used to find DO and CBOD. Secondary variables such as acidity, temperature, and conductivity were used during a period when the river flow is low and high, especially between the periods in January and April when samples were collected from the river, which were taken from four stations. With a few exceptions, the simulated findings have demonstrated a good fit with observed data. When analyzing the results, it was found that the results are acceptable because they showed the real value of dissolved oxygen, which has a value of 4 mg/l, which reflects the possibility of using the Tigris River. After all, it obtains a sufficient percentage of oxygen to ensure that it is healthy for human use. In various instances, the CBODu and dissolved oxygen showed some variances between the simulated and observed values. CBODu simulated levels were less than 5 mg/l in January, and by April, which plummeted to less than 2.7 mg/l. The findings revealed that when the distance from the headwater grew owing to riverbank works, the CBODu and DO, exhibited some variations between the simulated and actual datasets at various places. CBODu simulated levels were less than 5 mg/l in January, and by April, they had plummeted to less than 2.7 mg/l. The findings also revealed that when the distance from the headwater rose owing to riverbank operations, the concentrations of DO, BOD, and alkalinity increased continuously. The highest BOD concentration is observed at Station 4, primarily attributed to the point of confluence between the Tigris River and Diyala River. Furthermore, there was only a minor variation in pH and EC measurements along the river (Al Kindi et al., 2021).

Adnan et al. (2022) investigated the TMD in Batu Pahat River to explore the water quality and pollutant concentrations. Due to the TMD Load is one of the greatest techniques that might be utilized to control the quality of water (TMDL), the identification of physical, chemical, and organic characteristics in the river's body aids TMDL, which aimed to determine or limit the amounts of pollutant concentrations. Water quality sampling for this study took place from May 1 through May 15, 2021, for two weeks. The appropriate time for water sampling was established before it was carried out to distinguish between low and high flow. Dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), total suspended solids (TSS), and pH were six parameters that were examined. At CP6, the DO levels were at their greatest, whereas at CP4, they were at their lowest. This value has a strong relationship to the site's activity and environment because CP6 is situated in a workshop area with slow-moving water. CP4 is located within the vicinity of the wet market area, characterized by stagnant water, leading to a decrease in dissolved oxygen (DO) levels. In addition to elevated levels of COD, BOD, TSS, and NH_3-N, CP_4 exhibits the highest concentrations of COD and BOD, largely due to the discharge of effluent from the wet market. Overall, the water quality in the Batu Pahat River is still considered to be good. But the water quality in some parts of this river, especially those near commercial and industrial areas, was low (Adnan et al., 2022).

Ravinashree et al. (**2022)** investigated water quality under the influence of several environmental conditions, assuming that the river was in a state of continuous flow**.** Indian Bhavani River investigation deals with measuring the inorganic suspended solids (ISS) in addition to CBOD. The QUAL2K was utilized using environmental data and hydraulic at a short part of the River. To examine the model's reaction to the chosen range of parameters, several case studies were created. The model's findings imply that ISS, DO, and CBOD can serve as the model's fundamental building blocks in the absence of additional information about the pollutants. This study indicated that DO had a significant impact on both organic and inorganic pollutants. Under the chosen ranges of organic pollutants, the river's biodegradation potential is predicted to be consistent. This is not the case, though, if the model is to be applied to a scenario with high contamination levels. The ability to build a data-limited model can be judged by the methods used to choose input parameters, split data, choose a model structure, and choose a validation strategy.

Samsuri & Adnan (2022) conducted an investigation in 2022 on the water quality modeling program called QUAL2K. The study focuses on water quality modeling techniques to develop a strategy for implementing Total Maximum Daily Load (TMDL) and quantify six specific water quality metrics in the Batu Pahat River. The river pollution is primarily caused by PO and NPS sources, with the quality declining due to both point and non-point sources. The river is divided into three main land use categories (commercial, residential, and agricultural), with six different types of activity. Water samples were collected at 11 sample checkpoints along the river, and the Department of the Environment's National Water Quality Index (WQI) was used to evaluate the river's water quality. The majority of water quality metrics exhibit high concentration levels in the CP4 Wet area due to low DO concentration and minimal discharge. Commercial land uses have emerged as the primary source of pollutant loading in the Batu Pahat River for both low tide and high tide flow, surpassing residential and agricultural land uses. The current BOD pollution loading attributed to commercial land uses is recorded at 1236.41 kg/day, while residential land uses contribute 899.33 kg/day, and agricultural land uses contribute 23.384 kg/day. Considering a TMDL with a 15% Margin of Safety (MOS), the recommended BOD limits for high tide are 1813.9 kg/day for commercial land uses, 1034.23 kg/day for residential land uses, and 26.89 kg/day for agricultural land uses. For low tide flow, the current BOD pollution loading from commercial land uses amounts to 1185.45 kg/day, with residential land uses contributing 780 kg/day and agricultural land uses contributing 25.29 kg/day.

2.8 Summary

In comparison with the previous studies, it was noticed that the Hilla River water quality has not been simulated by a tool such as QUAL2K model to show the best management scenarios that can be used by decision-makers. As a result, the river needs to be modeled by QUAL2K to develop a base for exploring different water quality parameters by other researchers.

CHAPTER THREE

MATERIALS AND METHODS

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3.1 Introduction

This chapter discusses two major parts. The first part gives detailed information on the study area, the Hilla River, including the geometric information and environmental dilemmas as well as the monitoring program conducted. On the other hand, the second part explains the methods and tools applied to attain the objectives of this research, including the data processing and the river model simulation.

3.2 Study area and background

Figure (3.1, a and b) depicts the location of Hilla River and the sampling stations along the river. The Hilla River, one of Iraq's greatest water sources, was formerly the Euphrates River's main stream, but today the river is a branch from the Euphrates River starting from Al Hindiyah Barrage. The research span along the river extended from Bata Bridge (S1) to Al Faris (S9), encompassing key points such as 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). The river length is located between latitudes of 32^{o}27'54.35" and 32^{o}30'56.39 and longitudes of 44^{o}26'02.09" and 44^{o}26'27.08" with total river length of 6.8 kilometers at flow rates of (90, 100, 110, 130, 140, and 150) m^3/s along the river during the study period. Its bed width is about (40 - 60) m with water depth of (5 - 7) m and velocity of (0.3 - 0.5) m/s. The increase of river pollutions led to disease and cancer outbreaks and prompted studies into the quality of the water which gives people low quality water to drink [Ministry of Water Resources, MOWR, 2018] (Apha). The climate in ancient Babylonia. The region is a scorching, arid desert. Comfortably, the temperature reaches to 40 degrees Celsius.

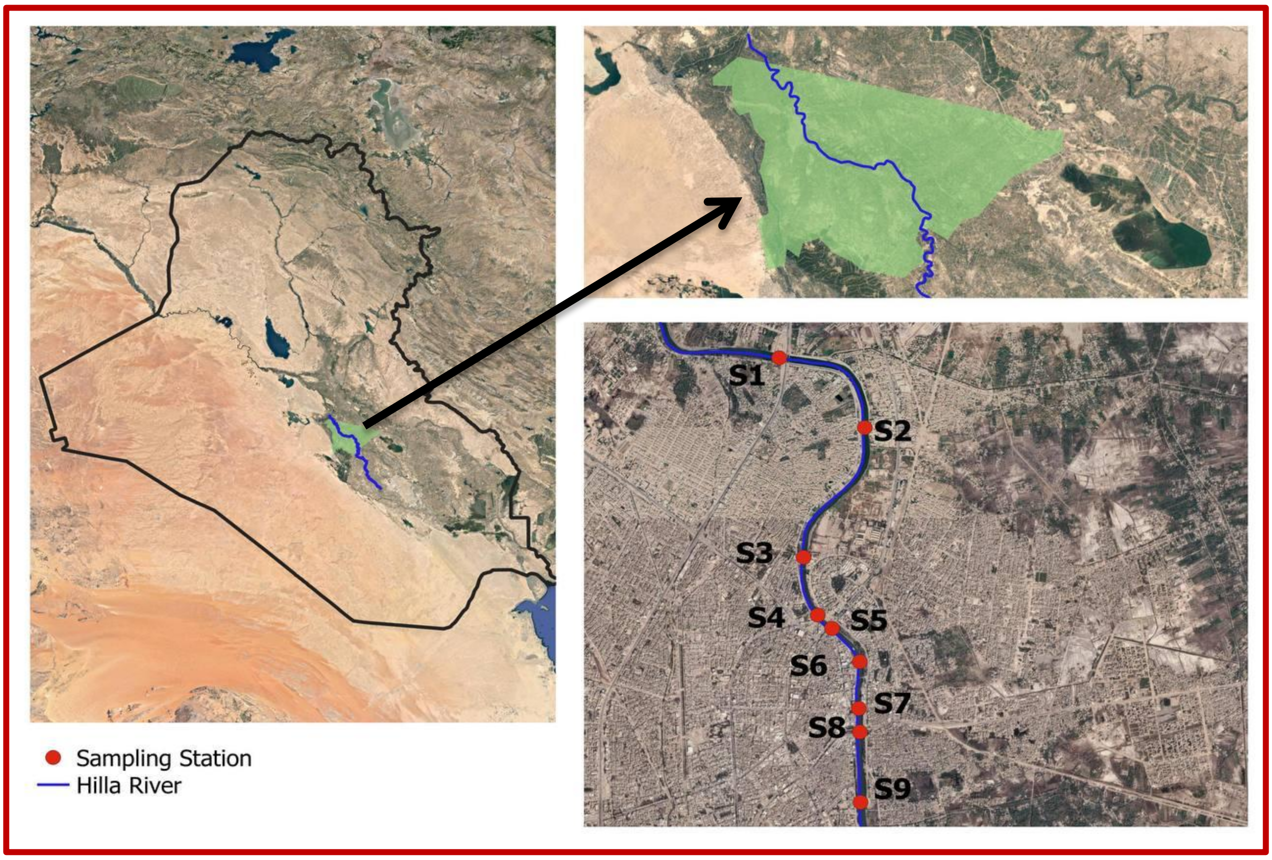

Fig. (3.1): (a) The study area and sampling stations.

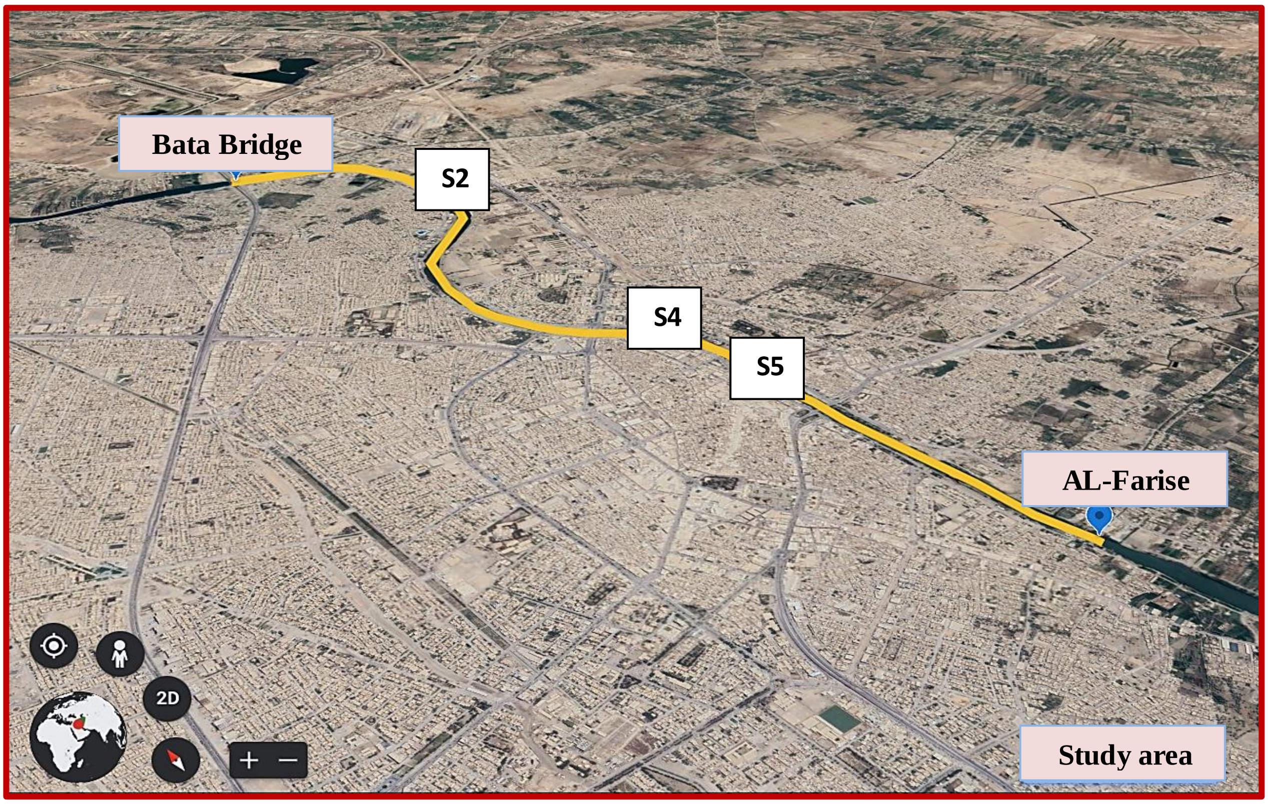

Fig. (3.1): (b) Hilla River study length (Google earth).

3.3 Water quality management

Monitoring the water quality is essential to integrated river basin management. The river ecology suffers from vegetation removal in consequence to the riparian corridor and removal of snags from the watercourses; thus, habitats for a variety of riparian and aquatic fauna are diminishing. The presence of pollution point sources along the river can have several negative effects on the river ecosystem and its water quality. These effects can be significant and wide-ranging, depending on the nature and extent of the pollution such as industrial discharges or sewage outfalls that introduce pollutants directly into the river. These pollutants can include chemicals, heavy metals, pathogens, nutrients, and other harmful substances. As a result, the water quality in the affected area can decline, making it unsuitable for various uses, including drinking water supply, recreational activities, and supporting aquatic life. In addition, pollutants can be toxic to aquatic organisms, leading to fish kills, reduced biodiversity, and disruptions in the food chain. Fish and other aquatic species may suffer from reduced growth, reproductive problems, or even population declines. Sensitive species are often the first to be impacted. Polluted water can impose health risks to humans who come into contact with it. This includes the risk of waterborne diseases, skin irritations, or other health problems. Ingesting or using polluted water for domestic purposes can lead to serious health issues.

3.4 Sampling stations and laboratory tests

Integral river basin management depends on regular water quality monitoring. Pollutants are frequently dumped into the river from the surrounding area, harming the ecology and reducing the habitats of many aquatic and river creatures. Samples of water were taken from the river stream on October 2022 and January 2023 once every season. In order to assure higher water quality, the research concentrated on assessing the Hilla River as a raw water supply. The Hilla River in Iraq has needed higher water quality; hence, this study concentrate on assessing the Hilla River as a raw water supply (Najem & Alwash, 2018). In order to assure water quality management, the study included taking water samples from specified stations for on-site and laboratory analysis. These samples were used to assess the physical, chemical, and biological features of rivers. Nine water quality monitoring stations are situated along the considered river length as shown in Table (3.1).

Table (3.1): The Hilla River monitoring stations during the study.

Station Number	Station Name
S1	Bata Bridge
S2	Marjan Hospital
S3	Babel Passport Department
S4	First Bab Al-Hussein Bridge
S5	Second Bab Al-Hussein Bridge
S6	Old Governorate
S7	Al-Atiq Bridge
S8	Al-Hunud Bridge
S9	Al Faris

The approach utilized in this study comprises taking samples from split river side sites. Additionally, the approach comprises processing and analyzing data gathered via Google Earth, atmospheric meteorological knowledge, and laboratory data in order to extract engineering information for usage in compliance with QUAL2K model standards. Additionally, the technique calls for using the QUAL2K model. In order to convert the model's inputs to the platform used to determine water quality, Google Earth data was imported into the software.

There are various tools and instruments used for testing water quality parameters in field and lab. The selection of specific tools depends on the parameters you want to measure and the level of accuracy required. Here are some commonly used tools for water quality testing, see Figure (3.2) for some of them:

- pH Meter: measures the acidity or alkalinity of water by determining the concentration of hydrogen ions.
- Conductivity Meter: measures the ability of water to conduct electrical current, providing an indication of the total dissolved solids or salinity.
- Dissolved Oxygen Meter: measures the amount of oxygen dissolved in water, which is crucial for aquatic life and indicates the water's ability to support organisms.
- Turbidity Meter: gauges the haziness or turbidity of water due to suspended particles. Elevated turbidity levels can impact the penetration of light and aquatic ecosystems.
- Multiparameter Water Quality Meter: combines several measurements into a single device, typically including parameters like pH, temperature, dissolved oxygen, conductivity, and turbidity.
- Water Testing Kits: These kits often contain a range of reagents and test strips or tablets for rapid field testing of specific parameters such as pH, chlorine, nitrate, phosphate, or hardness. They are typically portable and suitable for on-site testing.

➢ The samples were tested in the private laboratory in Al-Dewaniyah City. The standard methods for the examination of water and wastewater (APHA, 2017) were employed for all analyses. It's important to note that the specific tools require will depend on the parameters of interest and the level of accuracy needed. will depend on the parameters of interest and the level of accuracy needed.

Fig. (3.2): Instruments used in this study.

3.5 Methodology

Figure (3.3) displays the modeling approach conducted in this study. There are four parts in the study's approach. The initial step is to gather unprocessed data from stations that have been divided into groups according to the chosen criteria. The second step displays the handling and evaluation of data taken from the lab in order to comply with the QUAL2K model's standards, taking into account the meteorological data and daily weather. The QUAL2K model is created in the third step, and the process of turning QUAL2K outputs into a water quality knowledge platform using the program outcomes constitutes the last stage.

3.5.1 Data inputs

There are two different data inputs required by the model: primary and secondary, depending on the manner of collection. Primary data is information gathered directly from the primary source of the sample, whereas secondary data is information gathered inadvertently from other sources. While experiments, surveys, and direct measurements are used to gather primary data, secondary data is gathered from a variety of sources, including literature, collections from computerized databases, mathematical models, and information systems.

Secondary data is typically faster, quicker, and more cost-effective to obtain than primary data. Hydraulic data readings from the Hilla River were used in the current investigation to calculate the river flow and provide QUAL2K input data. To assess the QUAL2K model score, on-site measurements and water sample collection are also included in the raw data. On the other hand, secondary information for this study was gathered from many sources and organizations, including the Ministry of the Environment (MOE). Spatial data, such as that from Google Earth, makes up the secondary data that was gathered. Additionally, non-spatial data such as information from water quality monitoring, sources of pollutants, and climatic data are included in secondary data.

3.5.1.1. Primary data

Running the QUAL2K model requires the hydraulic data to function properly. Included in this data are the headwater flow rates, the reach length, channel slope, cross-sectional data, the positions and upstream height in addition to downstream at each reach, and coefficient value of roughness .

3.5.1.2. Secodary data

The heights above and below the stream, along with the slope of the channel at each span, are the most important variables for the QUAL2K model. In general, hydrological studies use raster-based Google Earth to depict surface elevations supported by a Geographic Information System (GIS) in addition to know the weather conditions.

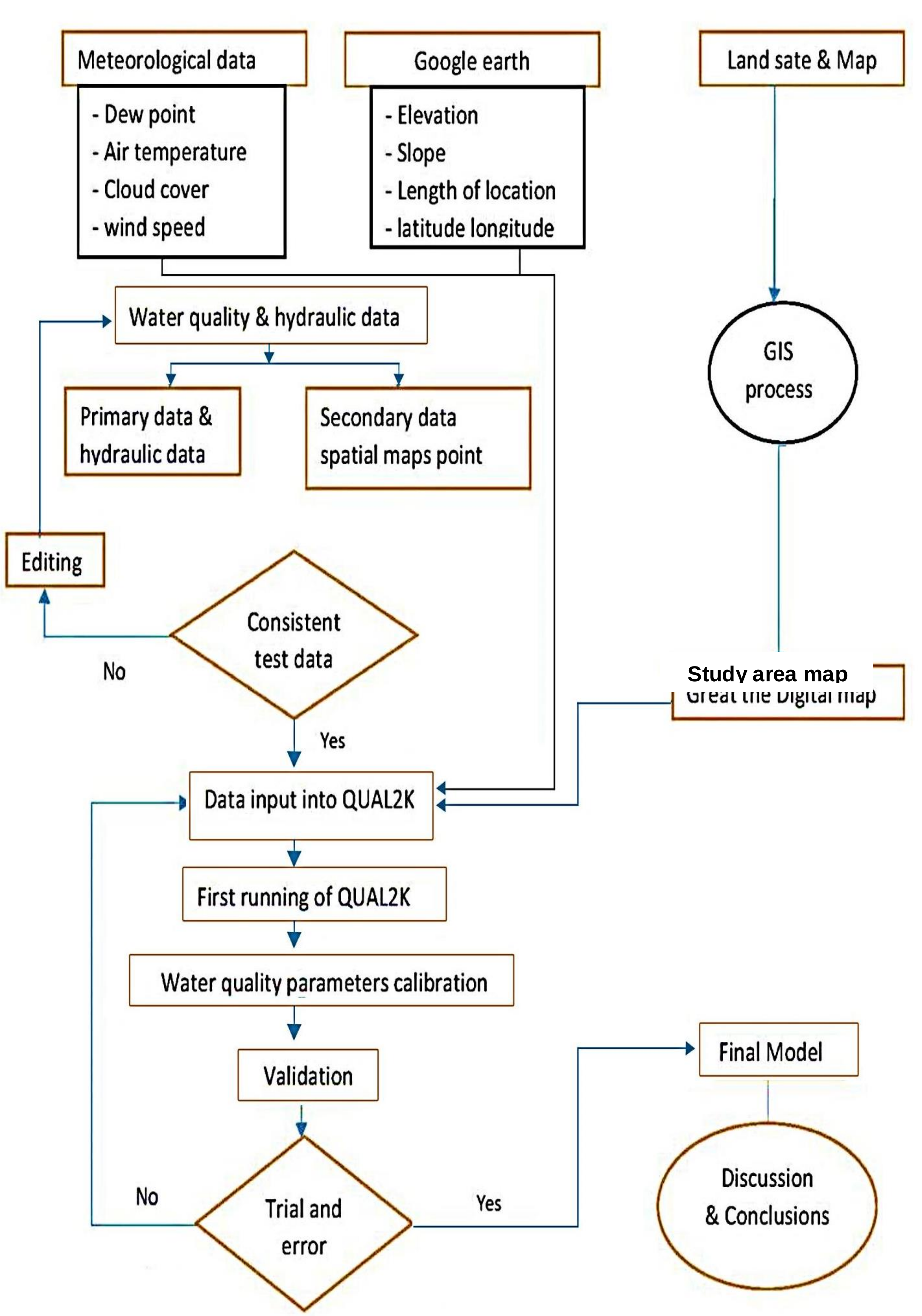

Fig. (3.3): The flow chart of the research methodology.

3.5.2 Model description

This study employed the QUAL2K model for simulating the water quality of the Hilla River. The subsequent section provides a concise overview of the key characteristics of QUAL2K (Chapra et al., 2003).

QUAL2K is a water quality model for river stream that is designed to serve as an upgraded iteration of the QUAL2E (Brown & Barnwell, 1987) . The United States Environmental Protection Agency (USEPA) offers the model for free, and it provides a lot of documentation Environmental Protection Agency (EPA) (Cho & Ha, 2010). Various water quality factors, such as temperature, pH, dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), organic nitrogen (ON), and sediment oxygen demand (SOD). Phytoplankton and bottom algae are among the elements that make up total nitrogen (TN), total phosphorus (TP), organic phosphorus (OP), nitrate nitrogen (NO_3-N), and ammonium nitrogen (NH_4^+-N) (Hamilton & Schladow, 1997). The model is applicable to well-mixed streams and assumes that only the main flow direction would experience dispersion and advection transport (longitudinal direction). The model equation takes into account dilution, advection-dispersion, chemical interactions, external load (Azzellino et al., 2006).

QUAL2K is similar to Q2E in the following aspects:

• One-dimensional model in the longitudinal direction: The channel is mixed laterally and vertically.

• Branching: A main stem river and branching tributaries might make up the system in the model.

• Constant-state hydraulics simulated a steady and non-uniform flow with heat budget on the dial: The heat budget and temperature are modeled as weather functions on a dial time scale.

• Water-quality kinetics in dial on a discrete time scale: All variables affecting water quality are modeled.

• Inputs of mass and heat loads and withdrawals are modeled for both points and non-points.

In addition, the framework of QUAL2K includes new elements:

• Interface and Environment of Software in the Microsoft Windows environment: Fortran 90 is used to program mathematical operations. The graphical user interface is Excel. Visual Basic for Applications, a Microsoft Office macro language, is used to program all interface actions (VBA).

• Segmenting models: The system is divided by Q2E into river reaches made up of similarly spaced components. The system is further broken down into reaches and components by QUAL2K. In comparison between Q2E and QUAL2K, the size of Q2K element dissimilar in reach. Any element also allows for numerous loadings and withdrawals.

• The speciation of carbonaceous BOD: Two types of carbonaceous BOD are used by QUAL2K to represent organic carbon. These are the rapidly oxidizing and slowly oxidizing types (fast CBOD).

• Anoxia: By lowering oxidation processes to zero at low oxygen levels, QUAL2K accommodates anoxia. Additionally, denitrification is envisioned as a first-order mechanism that intensifies at low oxygen levels.

• water-sediment interactions: Nutrient and dissolved oxygen fluxes between sediment and water can be internally simulated rather than prescribed. In other words, oxygen (SOD) and nutrient fluxes are modeled as functions of the concentrations of soluble forms in the water above the sediment, the settling of particulate organic matter, and processes taking place within the sediment.

- pH: Total inorganic carbon as well as alkalinity are both simulated. Based on these two values, the pH of the river is then calculated. Accomplish a set of kinetic parameters. Many of the kinetic characteristics may be specified in QUAL2K on a reach-by-reach basis.

3.5.3 Model development

Figure (3.4) depicts the process of creating and modifying the water quality model, from QUAL2K to output platform.

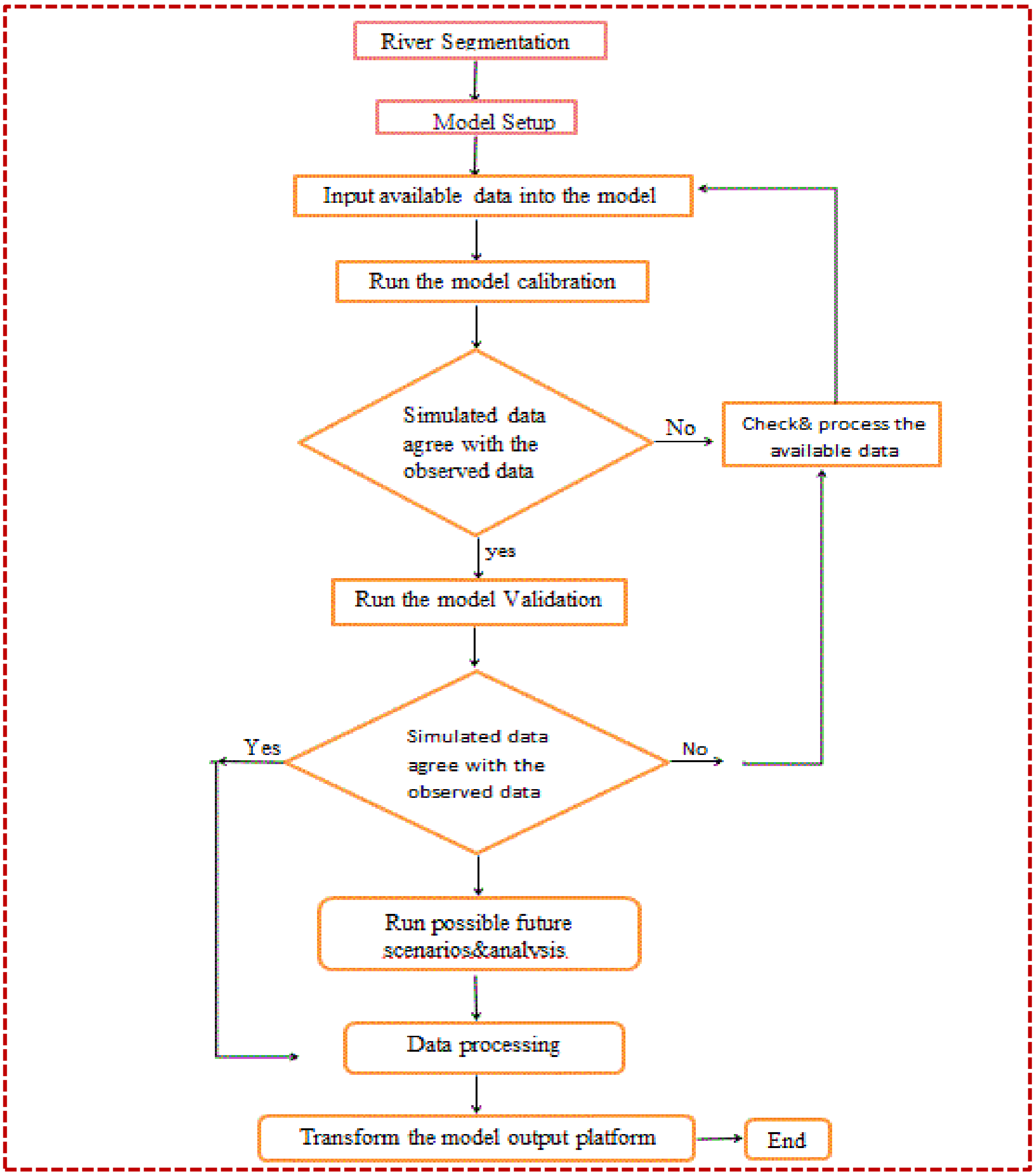

Fig. (3.4): QUAL2K Model development steps.

3.5.3.1 Hilla River segmentation

The distribution of water quality along a river was simulated using the QUAL2K model. This process involves dividing the river's length into segments, each of which is further subdivided into evenly spaced elements. In this study, the Hilla River, which spans a length of 6.8 kilometers, was divided into appropriate segments, into five reaches from the upstream boundary (headwater) to the downstream boundary. Figure (3.5) shows the segmentation of the river system. The river system was covered by nine stations, as listed in Table (3.1), along the river length to get the required data for building the model.

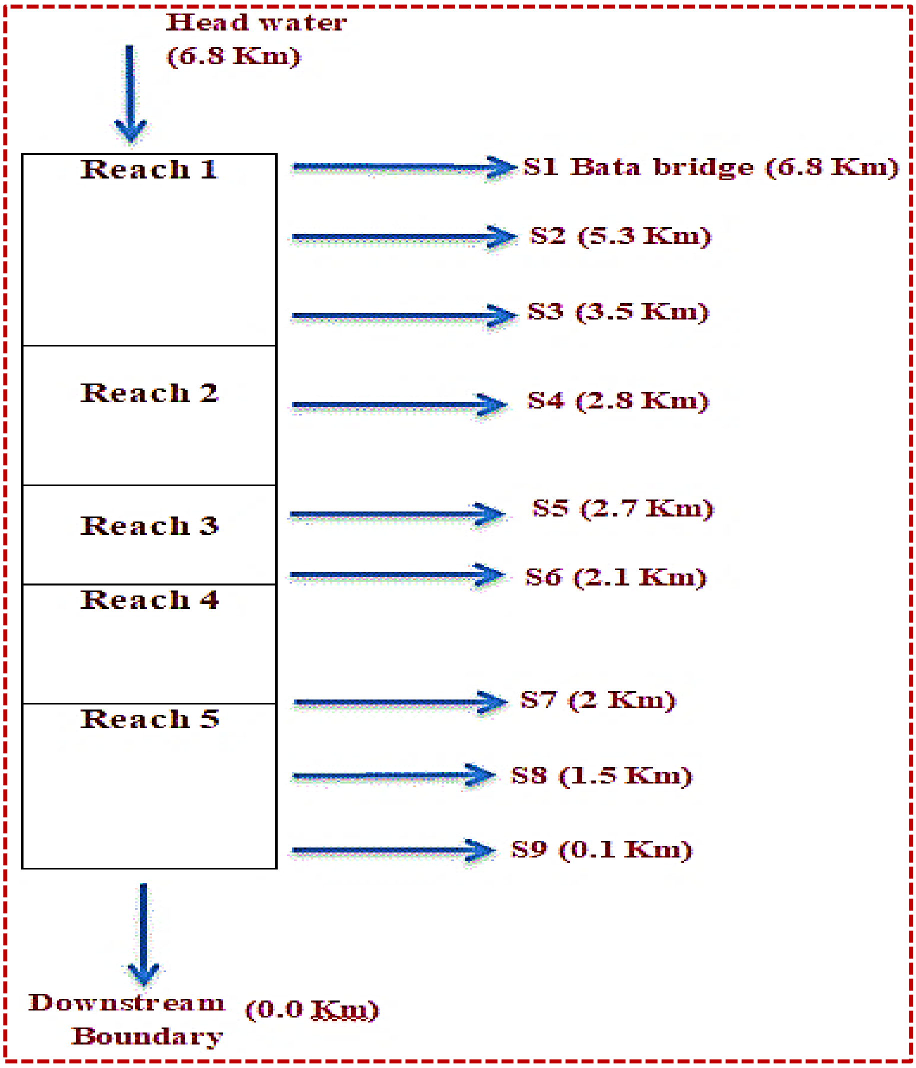

Fig. (3.5): The division of the study area within the Hilla River using the model.

For every model element, the model conducts a steady-state flow balance, as depicted in Figure (3.6) where:

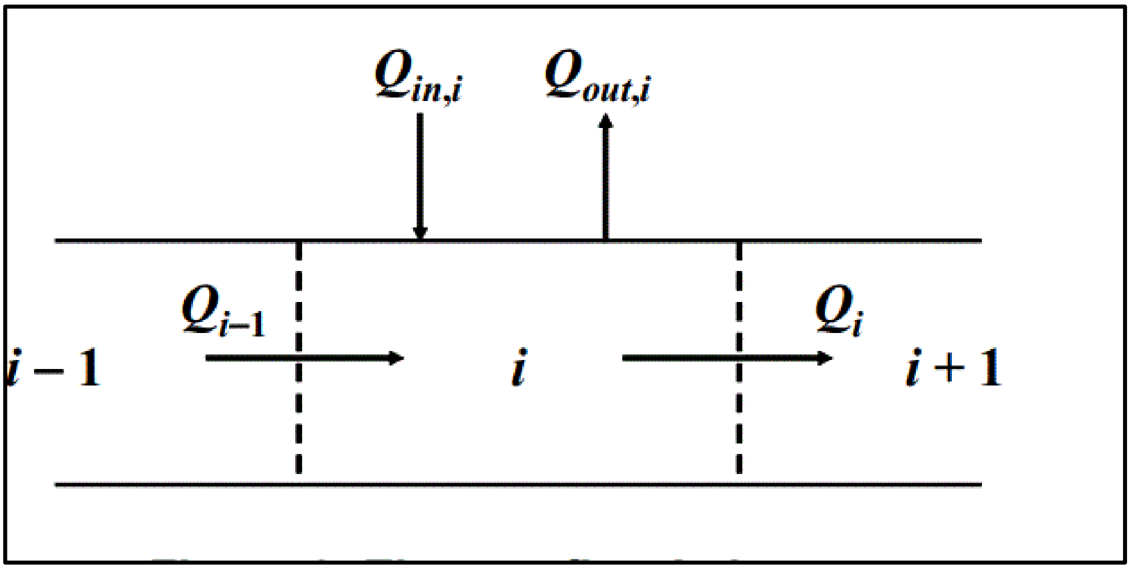

Fig. (3.6): Reach flow balance.

$$Q_i = Q_{i-1} + Q_{in,i} - Q_{out,i} \quad (3.1)$$

Where:

Q_i = outflow from element i into the downstream element i + 1, m^3/d

Q_{i-1} = inflow from the upstream element i – 1, m^3/d

$Q_{in,i}$ = the total inflow into the element from point and nonpoint sources, m^3/d

$Q_{out,i}$ = the total outflow from the element due to point and nonpoint withdrawals, m^3/d.

Once the outflow for each section has been established, the depth and velocity are calculated using one of three methods: weirs, rating curves, or Manning equations.

Each section is envisioned as a trapezoidal canal (Figure 3.7). Assuming constant flow, the Manning equation was used to get the following connection between flow and depth (Chapra & Canale, 2006):

$$Q = \frac{S^{1/2}}{n}\frac{Ac^{5/3}}{p^{2/3}} \quad (3.2)$$

Where:

Q = flow, m^3/d

S = bottom slope, m/m

n = the Manning roughness coefficient

Ac = the cross-sectional area, m^2

P = the wetted perimeter, m

The cross-sectional area of a trapezoidal channel, Figure (3.7), is calculated as:

$$A_c = [B_\circ + 0.5(S_{s1} + S_{s2})H]H \quad (3.3)$$

Where:

B_0 = bottom width, m

S_{s1} and S_{s2} = the two side slopes, m/m

H = element depth, m

The wetted perimeter (P) is computed as:

$$P = \left[B_\circ + H\sqrt{S^2{}_{s1} + 1} + H\sqrt{S^2{}_{s2} + 1}\right] \quad (3.4)$$

After substituting Equations (3.3) and (3.4), Equation (3.2) can be solved iteratively for depth as (Chapra & Canale, 2006) :

$$H_k = \frac{Qn^{3/5}\left(B_\circ + H_{k-1}\sqrt{S^2{}_{s1}+1} + H_{k-1}\sqrt{S^2{}_{s2}+1}\right)}{S^{3/10}[B_\circ + 0.5(S_{s1}+S_{s2})H_{k-1}]} \quad (3.5)$$

Where:

k = 1, 2, …, Ni

Ni = the number of iterations.

Suggested values for the Manning coefficient are listed in appendix C. Manning's n typically varies with flow and depth (Gordon et al., 1992). As the depth decreases at low flow, the relative roughness usually increases. Typical published values of Manning's n, which range from about 0.015 for smooth channels to about 0.15 for rough natural channels, are representative of conditions when the flow is at the bankfull capacity (Rosgen, 1996). Critical conditions of depth for evaluating water quality are generally much less than bankfull depth, and the relative roughness may be much higher. For example, in upland streams, rather than the type of bed material, the roughness is heavily influenced by the pool-riffle structure and can be very large (Beven et al., 1979).

The method is terminated when the estimated error ($\mathcal{E}_a$) falls below a specified value of 0.001%, (Chapra & Canale, 2006):

$$\mathcal{E}_a = \left|\frac{H_{k+1} - H_k}{H_{k+1}}\right| * 100\% \tag{3.6}$$

The cross-sectional area is determined with Equation (3.3) and the velocity can then be determined from the continuity equation,

$$U = \frac{Q}{A_c} \tag{3.7}$$

The average element width, B (m), is computed as:

$$B = \frac{A_c}{H} \tag{3.8}$$

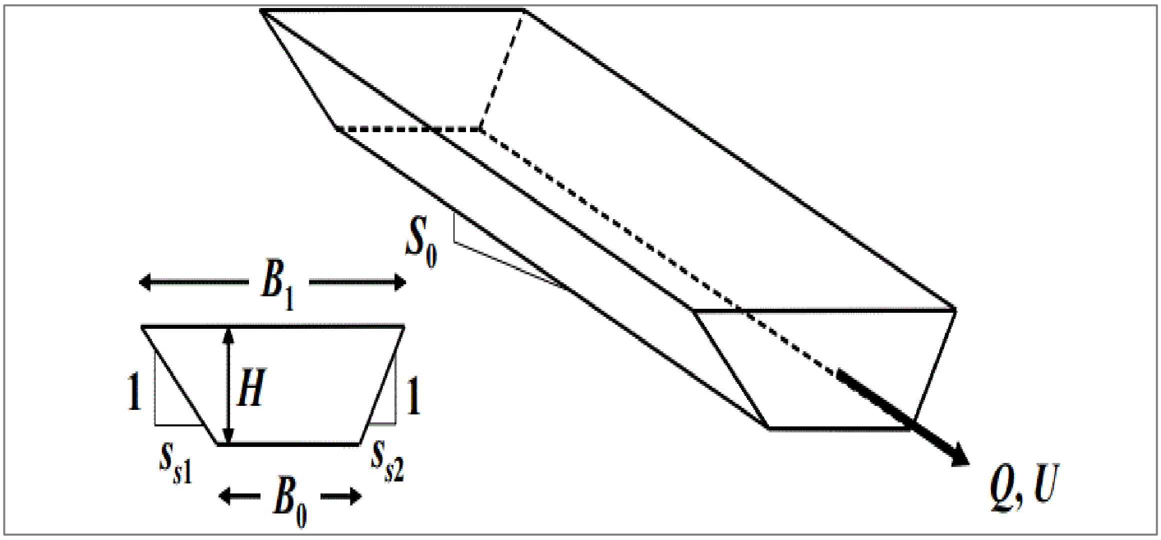

Fig. (3.7): Model representation of a trapezoidal channel.

The dispersion coefficient is recognized as a key parameter that defines the river or stream's capacity to disperse pollutants (Himesh et al., 2000). A hydraulics based formula is used in the QUAL2K to internally calculate longitudinal dispersion for two segments boundary based on the channel hydraulics (Fischer et al., 1979):

$$E_{p,i} = 0.011 \frac{U_i^2 B_i^2}{H_i U_i^*} \tag{3.9}$$

Where:

Ep,i = the longitudinal dispersion between elements i and i + 1, m^2/s

Ui = velocity, m/s

Bi = width, m

Hi = mean depth, m

Ui * = shear velocity, m/s, which is related to more fundamental characteristics by:

$$U_i^* = \sqrt{g H_i S_i} \tag{3.10}$$

Where:

g = 9.81, m/s^2

Si = sloping channel

3.5.3.2 Governing equations

The river segment has been subdivided into multiple sub-segments, each serving as a computational element. Each computational element maintains a hydrological balance with respect to flow, a thermal balance in relation to temperature, and a mass balance in terms of concentration. The model constituents are listed in appendix D. QUAL2K can be described in the following one dimension governing equation (Rafiee et al., 2014) :

$$\underbrace{V\frac{\partial c}{\partial t}}_{\text{Accumulation}} = \underbrace{\underbrace{\frac{\partial\left(A_c E\frac{\partial c}{\partial x}\right)}{\partial x}dx}_{\text{Dispersion}} - \underbrace{\frac{\partial(A_c U_c)}{\partial x}dx}_{\text{Advection}}}_{\text{Transport}} + \underbrace{V\frac{dc}{dt} \pm S}_{\text{Source \& Sinks}} \qquad (3.11)$$

Where:

V= volume, m^3

x = distance, m

C = concentration of water quality constituent in segment i, g/m^3

S = a result of reactions and mass transfer processes, constituents become sources and sinks, g/m^3/d or mg/m^3/d.

The assumptions in the model are;

1- The density of polluted water is constant and similar to clean water density.

2- Only longitudinal hydrodynamic dispersion occurs.

3- River flow systems assuming steady-state, non-uniform

The Q2K uses a finite difference to solve the governing equation and is configured as a one dimension steady state (Mustafa et al., 2017).

Constituent Model the QUAL2K model includes16 state variables which are : conductivity (s), inorganic suspended solids (mi), dissolved oxygen (o), slowly reacting CBOD (cs), fast reacting CBOD (cf), dissolved organic nitrogen (no) , ammonia nitrogen (na), nitrate nitrogen (nn) , dissolved organic phosphorus (po), inorganic phosphorus (pi), phytoplankton (a), detritus (mo), pathogen(x), alkalinity (Alk), total inorganic carbon (cT), and bottom algae (ab).

The general mass balance numerical scheme that results from applying Equation (3.12) for each element Figure (3.8) gives the folllowing constituent model, Equation (3.12):

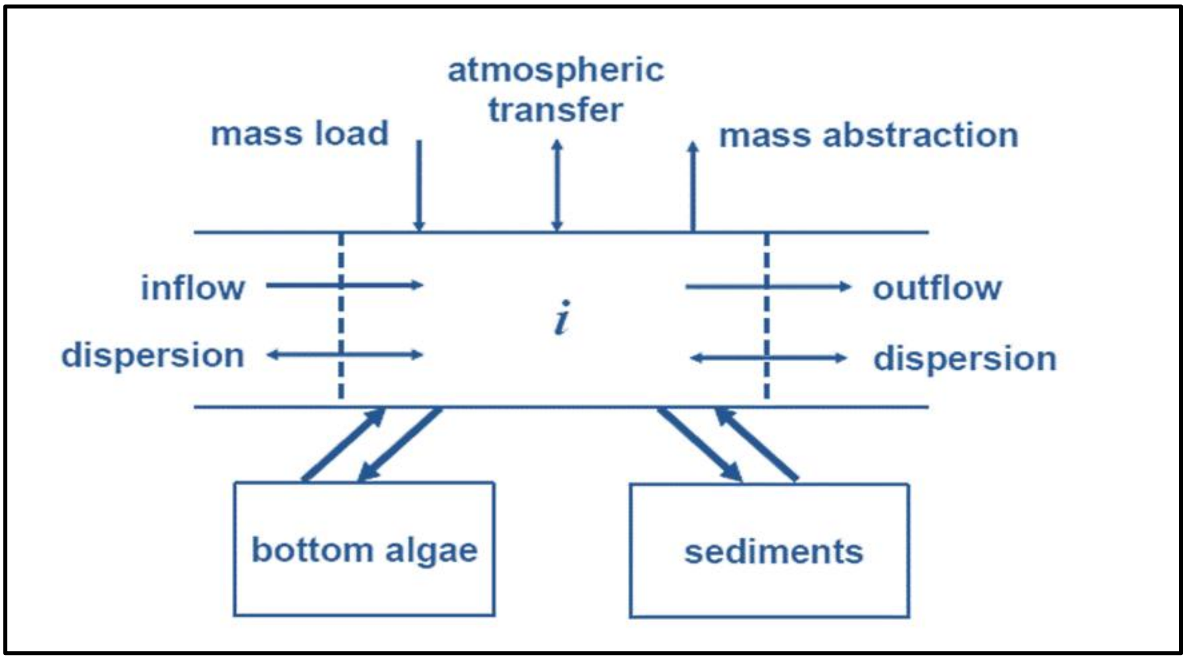

Fig. (3.8): Mass balance for an element.

$$\frac{d_{ci}}{dt} = \frac{Q_{i-1}}{V_i} C_{i-1} - \frac{Q_i}{V_i} C_i - \frac{Q_{ab,i}}{V_i} C_i + \frac{E_{i-1}}{V_i} (C_{i-1} - C_i) + \frac{E_i^{\bullet}}{V_i} (C_{i+1} - C_i) + \frac{W_i}{V_i} \pm S_i \qquad (3.12)$$

Where:

C_i = concentration of water quality constituent in segment i, g/m^3

W_i = the constituent's external loading, g/d or mg/d

$\dot{E}_i$ = the bulk dispersion coefficient between segments i and i + 1

$\dot{E}_{i-1}$ = bulk dispersion coefficients between segments i−1 and i, m^3/d

V_i = volume of segment i, m^3

t = time, d

The bulk dispersion coefficient is calculated as:

$$E_i^{\bullet} = \frac{E_i A_{c,i}}{(\Delta X_i + \Delta X_{i+1})/2} \quad (3.13)$$

The external load is computed as:

$$W_i = \sum_{j=1}^{psi} Q_{ps,i,j}\, C_{ps,i,j} + \sum_{j=1}^{npsi} Q_{nps,i,j}\, C_{nps,i,j} \quad (3.14)$$

Where:

$C_{ps,i,j}$ = the j^{th} segment (i) concentration of point sources, mg/l or µg/l.

$C_{nps,i,j}$ =the jth segment(i) concentration of non point sources i, mg/l or µg/l.

The schematic diagram in Figure (3.9) shows the sources and sinks of the water quality component caused by reactions and mass transfer processes in Equation (3.12).

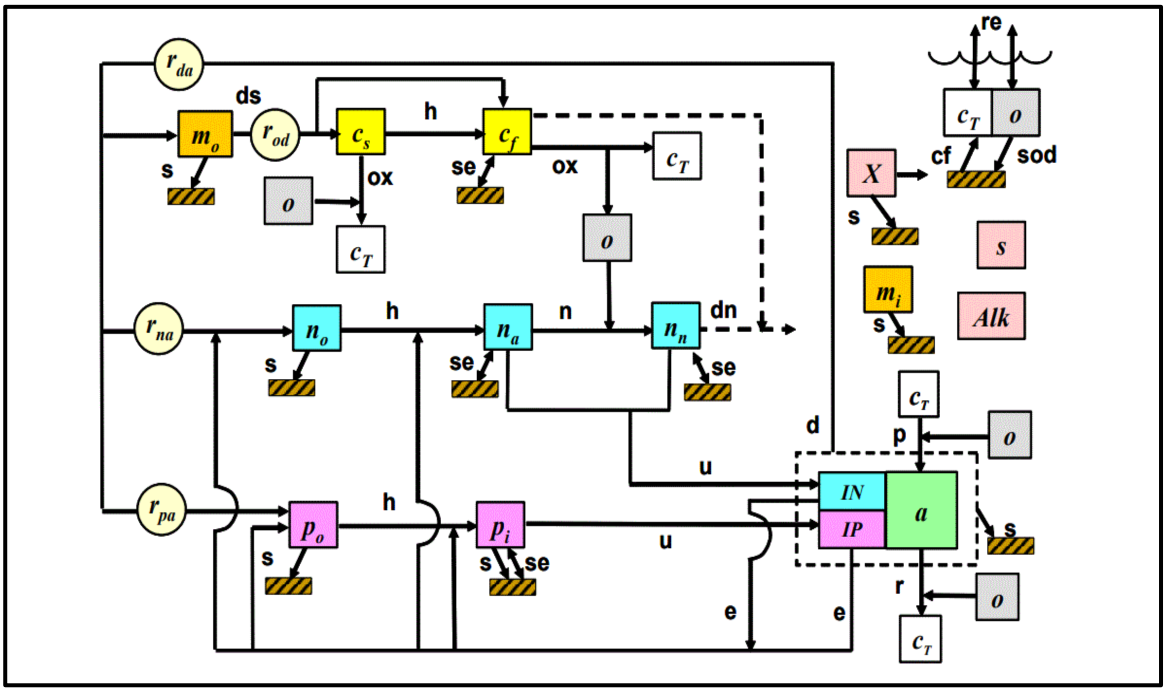

Fig. (3.9): Model kinetics and mass transfer processes (Steve Chapra et al., 2012),for each parameter definition see (Appendix D).

Within the model, various kinetic processes (ds for dissolution, h for hydrolysis, x for oxidation, n for nitrification, dn for denitrification, p for photosynthesis, d for death, and r for respiration) represent reactions and transformations. Meanwhile, mass transfer mechanisms (re for reaeration, s for settling, SOD for sediment oxygen demand, and cf for sediment inorganic carbon flow) play a role in the transport of substances. In stoichiometric conversions, the subscripts 'a' and 'd' denote chlorophyll a and dry weight for phytoplankton and bottom algae, respectively (Appendix D).

The equations below describe the "sources and sinks" of water quality metrics (DO, CBOD, and EC):

- Conservative Substance, conductivity (s): This does not undergo reactions (Ss = 0).

- Dissolved Oxygen (o): Plant photosynthesis increases dissolved oxygen. It is lost as a result of rapid CBOD oxidation, nitrification, and plant respiration:

$$So = r_{oa}PhytoGrowth + r_{od}BottAlgGrowth - r_{oc}FastCOxid - r_{on}NH_4Nitr - r_{oa}PhytoResp - r_{od}BotAlgRes + OXReaer \quad (3.15)$$

Where:

r_{on} = The ratio of oxygen to nitrogen consumed during nitrification.

r_{od} = The ratio of oxygen to nitrogen consumed during denitrification.

r_{oc} = The ratio of oxygen consumed per organic carbon oxidized to carbon dioxide

r_{oa} = The ratio of oxgyen to Bottom algae during photosynthesis and respiration.

Phyto Growth = Phytoplankton increase due to photosynthesis rate .

Phyto Resp = Phytoplankton lost via respiration rate .

BottmAlgGrowth = Bottom algae increase due to photosynthesis .

BottmAlgResp = Bottom algae lost via respiration .

$$OXReaer = Ka(T)(OS\ (T, elev) - O) \quad (3.16)$$

$Ka\ (T)$ = the coefficient for oxygen reaeration, which is dependent on temperature.

$OS\ (T,\ elev)$ = the saturation oxygen concentration (mg/l) at a particular temperature T and elevation above sea level.

- **Carbonaceous Biochemical Oxgyen Demand (CBOD):**

  - Slowly reacting CBOD($\boldsymbol{c_s}$) the concentration of slowly reacting carbonaceous biochemical oxygen demand ($\boldsymbol{cs}$) gradually rises as a result of detritus dissolution. It is subsequently reduced through the process of hydrolysis:

$$\boldsymbol{Scs} = \boldsymbol{r_{od}}\ \boldsymbol{DetrDiss} - \boldsymbol{SlowCHydr} \quad (3.17)$$

Where:

$$SlowCHydr = k_{hc}\,(T)cs \qquad (3.18)$$

DetrDiss = dissolution rate.

k_{hc} (T) = the temperature-dependent slow CBOD hydrolysis rate, 1/d

- **Fast-reacting carbonaceous CBOD (c_f)** is generated through the hydrolysis of slowly-reacting CBOD. Subsequently, it is reduced through oxidation and denitrification processes.:

$$Scf = SlowCHydr - FastCOxid - _{rondn}\,Denitr \qquad (3.19)$$

Where:

$$FastCOxid = F_{oxc}\,k_{dc}\,(T)_{cf} \qquad (3.20)$$

Where :

r_{ondn} = The ratio of oxygen equivalents lost per nitrate nitrogen.

Denitr = rate of denitrification [μgN/l/d]

$kdc\ (T)$ = the temperature-dependent fast CBOD oxidation rate, 1/d

$Foxc$ = attenuation due to low oxygen

- **Reaeration coefficient**

The reaeration coefficient (Ka) (at 20 ^{o}C) can be prescribed on the Reach Worksheet. If reaeration is not prescribed (that is, it is blank or zero for a particular reach), it is computed as a function of the river's hydraulics and (optionally) wind velocity,

$$k_a(20) = k_{ah}(20) + \frac{K_{Lw}(20)}{H} \qquad (3.21)$$

where k_{ah} (20) = the reaeration rate at 20 ^{o}C computed based on the river's hydraulic characteristics [d^{-1}]. K_{LW} (20) = the reaeration mass-transfer coefficient based on wind velocity [m/d]. H = mean depth [m].

Hydraulic-based Formulas:

- O'Connor-Dobbins (O'Connor and Dobbins, 1958):

$$k_{ah}(20) = 3.93\frac{U^{0.5}}{H^{1.5}} \qquad (3.22)$$

where U = mean water velocity [m/s] and H = mean water depth [m].

- Churchill (Churchill et al, 1962):

$$k_{ah}(20) = 5.026\frac{U}{H^{1.67}} \qquad (3.23)$$

- Owens-Gibbs (Owens et al, 1964):

$$k_{ah}(20) = 5.32\frac{U^{0.67}}{H^{1.85}} \qquad (3.24)$$

- Tsivoglou- Neal (Tsivoglou and Neal, 1976):

Low flow, Q = 0.0283 to 0.4247 cms (1 to 15 cfs):

$$k_{ah}(20) = 31{,}183\ US \qquad (3.25)$$

High flow, Q = 0.4247 to 84.938 cms (15 to 3000 cfs):

$$k_{ah}(20) = 15{,}308\ US \qquad (3.26)$$

where S = channel slope [m/m].

- Thackston-Dawson (Thackston and Dawson, 2001):

$$k_{ah}(20) = 2.16(1 + 9F^{0.25})\frac{U_*}{H} \tag{3.27}$$

where U* = shear velocity [m/s], and F = the Froude number [dimensionless]. The shear velocity and the Froude number are defined as:

$$U_* = \sqrt{gR_h S} \tag{3.28}$$

and

$$F = \frac{U}{\sqrt{gH_d}} \tag{3.29}$$

where g = gravitational acceleration (= 9.81 m/s2), R_h = hydraulic radius [m], S = channel slope [m/m], and H_d = the hydraulic depth [m]. The hydraulic depth is defined as :

$$H_d = \frac{A_c}{B_t} \tag{3.30}$$

where B_t = the top width of the channel [m].

- USGS (Pool-riffle) (Melching and Flores, 1999):

Low flow, Q < 0.556 cms (< 19.64 cfs):

$$k_{ah}(20) = 517(US)^{0.524} Q^{-0.242} \tag{3.31}$$

High flow, Q > 0.556 cms (> 19.64 cfs):

$$k_{ah}(20) = 596(US)^{0.528} Q^{-0.136} \tag{3.32}$$

where Q = flow (cms).

- USGS (Channel-control) (Melching and Flores, 1999):

Low flow, Q < 0.556 cms (< 19.64 cfs):

$$k_{ah}(20) = 88(US)^{0.313} H^{-0.353} \tag{3.33}$$

High flow, Q > 0.556 cms (> 19.64 cfs):

$$k_{ah}(20) = 142(US)^{0.333} H^{-0.66} B_t^{-0.243} \tag{3.34}$$

- Internal (Covar, 1976):

Reaeration can also be internally calculated based on the following scheme patterned after a plot developed by Covar (1976) (Figure 21):

- If H < 0.61 m, use the Owens-Gibbs formula
- If H > 0.61 m and H > $3.45U^{2.5}$, use the O'Connor-Dobbins formula
- Otherwise, use the Churchill formula.

This is referred to as option Internal on the Rates Worksheet of QUAL2K. Note that if no option is specified, the Internal option is the default.

- pH, alkalinity, and total inorganic carbon

Simulation is performed for both alkalinity and total inorganic carbon, which are then utilized to predict the pH of the river (Mustafa et al., 2017) .QUAL2K incorporates mathematical equations and algorithms to simulate the complex interactions and dynamics of alkalinity, total inorganic carbon, and pH in the water body. By considering factors such as nutrient dynamics, chemical reactions, dissolved oxygen dynamics, and other relevant processes, the model predicts the pH levels within the river system under different scenarios, including changes in pollutant loadings or control measures. The simulated pH values obtained from the QUAL2K model can provide valuable insights into the overall water quality conditions of the river or stream. They can help identify areas of potential concern, assess the impacts of pollution sources, and evaluate the effectiveness of water quality management strategies. By incorporating pH into the water quality modeling framework, QUAL2K enhances our understanding of the complex relationships between water quality parameters, enabling more informed decision-making for water resource management and protection. A comprehensive explanation of the processes and mathematical formulations governing the interplay of water quality state variables, along with the constituent-specific governing equations, can be found in the model's user manual.

Conclusively, the heat equilibrium illustrated in Figure (3.10) takes into account the heat transfers from neighboring segments, loads, extractions, sediments, and the atmosphere. (Chapra et al., 2003). A heat balance can be written for the element i as:

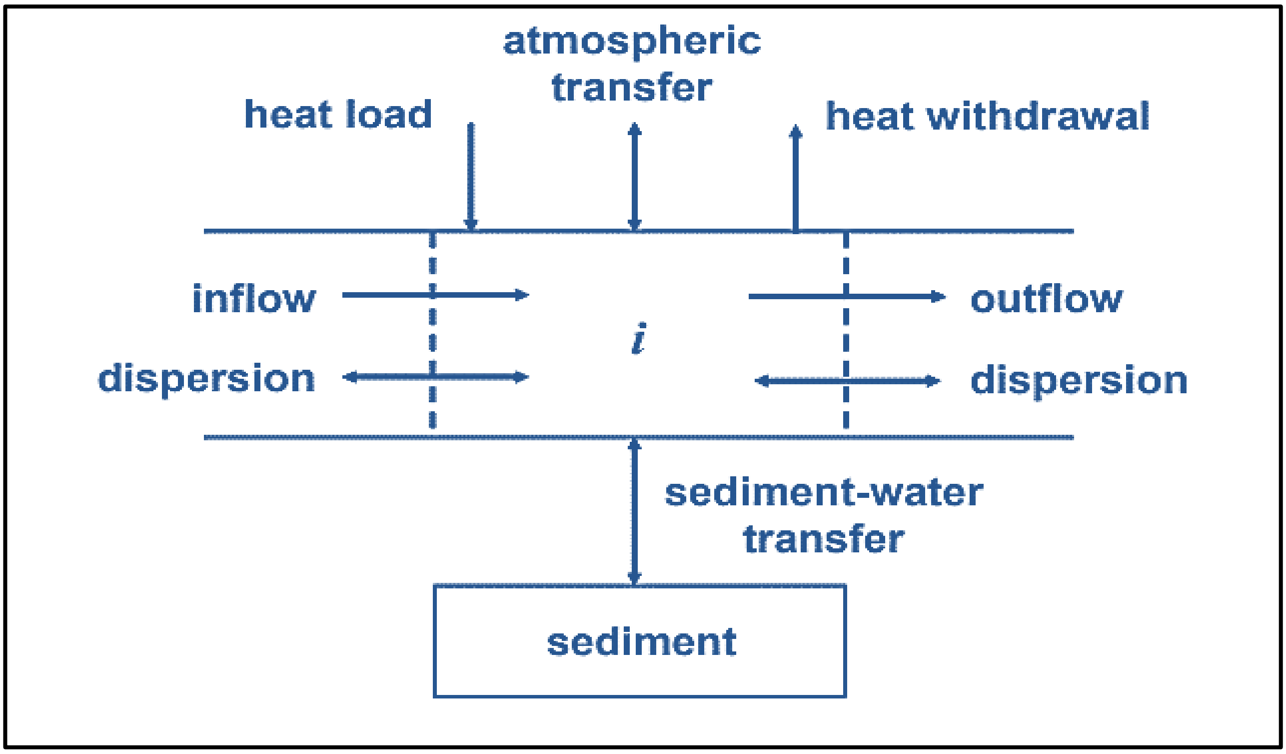

Fig. (3.10): Heat balance in a reach segment i.

$$\frac{dT_i}{dt}=\frac{Q_{i-1}}{V_i}T_{i-1}-\frac{Q_i}{V_i}T_i-\frac{Q_{out,i}}{V_i}T_i+\frac{E'_{i-1}}{V_i}(T_{i-1}-T_i)+\frac{E'_i}{V_i}(T_{i+1}-T_i)$$
$$+\frac{W_{h,i}}{\rho_w C_{pw} V_i}\left(\frac{\text{m}^3}{10^6\ \text{cm}^3}\right)+\frac{J_{a,i}}{\rho_w C_{pw} H_i}\left(\frac{\text{m}}{100\ \text{cm}}\right)+\frac{J_{s,i}}{\rho_w C_{pw} H_i}\left(\frac{\text{m}}{100\ \text{cm}}\right) \quad (3.35)$$

Where:

Ti = temperature in element I, ^{o}C

t = time, d

E'_i = the bulk dispersion coefficient between elements i and i + 1, m^3 /d

$W_{h,i}$ = the net heat load from point and non-point sources into element i, cal/d

ρ_w = the density of water, g/cm^3

C_{pw} = the specific heat of water, cal/(g^{o}C)

$J_{a,i}$ = the air-water heat flux, cal/(cm^2.d)

$J_{s,i}$ = the sediment-water heat flux, cal/(cm^2.d).

The net heat load from sources is calculated as:

$$W_{h,i}=\rho C_p\{\sum_{j=1}^{psi} Q_{ps,i,j}\, T_{ps,i,j}+\sum_{j=1}^{npsi} Q_{nps,i,j} T_{nps,i,j} \quad (3.36)$$

Where:

$T_{ps,i,j}$ = the temperature of the jth point source for element i, ^{o}C

$T_{nps,i,j}$= the temperature of the jth non-point source temperature for element i , ^{o}C

$$J_{s,i}=\rho_s C_{ps}\frac{\alpha_s}{H_{sed,\frac{i}{2}}}(T_{si}-T_i)*\frac{86{,}400S}{d} \quad (3.37)$$

Where:

$\boldsymbol{T_{si}}$ = the temperature of the bottom sediment below segment i, $°C$

$\boldsymbol{\rho_s}$ = the density of the sediments, g/cm^3

$\boldsymbol{C_{ps}}$ = the specific heat of the sediments, cal/(g $°C$)

Hsed,$\boldsymbol{i}$ = the effective thickness of the sediment layer, cm

αs = the sediment thermal diffusivity, cm^2 /s

$$J_h = I(0) + J_{an} - J_{br} - J_c - J_e \quad (3.38)$$

where I(0) = net solar shortwave radiation at the water surface

J_{an} = net atmospheric longwave radiation

J_{br} = longwave back radiation from the water

J_c = conduction

J_e = evaporation. All fluxes are expressed as cal/cm2 /d.

For more information on the specific procedures for surface heat flux and sediment-water heat flux see (Chapra et al., 2003).

3.5.4 Model implementation for Hilla River

In the present study, QUAL2K simulates the Hilla River's water quality, including DO, CBODu, pH, Alk, EC, and temperature. Input data for the model were gathered from Google Earth, the laboratory findings for analyzing the river samples, and the weather for the Hilla River on October 2022 and January 2023.

3.5.4.1 Model setup and data input

As previously indicated, QUAL2K calls for a variety of data dispersed over many spreadsheets. Within the QUAL2K model, there are two distinct categories of worksheets utilized for data input: simulation data worksheets and calibration data worksheets. The simulation data worksheets encompass information related to headwater, reach, diffuse, and point sources. On the other hand, the calibration data worksheets are specifically designated for hydraulic data and water quality data input. The sources of the data entered into the spreadsheets are shown in Table (3.2) Figure (3.11) shows QUAL2K worksheet.

Table (3.2): QUAL2K data input in the work sheet.

NO.	Worksheet name	Data
1	Headwater	Q, Channel Slope, roughness' n, Bottom width
		Elevation
		Water quality data parameters
2	Reach	Location (Up and downstream of each reach)
		Elevation (up and downstream)
		Channel slope, roughness, n, Bottom width
3	Point source	Location
		Inflow
		Water quality data parameters
4	Hydraulic data	River Discharge, manning coefficient
5	Water quality data	Locations of water quality stations
		Water quality parameters
6	Meteorology data	Air temperature, dew point temperature, wind speed, cloud cover

QUAL2K FORTRAN
Stream Water Quality Model
Steve Chapra, Hua Tao and Greg Pelletier
Version 2.12b1

System ID:		
River name	Hillia River	
Saved file name	HilliaRiver_run0	
Directory where file saved	F:\GradStudents\Shahad	
Month	10	
Day	29	
Year	2022	
Local time hours to UTC	-9	
Daylight savings time	No	
Calculation:		
Calculation step	0.03	hours
Final time	30	day
Solution method (integration)	Euler	
Solution method (pH)	Brent	
Time zone	Alaska Time	
Program determined calc step	0.023438	hours
Time of last calculation	1.77	minutes
Time of sunrise	##	
Time of solar noon	6:01 AM	
Time of sunset	12:39 PM	
Photoperiod	13.26	hours

Open Old File

Run Fortran

Fig. (3.11): The QUAL2K worksheet.

➢ <u>Headwater Data</u>

Hydraulic data and water quality parameters are the upstream water data that must be entered into the QUAL2K model. According to the study's goals and the available data, the form permits the insertion of a variety of water quality criteria. In headwaters, QUAL2K requires hydraulic information on height, discharge, cross-section (bottom width), channel slope, and roughness modulus "n." From sample points from each of the field measurements, this information was gathered. On the other hand, the criteria for measuring water quality were obtained using data on water quality monitoring.

➢ **Reach Data**

Channel information is required for each reach, together with the number of components and the distance in kilometers between upstream and downstream for each segmented reach. These statistics came from Google Earth. Table (3.3) lists the nodes and lines utilized in the QUAL2K model. Figures (3.12) and (3.13) show the reach segment length and geographic longitude and latitude calculated for this investigation using Google Earth. The segmentation of the input model and the locations and lengths of each segment are displayed in Table (3.4).

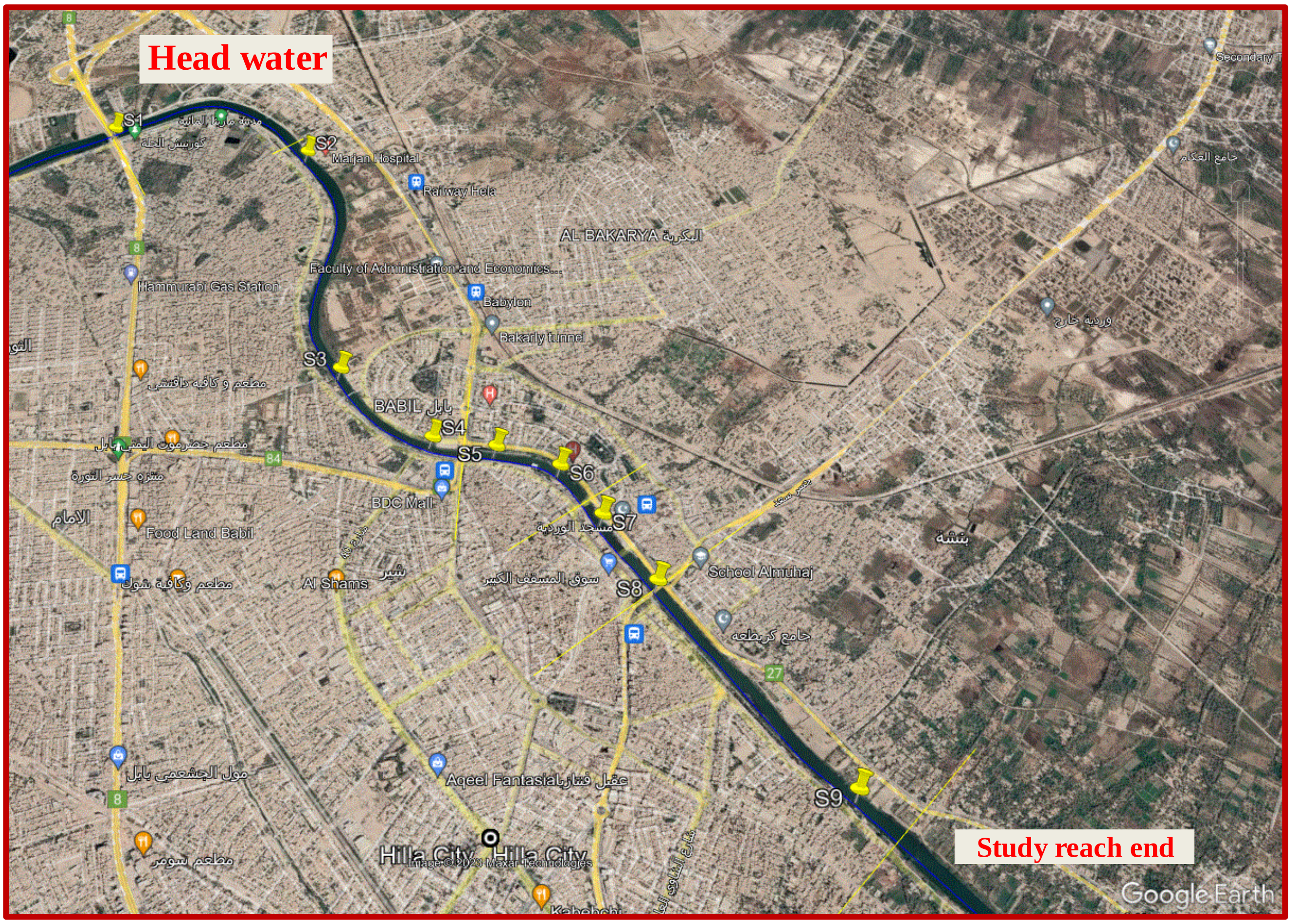

Fig. (3.12): Study reach (Google earth).

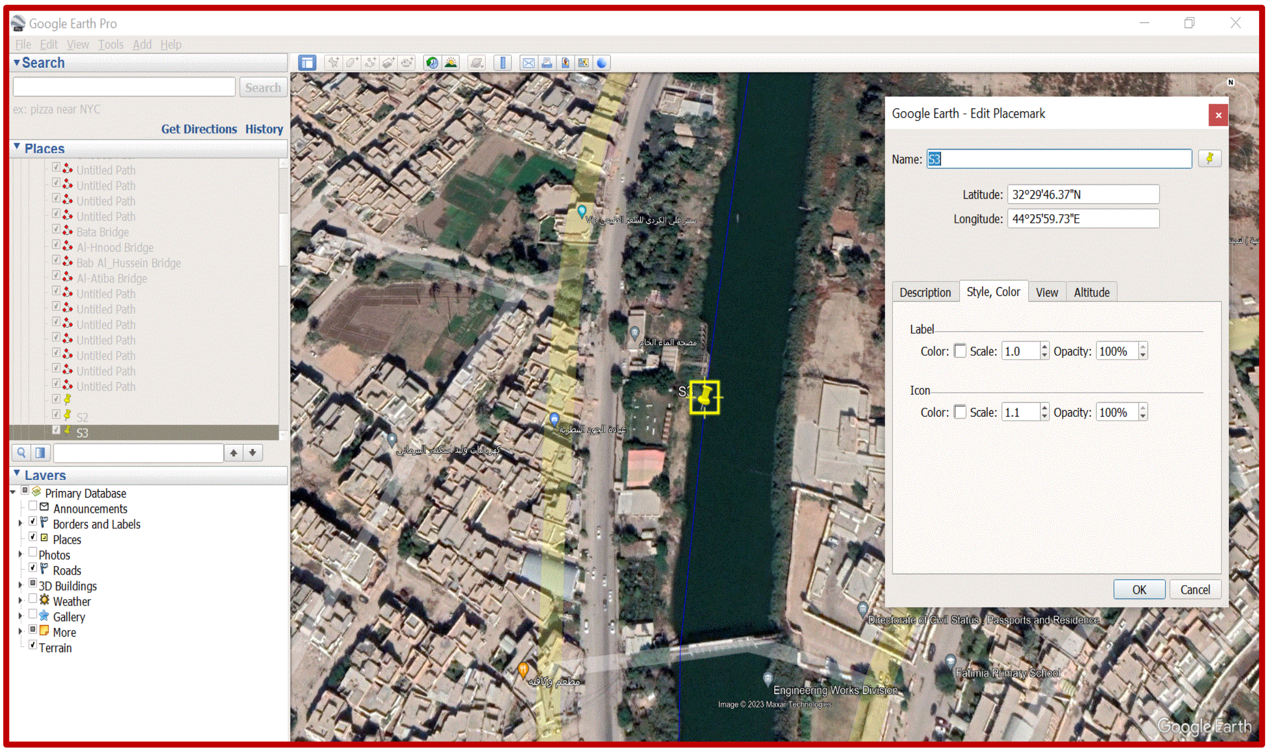

Fig. (3.13): Geographical coordinates of the segment (as obtained from Google earth).

Table (3.3): Reaches utilized in the QUAL2K model.

Reach No	Reach length (km)	Location		Element Number
		Up-stream (km)	Down-stream (km)	
1	1.50	6.800	5.300	6
2	2.40	5.300	2.900	10
3	0.90	2.900	2.000	4
4	0.50	2.000	1.500	2
5	1.50	1.500	0.000	6

Table (3.4): Location of each reach along the Hilla River.

Reach No	Downstream Location (km)	Elevation		Downstream					
		Upstream	Downstream	Latitude			Longitude		
				Deg	Min	Sec	Deg	Min	Sec
1	5.300	31	31	32.00	30	35	44.00	26	14.81
2	2.900	31	31	32.00	29	16	44.00	26	20.64
3	2.000	31	30	32.00	29	43	44.00	26	23.21
4	1.500	30	30	32.00	28	49	44.00	26	22.67
5	0.000	30	29	32.00	27	54	44.00	26	27.08

- **Point Sources Data**

are employed to input data pertaining to the system's point sources. The model defines the location as a single point with regard to the point sources based on its separation from the reaches downstream. As a result, Google Earth was utilized to locate the point sources.The gathered point source data was used to determine the inflow information for each point source.

- **Hydraulic Data**

Used to enter information about hydraulic systems The information used for hydraulic calibration is included in this spread sheet. The findings of the samples that were evaluated in the lab and the on-site temperatures, which were recorded in this worksheet, were used to determine the position of the measuring station.

- **Meteorology Data**

The required meteorological data for air temperature, dew point temperature, wind speed, and cloud cover in the low and high flow seasons are obtained from the weather site by watching the weather conditions for twenty-four hours and collecting the weather data for the same day of sampling from the chosen sampling locations as shown in Table (4.5) . This information is then used for the calibration and validation of the model.

Furthermore, the QUAL2K model's simulations of chemical, physical, and biological processes are represented by a system of equations with several parameters. Some of the variables are related to space, some are universal constants, and some are temperature-dependent. In-depth explanations of these parameters and related procedures may be found in the QUAL2K user's handbook (Chapra et al., 2006). The ranges of model rate parameters required for QUAL2K were determined using sources including the Environmental Protection Agency (EPA) guidelines (USEPA, 1985b) and documentation for the enhanced stream water quality models QUAL2E and QUAL2E-UNCAS. (Brown & Barnwell, 1987).

3.5.4.2 Model calibration and validation

To get high model performance, model calibration and validation are essential processes. The calibration and validation procedure is crucial for determining the accuracy of model simulations and the overall dependability of the calibrated model. In order to get the best possible agreement between the simulated and observed data, parameter values must be adjusted, or "tuned," during calibration. Numerical values must be provided for the model's parameters, state variable beginning condition, boundary conditions, etc. during model calibration. Model validation is the procedure of evaluating the level of dependability of the calibrated model using one or more independent data sets, i.e., data that were not used for calibration. It is a procedure for determining whether the model achieves the stated objectives. The model's calibrated parameters are kept constant. The independent beginning and boundary conditions (stream water quality, headwater stream discharge), which are added to the model to simulate new situations, are input while maintaining the calibrated model parameters (hydraulic conditions, climatic conditions, etc.) (Mohamed, 2003) (Ali et al., 2012) .

Hence, statistical errors including mean absolute error (MAE) and root mean square error (RMS) were used to assess the error between the predicted and observed water quality indicators (Najafzadeh & Azamathulla, 2013; Najafzadeh & Barani, 2011).

$$\boldsymbol{RMSE} = \sqrt{(\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \quad \textbf{(3.39)}$$

$$\boldsymbol{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - y_i| \quad \textbf{(3.40)}$$

Where:

n = number of observations

$\hat{y}_i$ = number of predicted data

y_i = umber of observed data

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The results and main findings of this study are discussed in this chapter to investigate the river water quality in two phases. The first phase includes the model calibration and validation process to ensure the robustness of the procedure and measurements of the water quality variables. The second one involved a parametric study by performing a sensitivity and management analysis for the measured variables. The parameters of the study are DO, CBODu, pH, EC, Alk, and Temp. Thus, this chapter consists of three parts. Model inputs data and the model calibration/validation are included in the first part in addition to the simulation results of the considered water quality constituents. The second part provides some proposed management scenarios for the Hilla River. Finally, sensitivity analyses and management scenarios were performed to highlight how some factors can impact the model performance.

4.2 Model calibration and validation

The examination of DO, CBODu, pH, EC, Alk, and Temp was the calibration parameters for the water quality model built in this work. Field measurements during the dry and wet seasons of October 2022 and January 2023 were used by the Q2K model for the process, see Appendix A & B. Based on information about the typical water quality, samples from the Hilla River water were obtained and tested. During the calibration of the model, a correction was applied for the missing water quality data at the headwaters. An adjustment was also made to the model inputs (coefficients) to establish an acceptable relationship between the calculated and observed data. The required information for the calibration purposes can be provided either directly by measurements or by utilizing input parameters and constant values from a complete model for a study area similar to the area to be observed in the current study (Edwards et al., 1997 and Daggupati et al., 2015).

Tables (4.1, 4.2, 4.3, 4.4 and 4.5) present the drinking water standards and the water quality input data for the model headwater and stations for both seasons in addition to the meteorological data. comparing the experimental results against the standards, it was obtained that the average value of DO (9.95 and 9.97 mg/l for October and January, respectively) was higher than the minimum Iraqi and WHO standards (which equal to 5 mg/l) and can be considered as an acceptable value. Concerning the CBODu limit, the average values for October and January were 2.12 and 2.06 mg/l, respectively, which were within the standards. Regarding pH, the October and January values (7.78 and 8.16 mg/l) were comparable to the standards (7.58 and 8.16 mg/l, respectively). The average value of EC was 1322.5 and 1565.05 mg/l for October and January, respectively, which are lower than the Iraqi and WHO standards (2000 mg/l). For the remaining parameters, ALK average values (120.13 and 143.5 mg/l), and Temp average values (23.22 and 14.70 ℃) which were acceptable compared to the standards. These measurements agreed with previous study performed by Al-Kareem and ALKizwini (2022) at the same study area.

Table (4.1): Iraqi standards (2009) and WHO standards (2017) for drinking water.

Parameter	Unit	Iraqi Standards	WHO Standards
BOD_5	mg/l	Nil	5
DO	mg/l	5	5
pH	-	6.5-8.5	6.5-8.5
EC	µs/cm	2000	2000
ALK	mg/l	200	120
Temp	℃	-	25

Table (4.2): Input field data for the model headwater a Bata Bridge Station (S1).

Parameters	Unit	Head water data (October 2022)	Head water data (January 2023)
BODu	mg/l	1.47	1.23
DO	mg/l	10.40	9.10
pH	-	7.58	8.16
EC	µs/cm	1316	1558
ALK	mg/l	122.50	142.00
Temp	°C	23.40	14.50

Table (4.3): Input field data along Hilla River, Iraq (October 2022).

Station	Parameter					
	CBODu (mg/l)	DO (mg/l)	pH	EC (µs/cm)	ALK (mg/l)	Temp (°C)
S1	1.47	10.4	7.58	1316	122.5	23.40
S2	1.45	10.11	7.765	1311	119.5	23.6
S3	1.53	10.08	7.815	1313	118.5	23.4
S4	2.23	9.91	7.835	1311	119.5	23.3
S5	2.31	9.88	7.83	1303.5	118	23.35
S6	2.40	9.85	7.765	1338	121.5	23
S7	2.48	9.82	7.86	1339	127.25	23
S8	2.54	9.80	7.83	1330	117	23
S9	2.73	9.75	7.805	1341	117.5	23
Parameter average	2.12	9.95	7.78	1322.5	120.13	23.22
Parameter min.	1.45	9.75	7.575	1303.5	117	23
Parameter max.	2.73	10.4	7.86	1341	127.25	23.6

Table (4.4): Input field data along Hilla River, Iraq (January 2023).

Station	Parameter					
	CBODu (mg/l)	DO (mg/l)	pH	EC (µs/cm)	ALK (mg/l)	Temp (°C)
S1	1.23	9.1	8.16	1588	142	14.5
S2	1.12	9.9	8.22	1573.5	143.5	14.65
S3	2.35	10.5	8.11	1563	141	14.65
S4	3.00	10.2	8.14	1557	143.5	14.65
S5	1.97	10.13	8.12	1564	143	14.8
S6	2.055	10.195	8.16	1560	139.5	14.7
S7	2.25	9.95	8.19	1557.5	148.5	14.8
S8	2.53	9.99	8.24	1563.5	143.5	14.8
S9	2.06	9.8	8.125	1559	147	14.79
Parameter average	2.06	9.97	8.16	1565.05	143.5	14.70
Parameter min.	1.12	9.1	8.11	1557	139.5	14.5
Parameter max.	3	10.5	8.24	1588	148.5	14.8

Table (4.5): Input meteorological data from weather site (October 2022 and January 2023) .

Month	Temp (°C)	Wind speed (m/sec)	Dew point (°C)	Cloud cover %
October	22	11	6	29
	22	15	6	29
	20	11	5	62
	20	10	2	18
	20	9	2	100
	17	9	2	82
	17	15	2	82
	18	15	3	73
	20	16	4	71
	21	15	4	69
	24	14	3	68

	26	14	4	31
	28	17	5	52
	30	18	5	52
	30	18	5	81
	31	19	5	91
	30	20	2	100
	29	21	4	100
	28	20	6	100
	26	18	7	100
	25	16	8	69
	24	15	7	37
	23	15	7	6
	23	15	6	11
	22	16	5	14
January	13	12	6	3
	12	11	6	2
	11	11	6	1
	10	11	6	0
	9	12	7	0
	8	12	6	0
	8	12	6	0
	8	13	5	0
	7	13	5	0
	5	12	5	0
	7	11	5	0
	10	10	5	0
	13	10	6	0
	15	11	6	0
	16	11	6	0
	18	12	6	0
	19	14	5	0
	20	16	2	0
	19	16	2	0
	18	15	2	0
	16	15	2	0
	14	15	2	0
	13	14	2	0
	12	14	3	0

Table (4.6) shows the final MAE and RMSE statistics error values for the model predictions compared to field data of the water quality parameters during the model calibration/validation processes. Errors indicated that there is good agreement during both dry and wet season. In developing countries with very precise data, consistent standard values are accepted (Hadgu et al., 2014). Hence, the QUAL2K model can be used as an excellent estimation and management tool for the river water quality compared to that repeated monitoring campaigns which need a lot of study and financial resources to aid decision-making and water quality management. This reduces the time and cost required for the periodically river monitoring.

Based on the calibrated model, the simulation results compared to field data are as follows:

Table (4.6): Statistics errors for predicted and measured water quality parameters.

Parameters	Mean absolute error (MAE)		Root means square Error (RMSE)	
	In dry season (Oct.)	In wet season (Jan.)	In dry season (Oct.)	In wet season (Jan.)
CBODu	0.426	0.382	0.549	0.53
DO (mg/l)	0.442	0.436	0.494	0.55
pH	0.84	0.61	0.95	0.70
EC (µS/cm)	94.587	52.37	126.434	53.132
ALK (mg/l)	3.141	2.973	3.564	3.821
Temp (C °)	2.684	0.683	6.099	0.717

4.2.1 DO

Figure (4.1) displays the model simulation result of DO along the river on October 2022. The model predictions fit the observed data well on the all stations from S1 to S9. Regarding the DO variation in the river, it was clear that DO values (ranging between 10.40 and 8.84 mg/l) slightly decreases and changes with increasing distance from the headwater of the path. The DO levels were high (about 10.40 and 9.06 mg/l) at the Bata Bridge station and began to decrease continuously until 2.7 km near the Babylon Passports Department, after which it continued to decrease gradually toward the last station on the river path where the levels dropped to about 8.84 mg/l. Human activities are the main reason that is responsible for the decline in DO levels at the Hilla City center due to the presence of many illegal spills along the river length, especially during the low flow season. In addition, the surface runoff that contains phosphorus and nitrogen levels from the agricultural areas can decline the DO levels. However, DO levels during this period were within the permissible limit, which is greater than the minimum DO value of 5 mg/l.

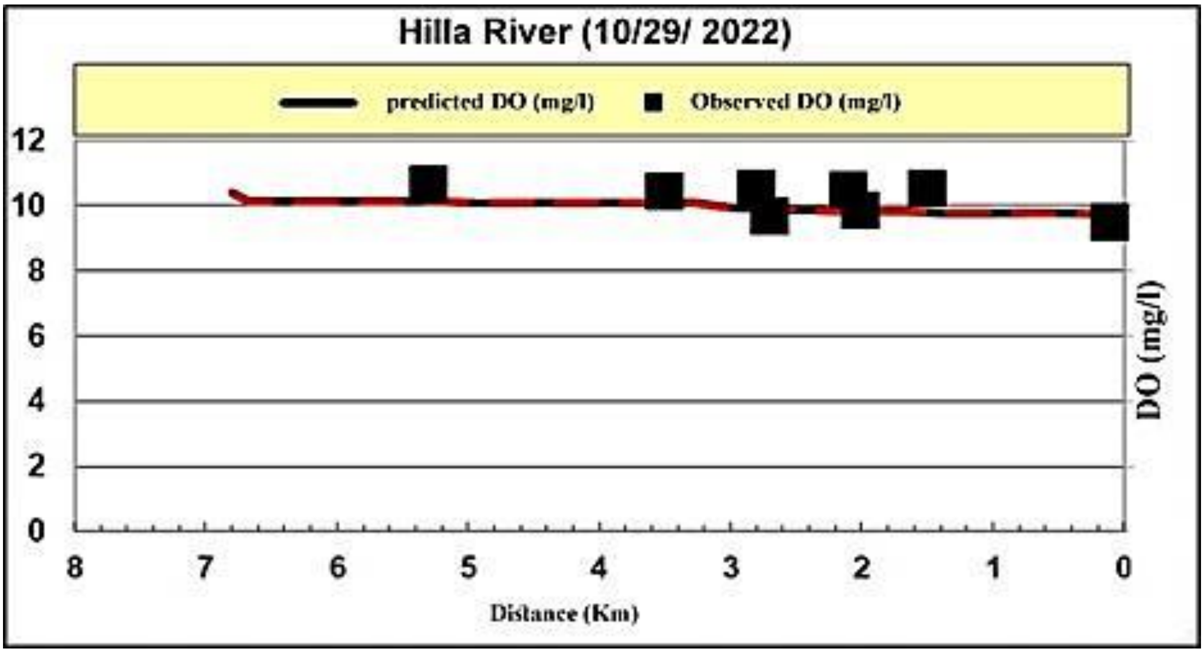

Fig. (4.1): Simulated DO level along the river compared to field data on October 2022.

For the wet season on January 2023, the DO distribution along the river reached higher levels as shown in Figure (4.2) due to the high flow, but the change was slight. During this period, the high flow increases the mixing in the river and this in turn reduces the spills impact on the river DO level. Similar to the model performance during the dry season, good agreement with field data was achieved. It was found that the value of DO increased slightly and changed as the distance increased from about 9.8 mg/l at Bata Bridge station (S1) to reach more than 10 mg/l toward the river downstream. The DO level began to increase continuously until 3.5 km distance. After this point it raised to about 10.5 mg/l. It should be noted that the maximum and minimum value of DO level were 10.5 and 9.8 mg/l, respectively, meeting the DO level target quality criteria for minimum dissolved oxygen of 5 mg/l during the study period. The simulated results were consistent with previous technical reports, although QUAL2K is a steady-state model

(Antanasijević et al., 2014), indicating to the efficient model predictions that can be depended on.

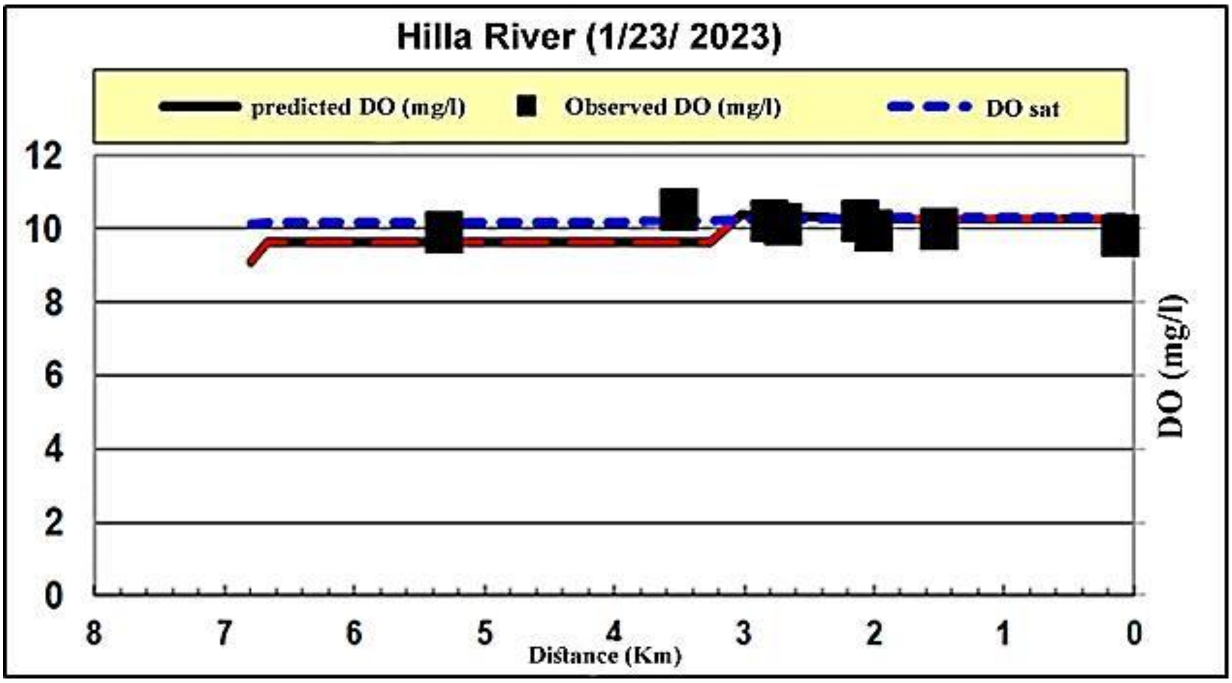

Fig. (4.2): Simulated DO level along the river compared to field data on January 2023.

4.2.2 CBODu

Figure (4.3) shows the CBODu model simulated results compared to field data. The model pattern the measurement with very low statistics errors, as show by Table (4.6), which reflecting the model robustness. It can be seen that the concentration of CBODu was almost constant (about1.43 mg/l) and started to increase clearly at a distance about 3.5 km from the headwater station to reach (about 2.75 mg/l) at the last station. Because the river self-purifies and there is no evidence of strong source of spill along the first 3.5 km, the concentration of the river CBODu was varied slightly. After this distance, there is an evidence that spills exist along the river length. Comparing CBODu to DO simulation results Figures (4.1 and 4.3) reveal the reverse relationship between DO and CBODu values due to the presence of illegal organic matter load from point sources in which as CBODu concentration increases, the DO concentration decreases after the kilometer number 3.5.

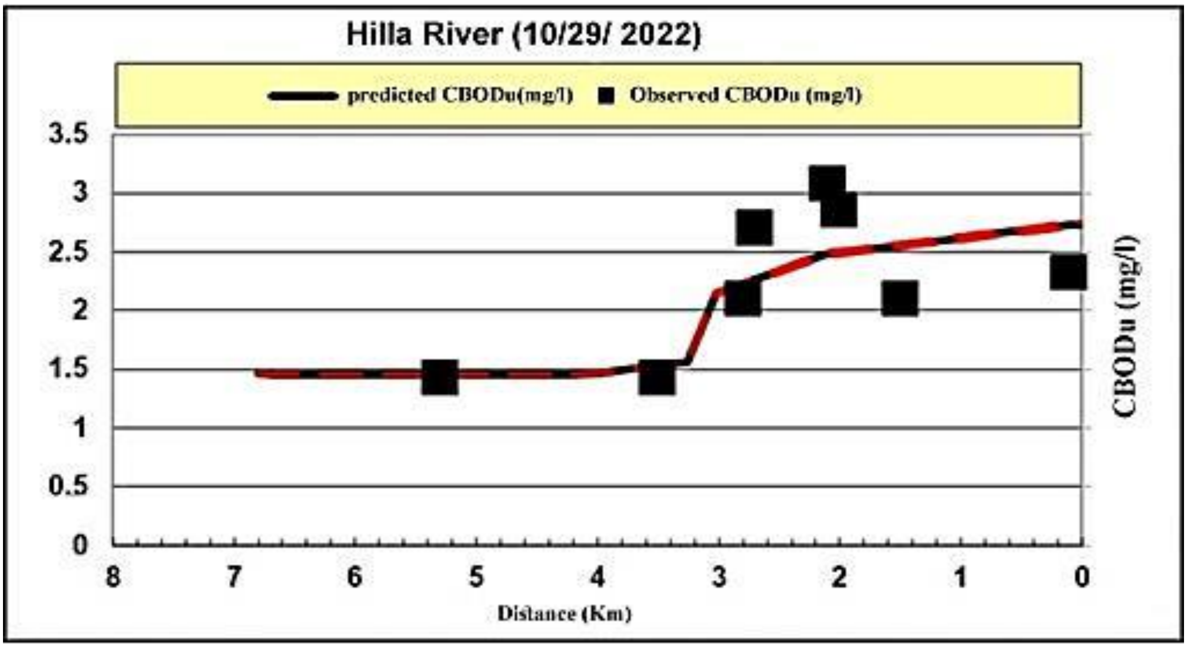

Fig. (4.3): Simulated CBODu along the river compared to field data on October 2022.

Regarding the CBODu model predictions during the wet season (on January 2023), Figure (4.4) displays the behavior of CBODu for the river. It can be seen that there is a similar simulation trend in the CBODu values to those of October 2022 except that the January 2023 values dropped down. This outcome reflects the previous model simulation of DO levels in the river. As the flow increased from October 2022 to January 2023, the CBODu values became lower due to the higher mixing process in the river, dispersing organic matter quickly and preserving DO levels in the river. This increases the river's ability to remove pollutants and reduces pollutant concentration gradients (Kubba et al.; Mustafa et al., 2017), diluting the concentrations of pollutants that flow into the river. In addition, during wet seasons, headwater temperatures drop from 21 °C to 13 °C, which increases oxygen solubility (Adeyemo et al., 2008). The lower bacterial activity during the low temperature period can reduce the amount of consumed DO from the river (Gerardi, 2006). However, all CBODu values were within the permissible limit.

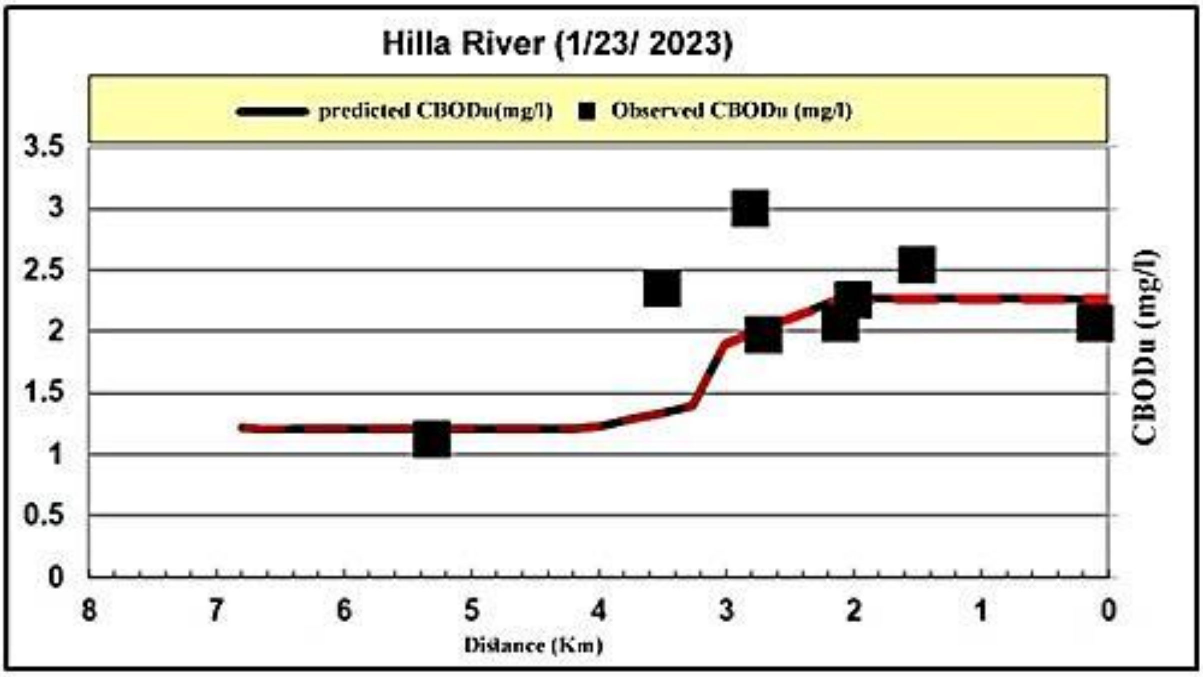

Fig. (4.4): Simulated CBODu along the river compared to field data on January 2023.

4.2.3 EC

According to the model output of Figure (4.5), the EC simulated values of October 2022 were around its average measured data of 1322.5 µs/cm along the river length with low statistics error, as clear by (Table (4.6)).

Hence, an important parameter in environmental studies to assess water quality is EC. It reflects the ability of water to move electric current (M Ezzat et al., 2012), which is affected by temperature and solids directly. Organic and dissolved substances are each present in the river water (Jayalakshmi et al., 2011). Based on previous studies related to the Tigris, Euphrates, and Shatt al-Arab rivers' EC, it was noticed that EC value kept increasing with the flow of the river. This can be attributed to the nature of the soil concerning and its direct relationship to salinity and total dissolved solids, as well as to the multiple uses of water along these rivers (Maulood et al., 1993). Since the Hilla River is a branch from the Euphrates River, Hilla River is impacted by the Euphrates River water characteristics and therefore the river EC simulated values follow the river water source.

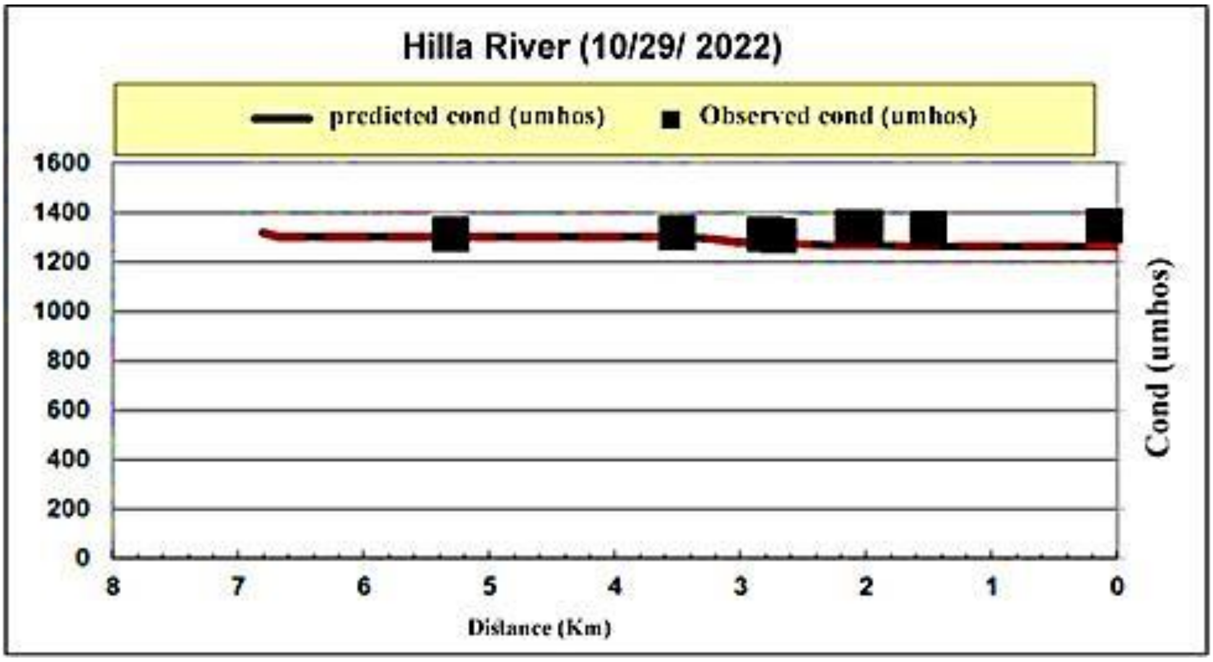

Fig. (4.5): Simulated EC along the river compared to field data on October 2022.

For the model results of EC (on January 2023) in Figure (4.6), EC values were in good agreement with field data too, but they were higher in the river water (around 1565 µs/cm) compared to October 2022. This can be attributed to the presence of extra sources of dissolved solids reaching the river water. The actions of humans and surface runoff, which increase the amount of dissolved salts in the river water, may resulted in high EC values (Al-Ridah et al., 2020).

EC is a way to measure total dissolved solids (TDS) indirectly. The wide difference in air temperature between dry and wet season in Iraq increases the soil salinity. During the dry season, an increase in evaporation and then an increase in salt concentration happens, which then generated an increase in EC as well as an increase in the concentrations of several soluble salts. As a result, a greater amount of dissolved ions and the concentration of ionized material reach the river water in winter due to surface runoff, groundwater, or rainfall, resulting in high values of EC in the river (Khaleefa & Kamel, 2021). Finally, the EC model predictions were less than the allowable limit of 2000 µs/cm during both seasons.

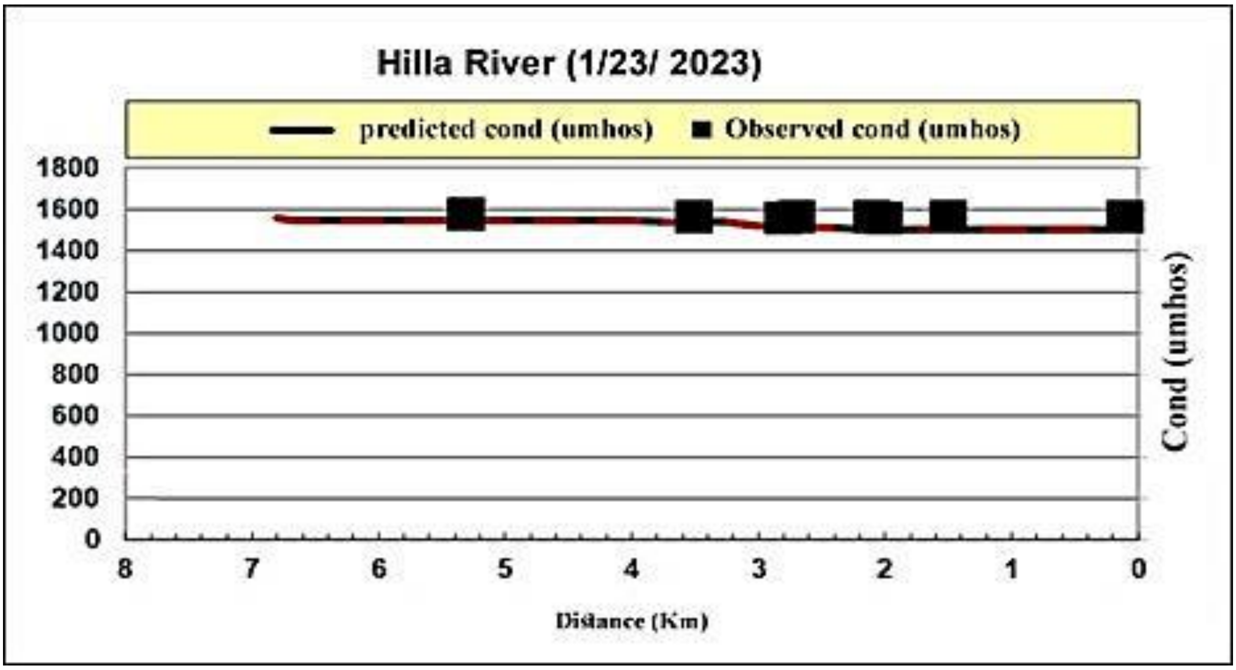

Fig. (4.6): Simulated EC along the river compared to field data on January 2023.

4.2.4 pH value

The model predictions of pH along the river are as shown in Figure (4.7 and 4.8). Based on the statistics errors in Table (4.6), good agreement was achieved by the model. Both results were around the average pH values of the river and within the permissible limits in Table (4.1). However, the river water can be classified as an alkaline since the pH values were greater than 7 during both seasons. The values of pH have a slight variation with distance during the dry and wet season in which the predicted curves decreased with distance gradually from 7.85 to 7.77 on October 2022 and from 8.22 to 8.07 on January 2023.

Because many proteins and enzymes change with high and low pH, the pH value, which is a measurement of acidity and alkalinity in water, is important for aquatic system and affects how species move in the water (Al-Zubaidi, 2011). Hence, the river water pH value has major effects on aquatic life. It enforces a lot of metabolic processes that can involve many soluble elements. When the pH is high, precipitates into hydroxides for reducing back (Mohammed et al., 2022). The preferred levels of pH vary from 6.5 to 8 (Kelly Addy et al., 2004). Outside this range, aquatic creatures are impacted. Low pH level allows toxic chemicals and heavy metals to be released into the water from soils (Nazir et al., 2015). Thus, aquatic species and plants may be later influenced by this river water.

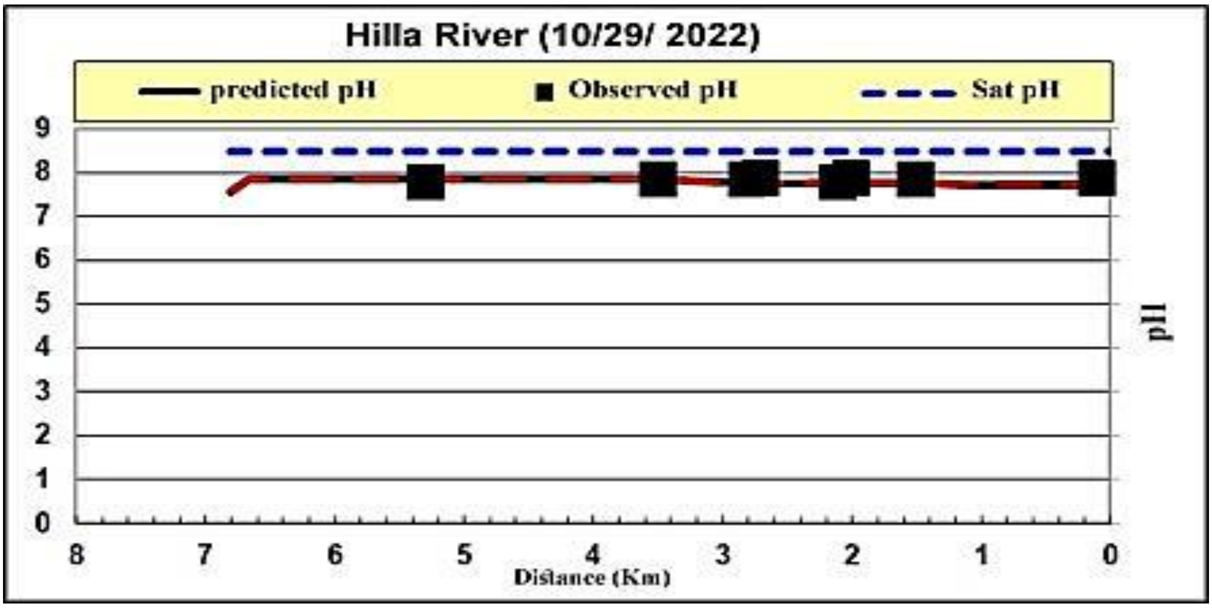

Fig (4.7). Simulated pH values along the river compared to field data on October 2022.

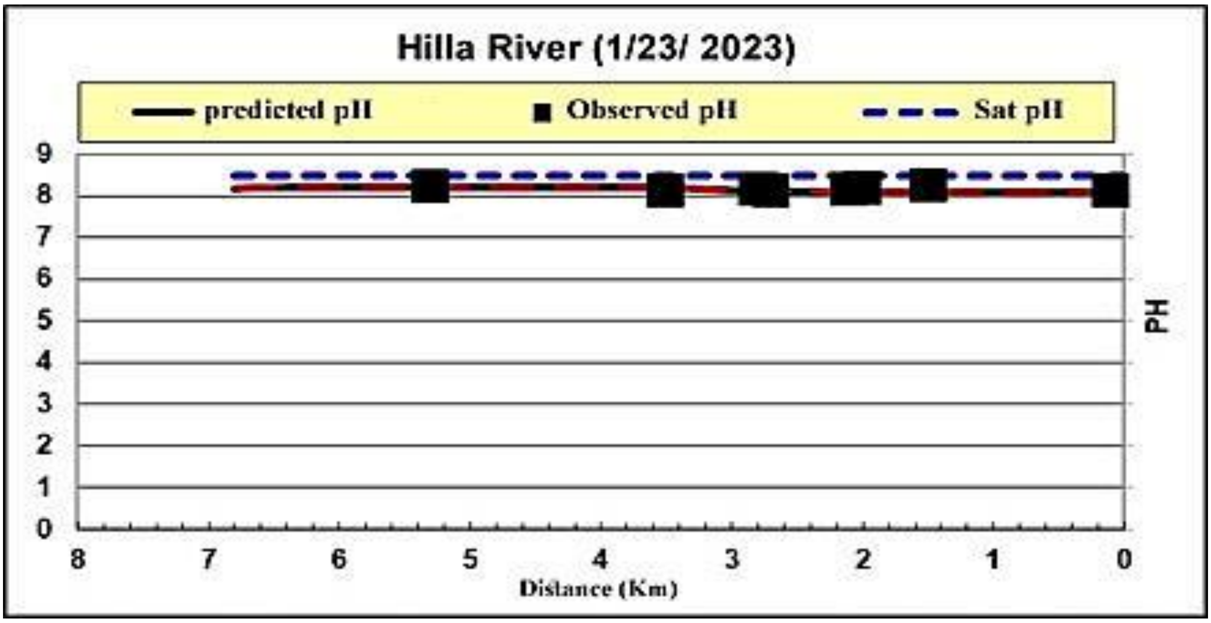

Fig. (4.8): Simulated pH values along the river compared to field data on January 2023.

4.2.5 Temp

Figure (4.9 and 4.10) present the simulation results of water temperature compared to field data. The model predictions fit the data well with low statistics errors. Obviously high temperature distribution was on October 2022 and low temperature distribution was on January 2023, and both were around the average value (23.22 and 14.7 ℃, respectively). However, slight variation in water temperature along the river exists due to the different mixing mechanisms in the three directions of flow.

Gas solubility in water is greatly impacted by temperature. As the temperature increases, the solubility of gases, including oxygen and carbon dioxide, decreases. Water temperature plays an important role in establishing the rate at which several biological and chemical processes develop in a water stream and also the amount of oxygen wholly dissolved in the water (Suski et al., 2006). There is no question that a 10 ℃ increase in temperature causes chemical reactions to come about at a rate that is 2-3 times faster (Agency, 2001) (Lamberti & Hauer, 2017). Thus, matching temperature field data by the model is very significant to match other water quality constituents efficiently.

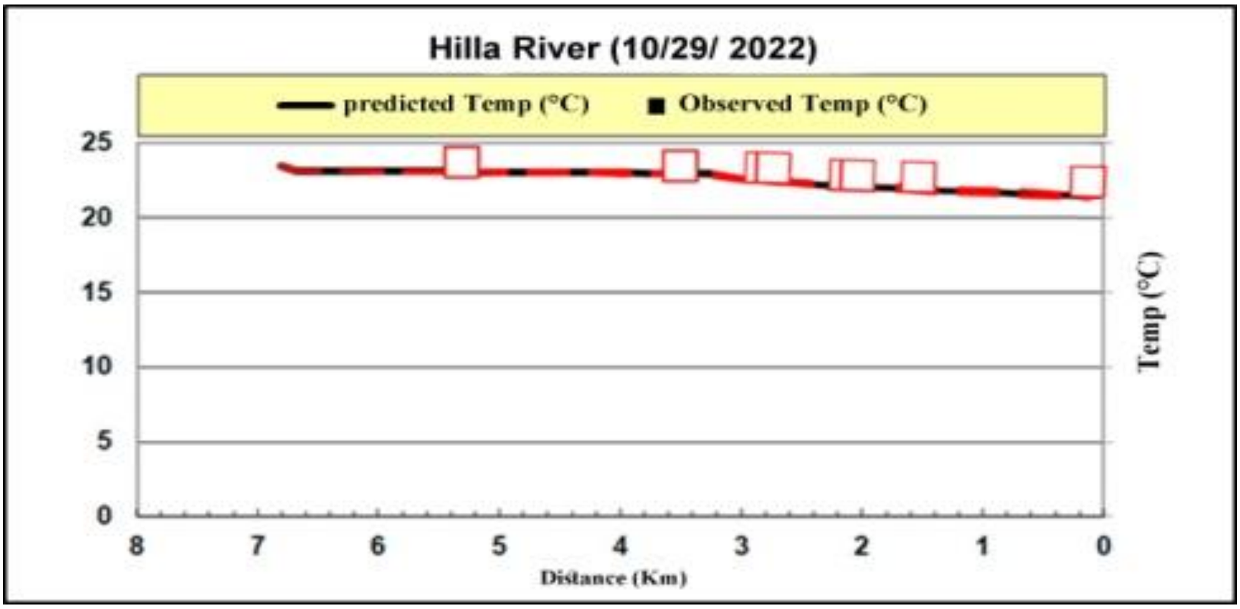

Fig. (4.9): Simulated Temp along the river compared to field data on October 2022.

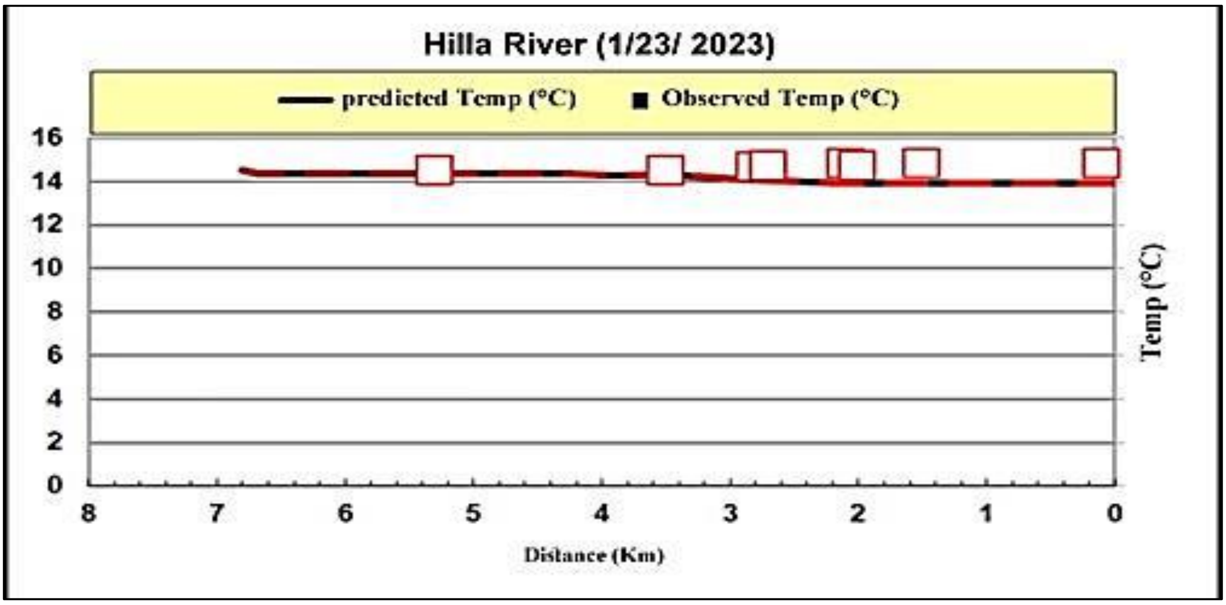

Fig. (4.10): Simulated Temp along the river compared to field data on January 2023.

4.2.6 ALK

The simulation results of ALK are as shown in Figure (4.11 and 4.12). Results were identical and within a range of 120 to 140 mg/l, meeting the Iraqi standards of 200 mg/l, as cleared by Table (4.1). Also, the simulation and estimation findings of ALK were close enough with low statistics errors during the model run. This ensured that the model stability and the constituents interaction were robust. There is a big difference in the river ALK values between the winter and summer season. During a time period of about two months, the ALK values of the river water increased by about 16.7%. In summer, the ALK value ranged from 122.5 mg/l at first station to the lowest value of 117.5 mg/l downstream the river length (at 6.8 km). Similar ALK pattern happened on Winter, but ALK values were higher (around 140 mg/l).

Alkalinity refers to the body of water's capacity to work as a buffer(Jiang et al., 2019). It measures an element of water's capacity to equalize acids and bases and keep the pH relatively steady. Compounds such as bicarbonates, carbonates, and hydroxides are present in water that acts as a buffer and react with the H^+ ions in the water to increase its pH, making it more basic. Without the ability to buffer, a small amount of any acid would cause the pH to be shifted immediately. Aquatic animals benefit from a pH range that is stable and within reasonable bounds. The water body is more likely to remain stable when the alkalinity is higher. A water body with a high alkalinity level may counter acidic substances from rainfall or basic that inputs from wastewater, meaning that only slight changes in pH occur due to the fluctuations in CO_2 concentrations during the day (Addy et al., 2004). In addition, alkalinity occurs in rocks, soil, salts, some plant activities, some industrial effluent discharges, and detergents and soap-based goods. If the local geology has a lot of calcium carbonate, the alkalinity of the water in the area will normally be high.

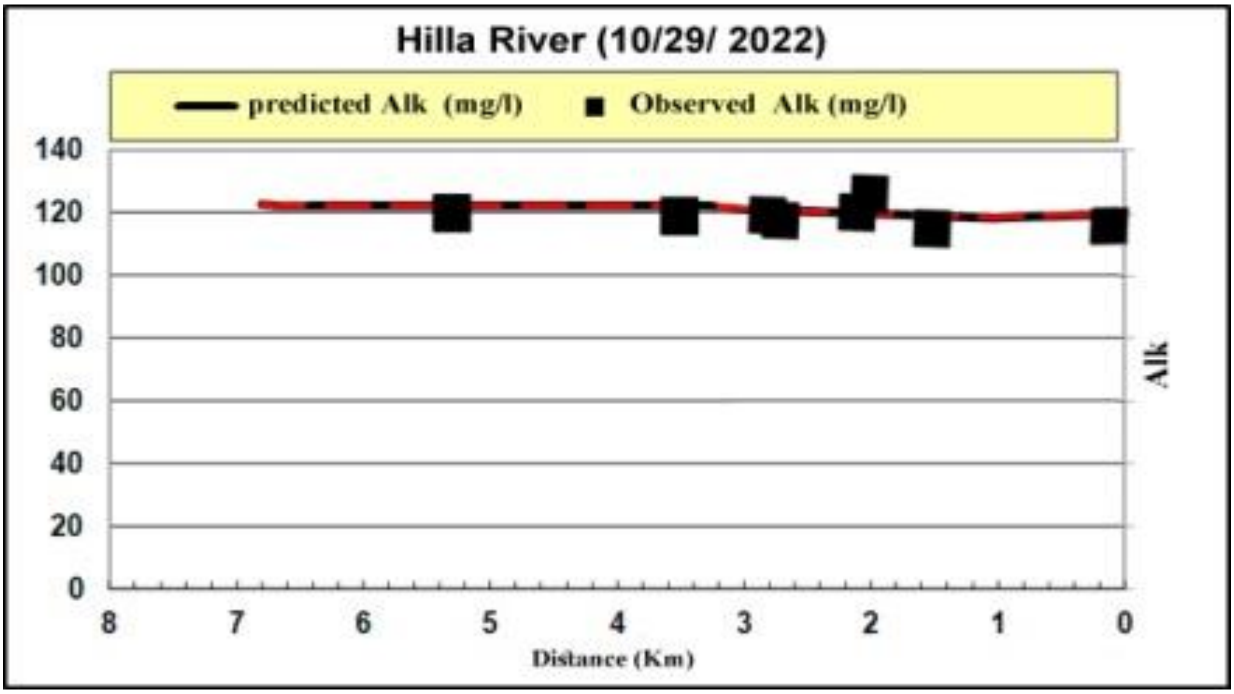

Fig. (4.11): Simulated ALK along the river compared to field data on October 2022.

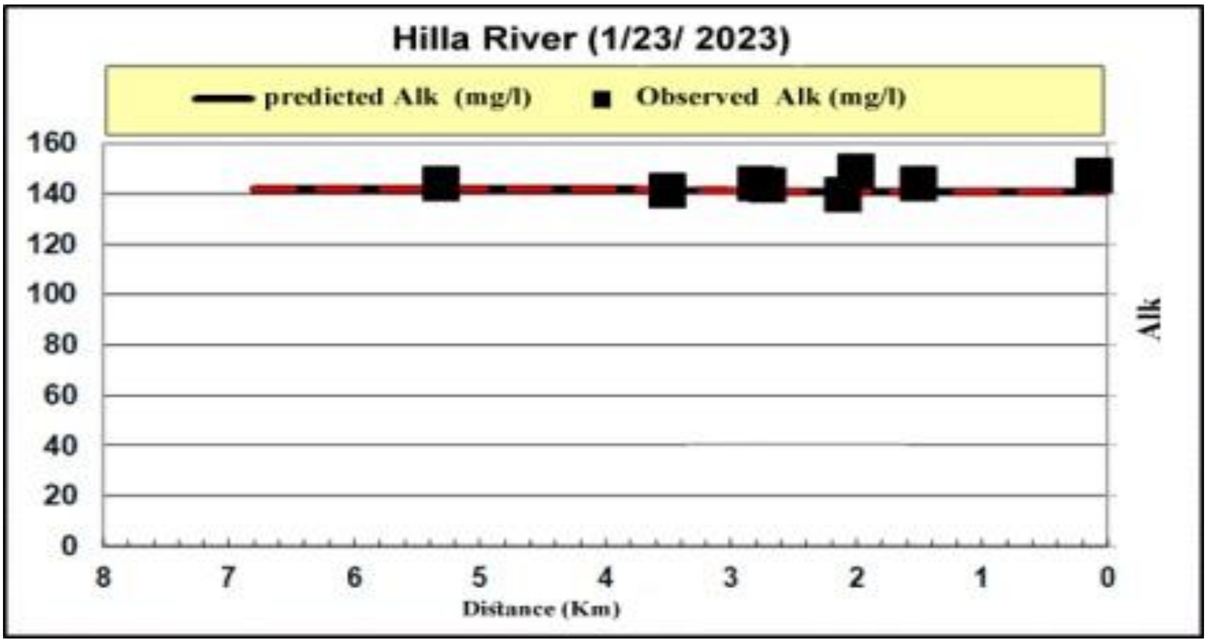

Fig. (4.12): Simulated ALK along the river compared to field data on January 2023.

4.3 Model sensitivity analysis

In order to investigate the influence of changing the river conditions on the QUAL2K simulation, the main inputs of the calibrated and validated model were varied significantly. This analyses were performed by changing one model input and keeping the others without changing. Then, the model simulation results were displayed to be explored for this specific change outcomes. This analysis is important because it gives an indication to the user on how some variable can influence the model simulation and stability. Here are some important circumstances that have a big role on QUAL2K model simulation:

4.3.1 Effect of river flow rate variation on DO

The river flow rate was increased significantly by 10%, 20%, 30%, 40%, and 100%, and the model simulation results of each run were summarized in Figure (4.13). Generally, the river flow rate affected the model simulation of DO by reducing its level along the river slightly. However, this reduction behavior is for the Hilla River model setup only and could be different for other rivers depending on the river conditions such as absent algae, bacterial activity decomposition of organic matter, and bottom sediments (Freixa et al., 2016). Hence, the decrease in DO level along Hilla River due to the river flow can be seen in the model simulation of January 2023 Figure (4.2 compared to 4.1). On winter season, the Hilla River flow reached the city with high sediment demand and nutrients from agricultural areas upstream the river. In both cases, however the river DO level is good. For each model run in Figure (4.15), the trend of DO level in the river is the same, reflecting the model stability of each run.

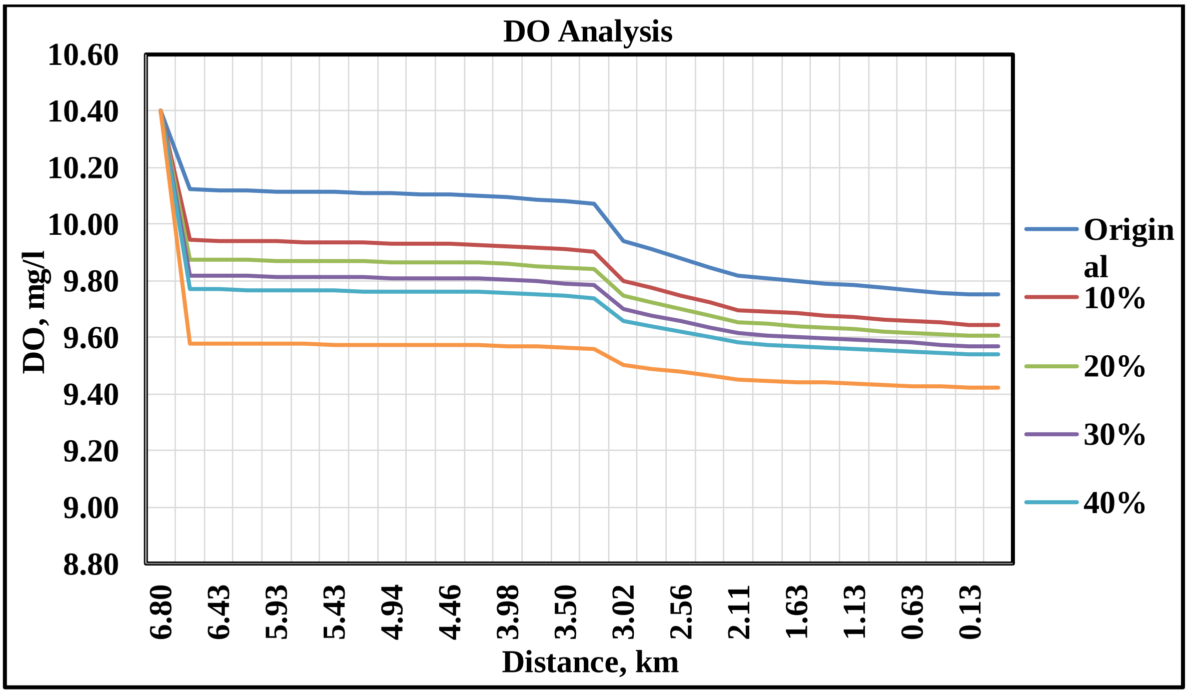

Fig. (4.13): Sensitivity of the model DO simulation to increase the river flow.

4.3.2 Effect of river flow rate variation on CBODu

Similar to the river DO analysis by changing the flow, the model simulation behavior of CBODu was investigated. The flow rate was increased by 10%, 20%, 30%, 40%, and 100%, and the model results were as shown in Figure (4.14). The model output shows reduction behavior to the CBODu distribution in which the high flow decreases the CBODu values. This outcome happens naturally due to the dilution and dispersion process that takes place with high river flow, spreading organic matter far away, and eventually it will be vanished. Thus, it is important to assess CBODu in the river along with flow rates at the same time period.

Consequently, for each model run in Figure (4.1), the model was stable because same patterns were achieved by the model too.

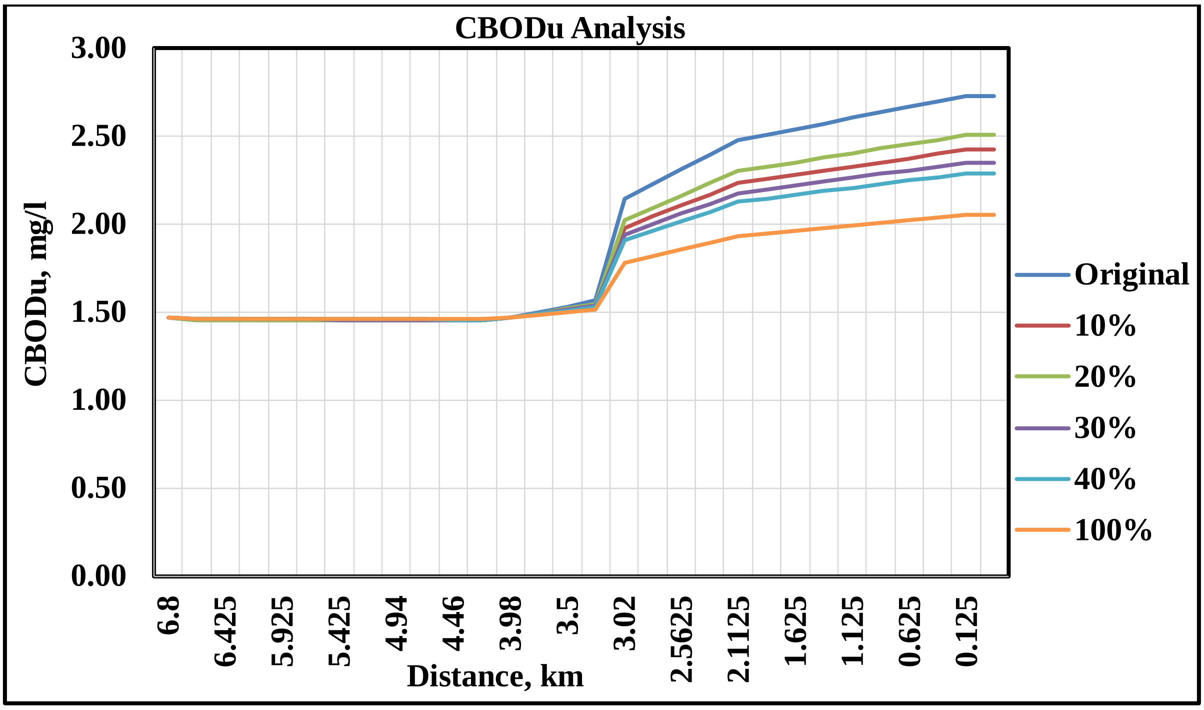

Fig. (4.14): Sensitivity of the model CBODu simulation to increase the river flow.

4.3.3 Effect of river flow rate variation on EC

The simulation behavior of the EC values in Hilla River was explored in the same way that the analysis of river DO and CBODu was investigated by modifying the flow. The flow rate was raised by 10%, 20%, 30%, 40%, and 100%, and the model results were as shown in Figure (4.15). The results showed that in case of increase the flow rate of water, the conductivity of the water increased due to increase the ions in the river water (Kim et al., 2020). As the river flow rate increases, the quantity of inorganic chemicals and salts that come from the river upstream increases the river EC. Even though adding extra water to the river can reduce its EC by dilution, the river EC became higher in the present scenario due to the assumption that all other model inputs were kept constant during the simulation period of increasing flow rates. However, the increase in the amount of water coming from the Hindiya Dam, the Hilla River source at the Euphrates River, contains high amount of salts and inorganic chemicals naturally. This finding was noticed during the data collection period in this study, see EC values in Table (4.2, 4.3, 4.4). During winter season Hilla River received higher values of EC than the summer season. This behavior depends on the concentration of dissolved salts in the water and varies according to the geological regions of the river and due to the difference in dissolved minerals. In addition, surface runoff and rainfall on the river surrounding lands upstream the river can wash salts into the river water, rising the EC values downstream.

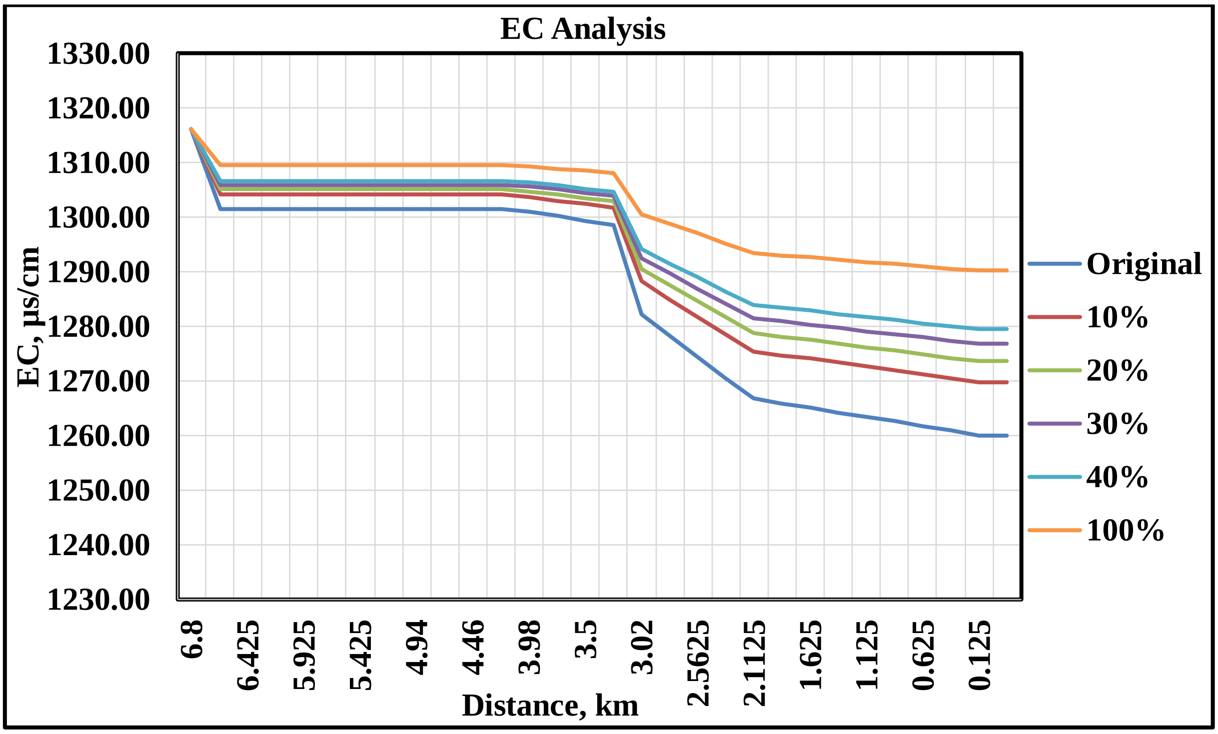

Fig. (4.15): Sensitivity of the model EC simulation to increase the river flow.

4.3.4 Effect of river flow rate variation on ALK

Figure (4.16) shows how the ALK simulation results can be impacted in Hilla River by raising the flow rate by 10%, 20%, 30%, and 40%, and 100%. Similar to the model behavior related to EC behavior was resulted. Increase the river flow rate led to increase the alkalinity of the water. Hence, it is clear that the river upstream water contains salty ions. This demonstrates the higher ALK values on Winter compared to its values on summer. Correspondingly, EC became higher on Winter too since these ions are counted in EC solids.

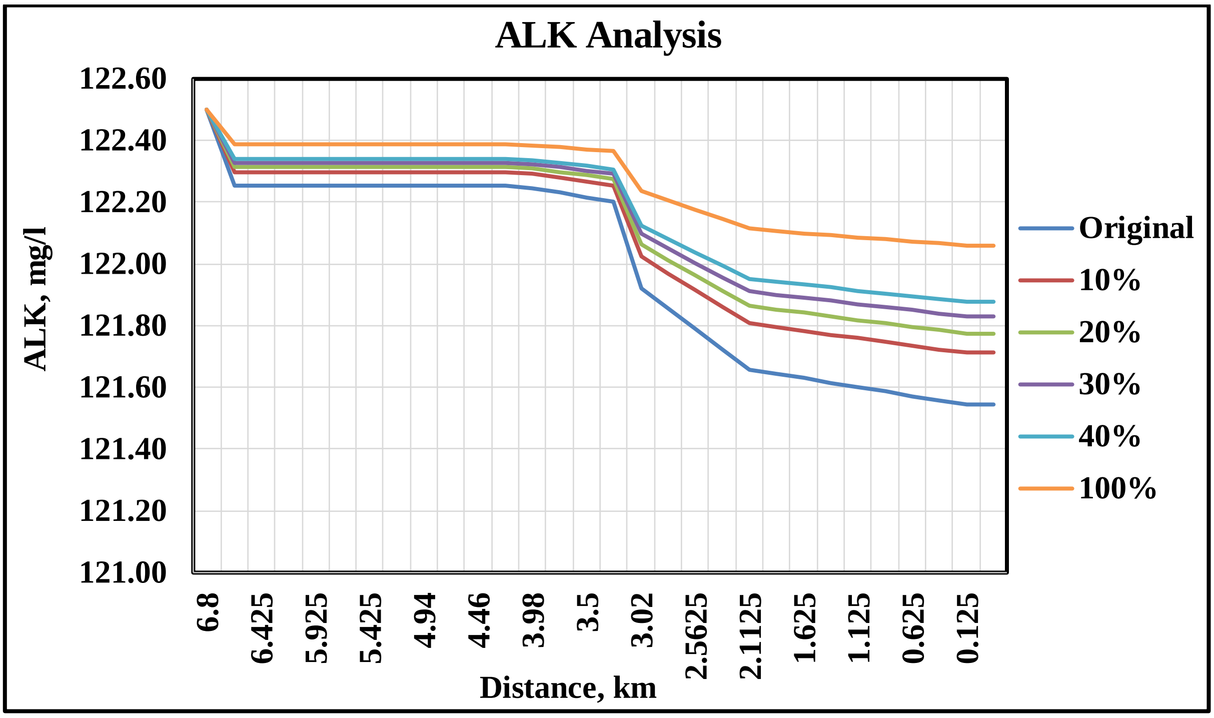

Fig. (4.16): Sensitivity of the model ALK simulation to increase the river flow.

4.3.5 Effect of river flow rate variation on pH value

The river flow rate was increased significantly by 10%, 20%, 30%, 40%, and 100%, and the model simulation results of each run were summarized in Figure (4.17). The outcomes revealed that the increase of flow rate caused a slight growth in the pH values. The pH value of water raised due to the raising of basic substances in the water source. This can be seen in the higher ALK values with higher flow. However, this increase doesn't have a big impact on the river water pH acceptable limits. Consequently, slight pH values were found during Winter compared to Summer season, see Figure (4.7 and 4.8).

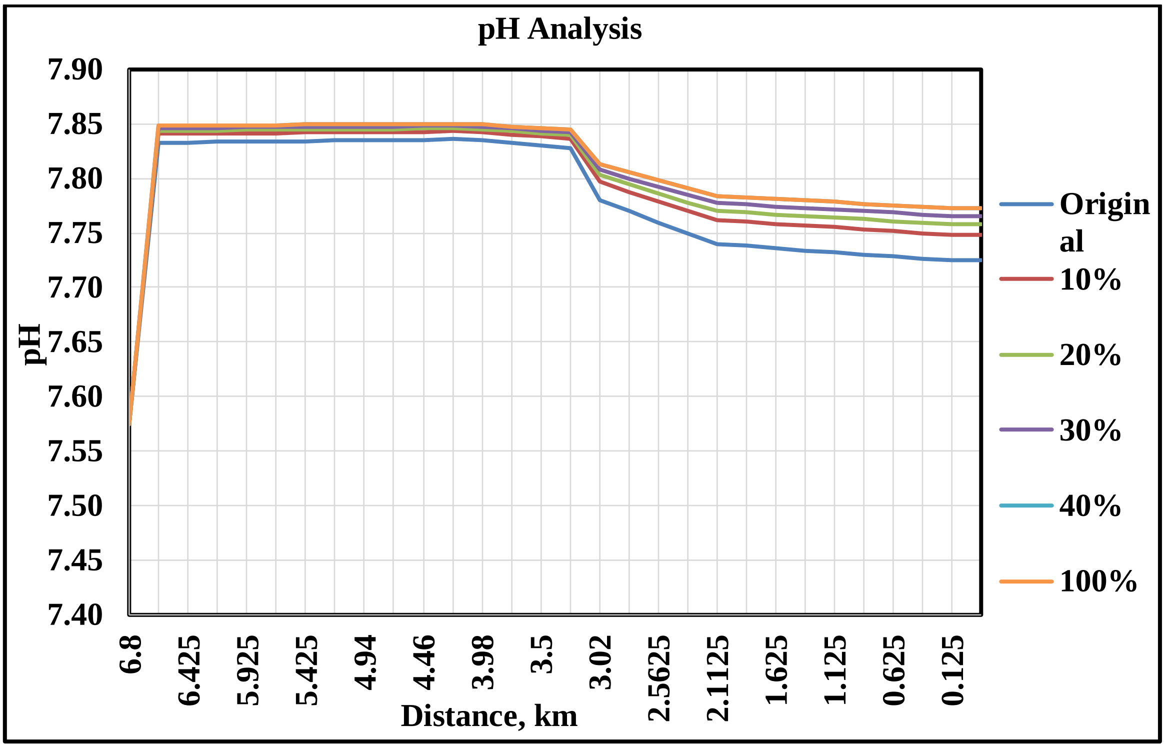

Fig. (4.17): Sensitivity of the model pH simulation to increase the river flow.

4.3.6 Model sensitivity to oxygen reaeration rate (Ka)

Reaeration is the most important dissolved oxygen source/sink in rivers. However, many other processes can increase the amount of dissolved oxygen in river water such as plant photosynthesis and respiration, organic matter decay, sediments transport …. etc. Dissolved oxygen can be added in water during night and day by aeration. Wind and waves, for example, can boost the rate of oxygen transport. This rate is affected by (1) water depth, flow rate, and wind speed, as well as (2) water temperature and salinity (Ji, 2008). The reaeration rate (*Ka*) is one of the most important variables that must be taken into account to simulate dissolved oxygen surface water bodies.

In this study, the effect of reaeration rate coefficient is highlighted as shown in Figure (4.18). In the calibration process of this model for both October 2022 and January 2023 model, the internal reaeration rate equation was implemented. Several schemes were built-in within QUAL2K model. Most of these equations are based on field studies of selected streams or laboratory channels. Summary of such equations were reported in (Al-Zubaidi & Wells, 2018) (Al-Zubaidi, 2018). To show changing the method of calculating *Ka* can vary the model results, the October 2022 simulated DO model was run using the other methods as shown in Figure (4.18). This feature is important to run the model, generally. It can be employed to calibrate the model. Nevertheless, the reaeration rate coefficient can be prescribed in the model by setting a specific value.

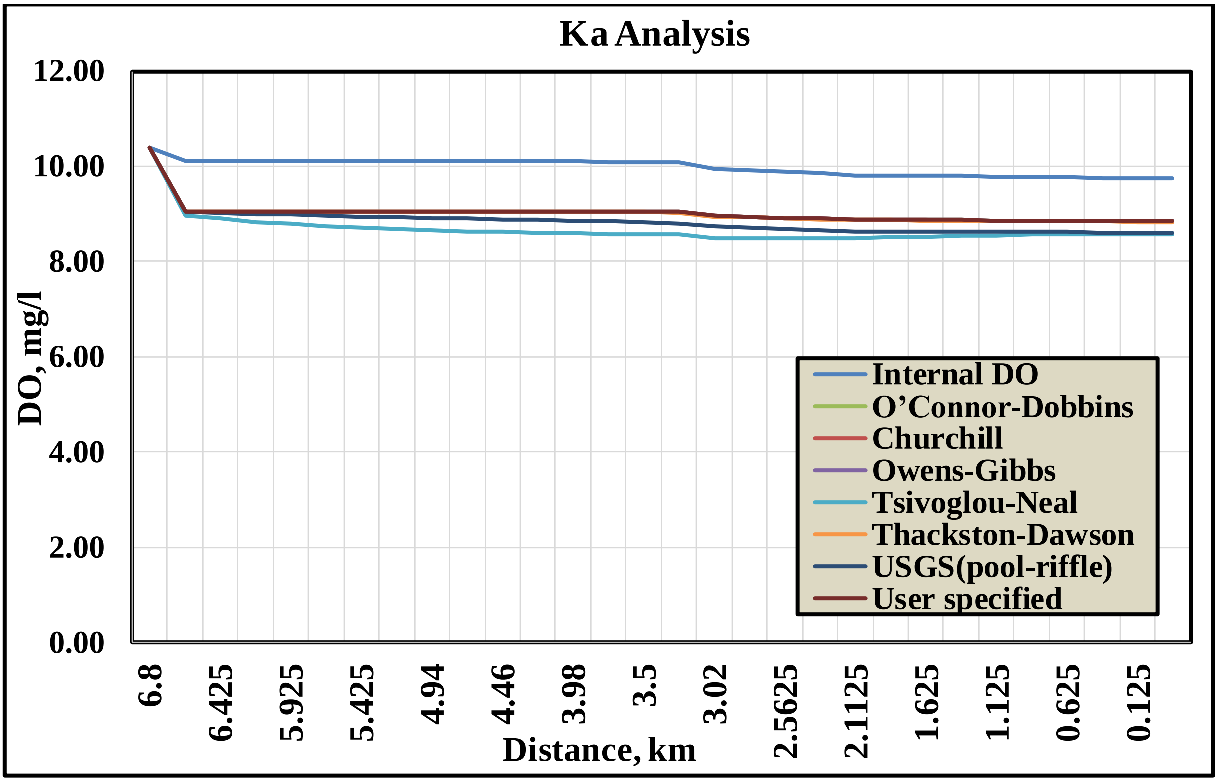

Fig. (4.18): Simulated DO behavior due to the change of reaeration rate.

4.3.7 Model sensitivity to CBOD oxidation rate (K_{dc})

The CBOD oxidation rate (K_{dc}) refers to the river capacity to remove or decompose waste materials such as organic pollutants, and plants and animals. It is a user-defined parameter in the model and can be employed for the model calibration. Increase the CBOD oxidation rate means that there is a decrease in the river dissolved oxygen level. The effect of CBOD oxidation rate is clear on the water quality constituents of the river, especially DO. Figure (4.19) shows a slight decrease in the DO level of Hilla River as a result of raising the value of K_{dc} from

0.09 to 0.2 and to 0.5 day^{-1}. Regarding CBODu, the effect of the CBOD oxidation rate was slight too due to the low CBODu concentration in the river as shown in Figure (4.20).

It should be noted that this reduction in the DO values was low when the CBOD oxidation rate increased to 0.2 day^{-1} and became more for 0.5 day^{-1}. Oxidation rate may increase due to chemical reactions; for example, the oxidation of inorganic compounds such as iron or sulfur can also consume dissolved oxygen. The oxidation rate, whether biological or chemical, directly affects the concentration of dissolved oxygen in the river water (Freixa et al., 2016). When there is a high rate of biological oxidation due to the presence of organic pollutants, it can lead to a significant decrease in dissolved oxygen levels, potentially causing oxygen depletion in the river water. Thus, the DO assessment for the river is important to know the impact of organic and inorganics pollution on river water quality health by highlighting the potential dissolved oxygen depletion in aquatic ecosystems. If the CBOD is high and exceeds the permissible limits in the water body, it can lead to oxygen depletion, which can harm aquatic life and disturb the balance of the ecosystem.

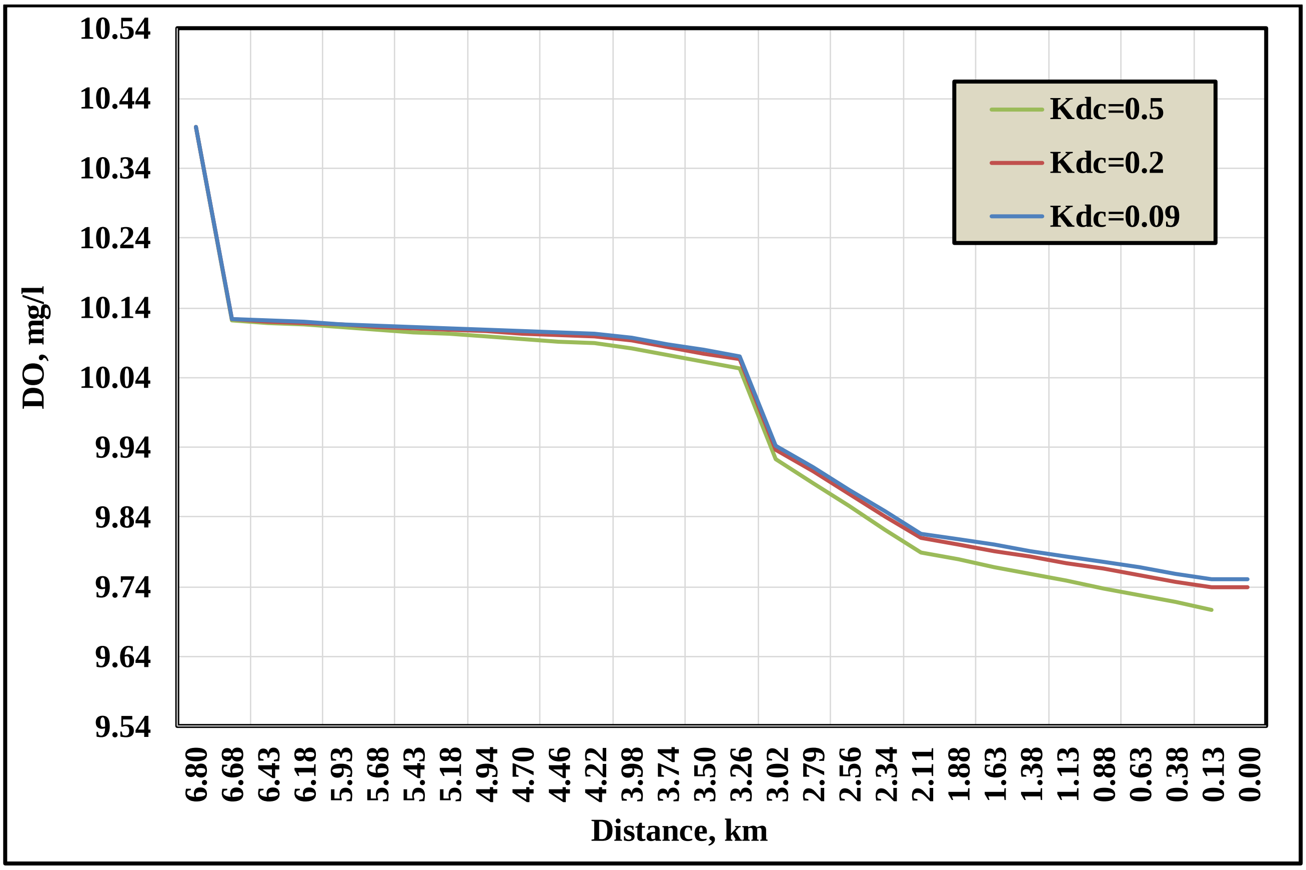

Fig. (4.19): Simulated DO behavior due to the change CBOD oxygen rate.

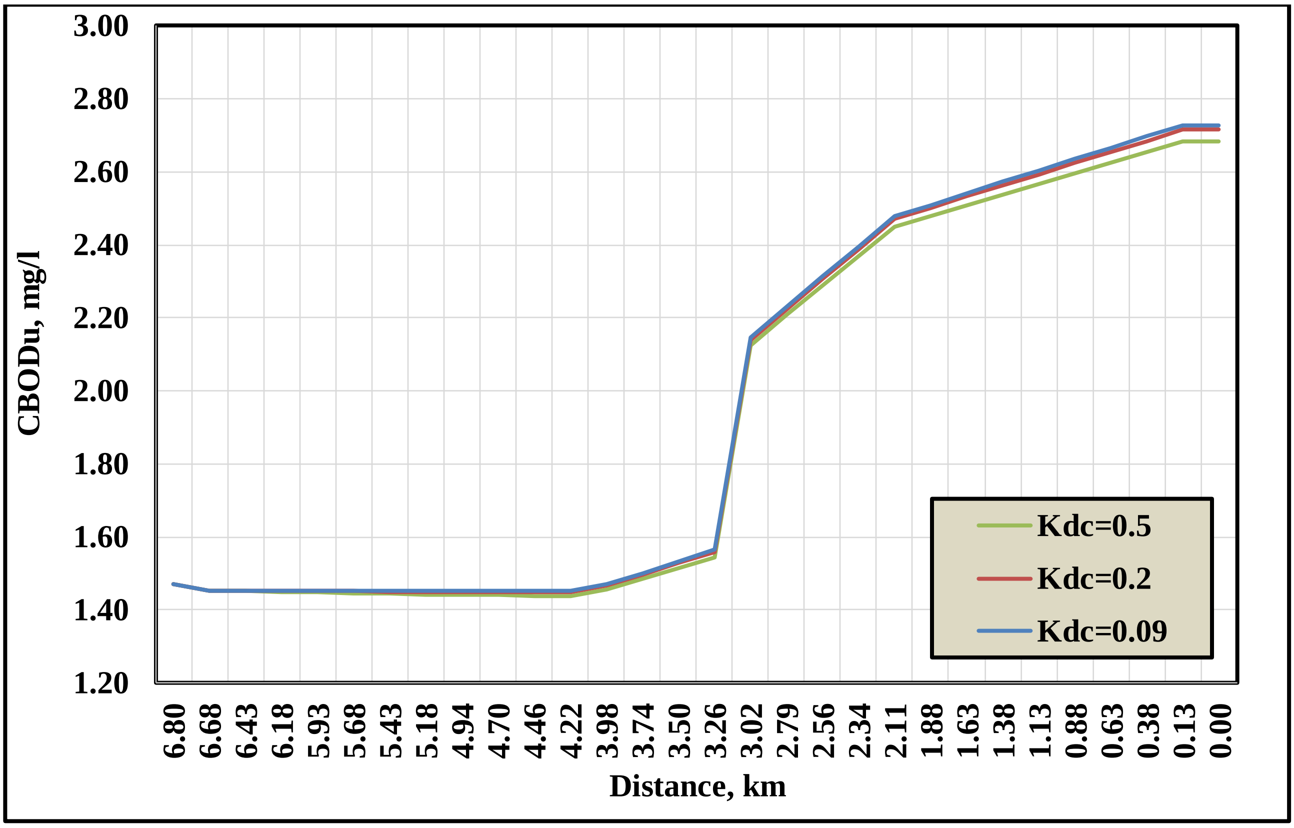

Fig. (4.20): Simulated CBODu behavior due to the change of CBOD oxygen rate.

4.3.8 Model sensitivity to Manning roughness coefficient

The water quality distribution in the river is impacted by the river flow conditions. Manning roughness coefficient which refers to the physical condition of the river has a big impact on the river flow rates. Thus, increase and decrease the manning roughness affects the river flow velocity and water quality. When the river flow rate decreases at low flow conditions, the relative roughness generally becomes higher. Typically, Manning's n values range from about (0.015 for smooth channels) to about (0.15 for rough natural channels) (Rosgen, 1996), see Appendix C. Therefore, the river roughness coefficient was increased from 0.03 to 0.08, 0.09, and 0.1 to explore the river velocity variation as shown in Figure (4.21). The outcomes exhibited that the increase of manning coefficient decreased the velocity of the river. As a result, the increase of n coefficient from 0.08 to 0.09, and 0.1 reduced the average velocity by 7.41% and 12.96%, respectively. This feature is also a useful tool for the model calibration.

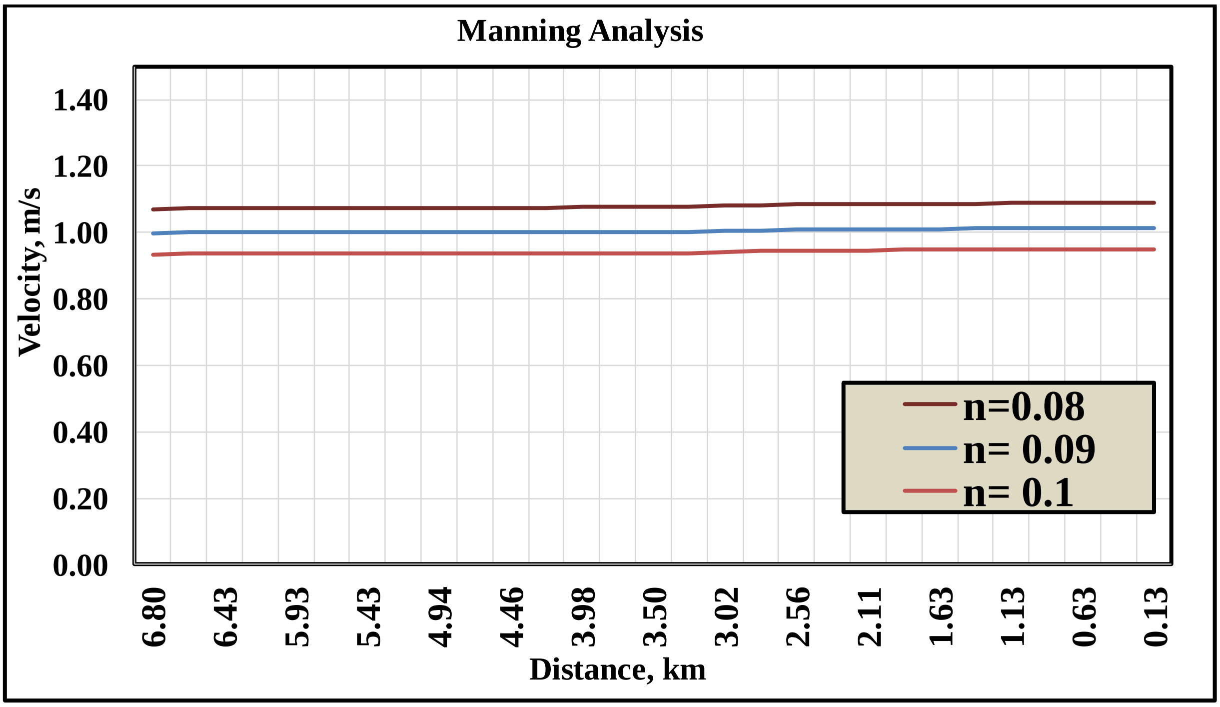

Fig. (4.21): Simulated velocity behavior due to the change of Manning coefficient.

4.4 Analysis of QUAL2K model management capability

To reveal the effect of QUAL2K model management capability, it was assumed that pollution point sources exist along the Hilla River with a flow rate of (1 m^3/s) at suggested locations. These sources release pollutants into the river, which is expected to directly affect the water quality in the river. The presence of the pollution source was imposed in two cases. The first case included the presence of one polluted source at a point located at the kilometer number 2.8, specifically at the (Bab Al-Hussein Bridge), as a result of the expectation of the presence of a pollution source of water at that point. The second case, which imposed the presence of a second pollution source next to the first source at the kilometer number 5.3 (Marjan Hospital). The influence of these point sources on the dissolved oxygen distribution of the Hilla River are as shown in Figures (4.22 to 4.25).

Regarding the first case which includes the presence of one pollution source at a point of 2.8 km, BOD_5 concentrations of 100, 150, and 200 mg/l were released successively. The outcomes exhibited that the existence of this pollution point source decreased the dissolved oxygen level downstream the outfall location, but the river DO level in case of 200 mg/l was huge and larger than the effect of 150 mg/l and 100 mg/L. Hence, the maximum decline in the DO level occurred at a BOD_5 concentration of 200 mg/l, which reduced the level to 8.95 mg/l less than the cases of 150 mg/l and 100 mg/l which reduced the level to 9.09 and 9.24 mg/l, respectively, as shown in Figure (4.22).

Concerning the second case which includes adding a second point source after the first one at a point of 5.3 km. The dissolved oxygen level reduced more than the first case. In this case, the minimum DO level became 8.78, 8.41, and 7.7 mg/l for the BOD_5 concentration of 100, 150, and 200 mg/l, respectively, downstream the outfall as shown in Figure (4.23). The worst case was the last one which is releasing BOD_5 of 200 mg/l at the both outfalls where the DO level decreased by 20% compared to the natural DO level of the river.

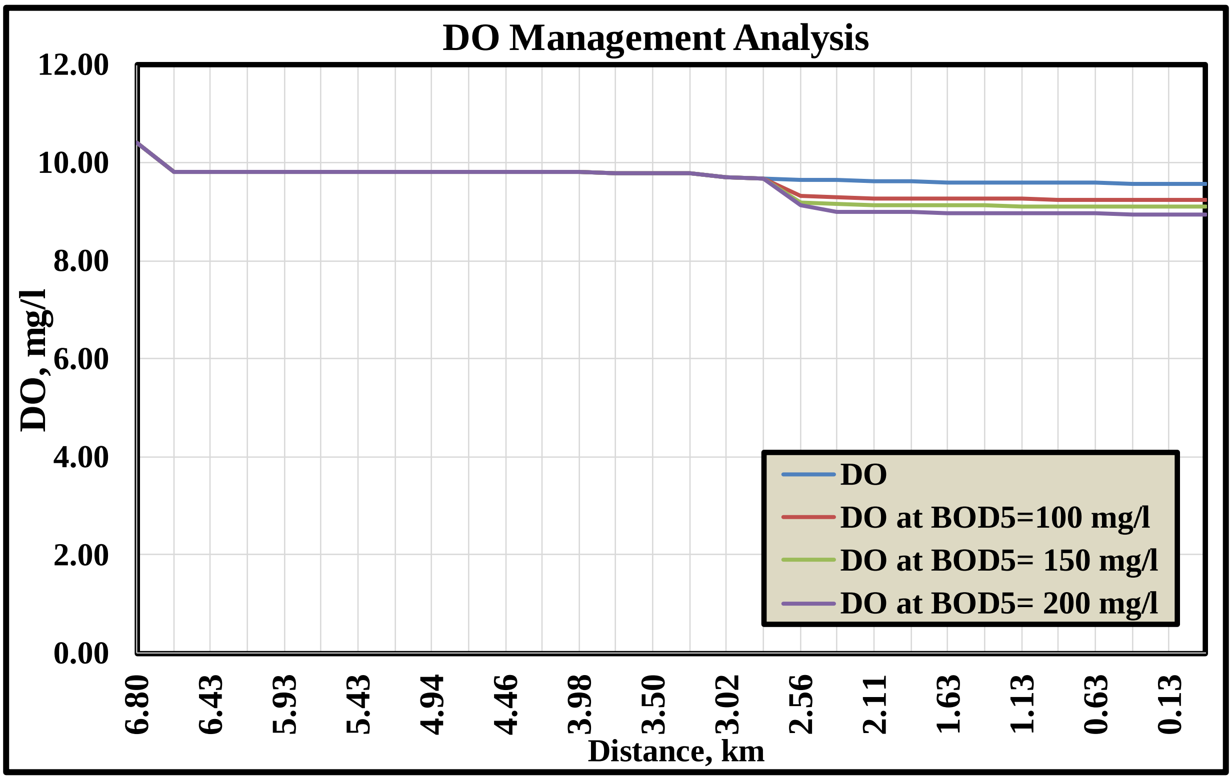

Fig. (4.22): Simulated DO level under the influence of a one BOD_5 point source.

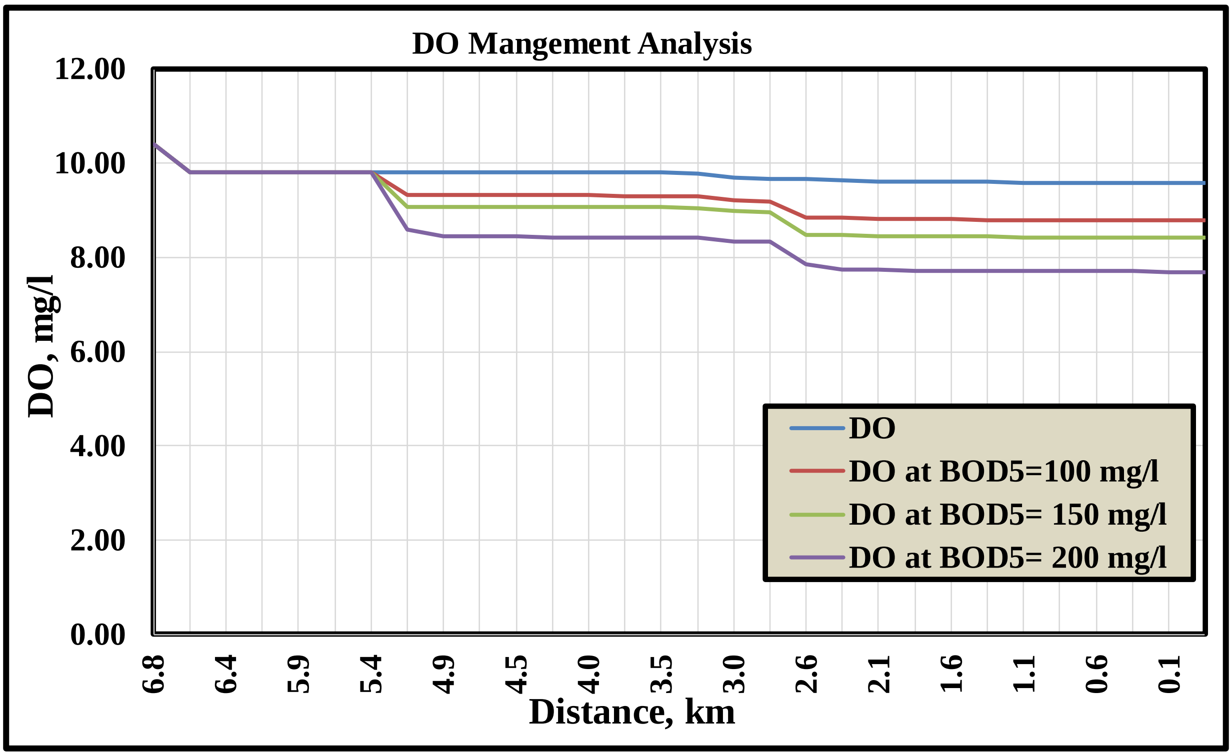

Fig. (4.23): Simulated DO level under the influence of two BOD_5 point sources.

Regarding CBODu distribution in the river, the first scenario involved the presence of a single pollution source located at 2.8 km with varying BOD_5 additions of 100 mg/l, 150 mg/l, and 200 mg/l. The results revealed that the presence of this pollution point source led to an increase in CBODu remarkably. Notably, the increment was the most pronounced at a CBOD concentration of 200 mg/l scenario, exceeding that of the 100 mg/l and 150 mg/l CBOD concentration. The maximum concentration of the CBODu distribution in the river occurred at the 200 mg/l scenario, where it increased to 3.1 mg/l compared to 2.98 mg/l for the 100 mg/l scenario and 2.82 mg/l for the 150 mg/l scenario, as illustrated in Figure 4.24. In the second case, which introduced a second point source along with the first one, the impact on CBODu distribution was even more significant compared to the single point source case. CBODu levels raised to 2.94 mg/l, 3.25 mg/l, and 3.59 mg/l for the scenarios of 100 mg/l, 150 mg/l, and 200 mg/l, as shown in Figure (4.28). The most critical situation was the 200 mg/l scenario, where CBODu decreased by 32% compared to the natural CBODu levels in the river.

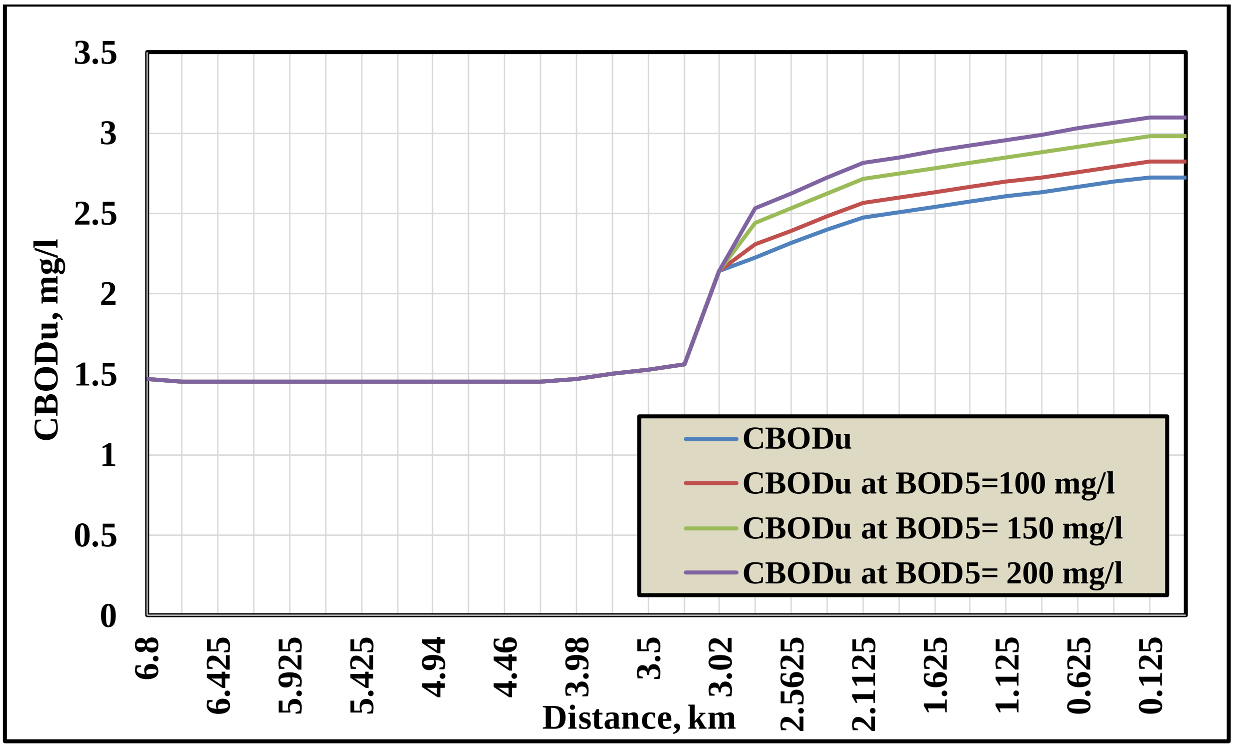

Fig. (4.24): Simulated CBODu under the influence of a one BOD_5 point source.

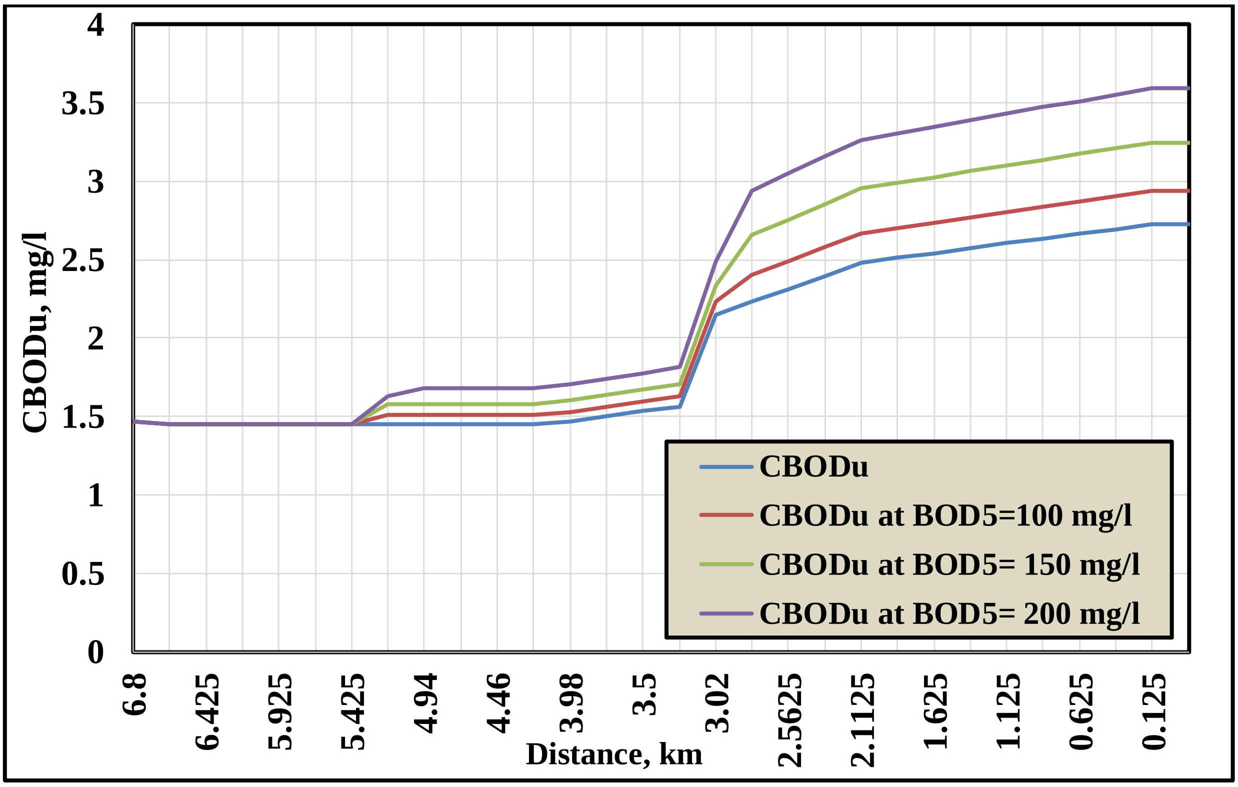

Fig. (4.25): Simulated CBODu under the influence of two BOD_5 point sources.

CHAPTER FIVE

CONCLUSIONS

AND

RECOMMENDATIONS

CHAPTER FIVE

CONCLUSIONS

AND

RECOMMENDATIONS

5.1 Conclusions

Based on the research results, the main conclusions are as follows:

1. Comparing the field water quality data to the standards, it was obtained that the average values of DO, CBODu, pH, EC, and ALK, and Temp for dry and wet seasons were within the Iraqi and WHO standards and can be considered as an acceptable value .

2. It was found that, during the dry season, the Hilla River DO level slightly decreased and changed with distance from the first station at the Bata Bridge location toward the last station at the Al Faris location due to the human activities of the illegal spills in addition to the surface run off from the surrounding areas along the river length. On the other hand, during the wet season, the level of DO became higher due to the river flow rate and mixing process conditions that become higher on winter. On both seasons, the DO levels in the river were within the permissible limit (greater than the minimum required level of 5 mg/l).

3. Although the CBOD concentrations along the river length met the standards, it was found that there is a slight increase happened after a distance of about 3.5 km from Bata Bridge location toward the Al Faris location downstream. This taken place on both seasons and impacted the DO levels after this distance simultaneously. Therefore, there is an evidence that spills exist along the river length mainly after the kilometer number 3.5. Hence, the higher river flow rate on the wet season reduced the CBOD values due to the higher mixing process, dispersing the organic matter quickly and preserving DO levels in the river.

4. On both seasons, the pH, EC, ALK, and Temp slightly decreased and changed with increasing the distance from Bata Bridge location toward the last station at the Al Faris location without violating the standards. Because this change was almost smooth along the river length, it can be concluded that the main constituent at the spill expected location was CBOD.

5. The model simulation results were very sensitive to the river flow rate variation in which increasing the river flow decreased DO and CBOD and increased EC, ALk, and pH depending on Hilla River water quality transport conditions.

6. The river reaeration rate coefficient (Ka) and CBOD oxidation rate (K_{dc}) play a major role in the model calibration/validation process and can change the DO and CBOD simulation results significantly. Applying different Ka calculation formula impacted the river DO pointedly. Also, increasing K_{dc} decreased the river DO and CBOD. Thus, it is important to specify the best calculation formula or the appropriate value of the coefficient during the initial model setup to meet the field measurements.

7. The effect of Manning roughness coefficient (n) is significant on the river water velocity in which increasing n coefficient from 0.08 to 0.09, and 0.1 reduced the average river velocity by 7.41% and 12.96%, respectively. Thus, this coefficient can be used for the model calibration based on the river roughness conditions.

8. The presence of illegal pollution outfalls along the river can be discovered by using QUAL2K model. Any jump located at the simulation curve refers to the point source existence. Therefore, the model can be implemented by the responsible agency to manage the Hilla River water quality. Loading the river by known point source of pollution can highlight the environmental impact.

9. Exploring of presence of CBOD pollution point source at a suggested point located at the kilometer number 2.8, at the Bab Al-Hussein Bridge, exhibited that the existence of this pollution point source decreased the dissolved oxygen level downstream the outfall location, but the river DO level in case of releasing 200 mg/l BOD_5 with a flow rate of 1 m^3/s was huge and larger than the effect of 150 mg/l and 100 mg/l. Adding more pollution sources can make the situation worse. Regarding the CBOD distribution in the river, the released CBOD from the point source led to an increase in CBOD remarkably, depending on the released pollutant concentration and flow rate. Therefore, it is necessary to manage the source of pollution by specifying the maximum daily load for each source along the river after exploring their illegal location.

5.2 Recommendations for future studies

The following recommendations can be applied for the future related studies.

1. Since Iraq may be experiencing a water crisis in the next few years, researches can be performed by using the QUAL2K model for other study areas to monitor and control pollution resources in the country and to protect and enhance water quality monitoring programs.

2. The model can be used to simulate the non-point sources impact on the water quality of the Hilla River, especially from the agricultural lands.

3. This study only looked at several water quality constituents (DO, BOD_5, EC, pH, Alk, and temperature). Therefore, other constituents can be explored such as NO_3, SO_3, Cl, algae, and heavy metals.

4. The QUAL2K results can be compared to other models such as HEC-RAS and COMSOL and calculating the statistics errors in order to highlight the model efficiency.

5. The QUAL2K results can be linked with remote sensing data for water quality monitoring purposes. It is important to look for the point sources locations along the river. Future studies can use the QUAL2K to solve this issue.

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APPENDIX

A

Appendix-A: QUAL2K Output for Calibration (29\10\2022)

Table (A-1):Model Output of DO, CBODu, pH , EC and Temp for model Calibration

Reach Label	X (Km)	Cond umhos	DO mg/l	Temp. (C)	PH	CBODu mg/l	Alk mg/l
water Head	6.80	1316	10.40	23.40	7.58	1.47	122.50
water Head	6.68	1301.54	10.12	23.13	7.83	1.45	122.25
water Head	6.43	1301.54	10.12	23.11	7.83	1.45	122.25
water Head	6.18	1301.54	10.12	23.10	7.83	1.45	122.25
water Head	5.93	1301.54	10.12	23.09	7.83	1.45	122.25
water Head	5.68	1301.54	10.11	23.07	7.83	1.45	122.25
water Head	5.43	1301.54	10.11	23.06	7.83	1.45	122.25
Reach2	5.18	1301.54	10.11	23.05	7.83	1.45	122.25
	4.94	1301.54	10.11	23.03	7.83	1.45	122.25
	4.70	1301.54	10.11	23.02	7.84	1.45	122.25
	4.46	1301.54	10.10	23.01	7.84	1.45	122.25
	4.22	1301.54	10.10	22.99	7.84	1.45	122.25
	3.98	1301.04	10.10	22.97	7.83	1.47	122.24
Reach 3	3.74	1300.18	10.09	22.94	7.83	1.50	122.23
	3.50	1299.33	10.08	22.92	7.83	1.53	122.21
	3.26	1298.47	10.07	22.89	7.83	1.56	122.20
	3.02	1282.17	9.94	22.59	7.78	2.14	121.92
	2.79	1278.27	9.91	22.51	7.77	2.23	121.85
	2.56	1274.40	9.88	22.43	7.76	2.31	121.79
	2.34	1270.56	9.85	22.35	7.75	2.40	121.72
Reach 4	2.11	1266.74	9.82	22.27	7.74	2.48	121.66
	1.88	1265.89	9.81	22.24	7.74	2.51	121.64
	1.63	1265.05	9.8	22.22	7.74	2.54	121.63
	1.38	1264.20	9.79	22.19	7.73	2.57	121.61
	1.13	1263.36	9.78	22.16	7.73	2.60	121.60
	0.88	1262.52	9.78	22.14	7.73	2.63	121.59
	0.63	1261.68	9.77	22.11	7.73	2.67	121.57
Reach 5	0.38	1260.84	9.76	22.08	7.73	2.70	121.56
	0.13	1260.00	9.75	22.06	7.72	2.73	121.54
	0.0	1260.00	9.75	22.06	7.72	2.73	121.54

APPENDIX

B

Appendix-B: QUAL2K Output for Validation (23\1\2023)

Table (B-1):Model Output of DO, CBODu, pH , EC and Temp for model Validation

Reach Label	X (Km)	Cond umhos	DO mg/l	Temp. (C)	PH	CBODu mg/l	Alk mg/l
water Head	6.80	1558.00	9.10	14.50	8.16	1.22	142.00
water Head	6.68	1543.96	9.66	14.37	8.19	1.20	141.62
water Head	6.43	1543.96	9.66	14.36	8.19	1.20	141.62
water Head	6.18	1543.96	9.66	14.36	8.19	1.20	141.62
water Head	5.93	1543.96	9.66	14.35	8.19	1.20	141.62
water Head	5.68	1543.96	9.66	14.35	8.19	1.20	141.62
water Head	5.43	1543.96	9.66	14.35	8.19	1.20	141.62
Reach2	5.18	1543.96	9.66	14.34	8.19	1.20	141.62
	4.94	1543.96	9.66	14.34	8.19	1.20	141.62
	4.70	1543.96	9.66	14.34	8.19	1.20	141.62
	4.46	1543.96	9.66	14.33	8.19	1.20	141.62
	4.22	1543.96	9.66	14.33	8.19	1.20	141.62
	3.98	1542.99	9.65	14.32	8.19	1.23	141.60
Reach 3	3.74	1541.33	9.64	14.30	8.18	1.29	141.55
	3.50	1539.66	9.63	14.28	8.18	1.34	141.51
	3.26	1538.01	9.62	14.26	8.17	1.39	141.46
	3.02	1521.35	10.41	14.10	8.12	1.89	141.01
	2.79	1516.80	10.37	14.06	8.11	1.99	140.89
	2.56	1512.29	10.34	14.01	8.10	2.08	140.77
	2.34	1507.80	10.31	13.97	8.08	2.17	140.65
Reach 4	2.11	1503.33	10.28	13.92	8.07	2.27	140.53
	1.88	1503.33	10.28	13.92	8.07	2.27	140.53
	1.63	1503.33	10.28	13.92	8.07	2.26	140.53
	1.38	1503.33	10.28	13.91	8.07	2.26	140.53
	1.13	1503.33	10.28	13.91	8.07	2.26	140.53
	0.88	1503.33	10.28	13.91	8.07	2.26	140.53
	0.63	1503.33	10.28	13.90	8.07	2.26	140.53
Reach 5	0.38	1503.33	10.28	13.90	8.07	2.26	140.53
	0.13	1503.33	10.28	13.90	8.07	2.26	140.53
	0.0	1503.33	10.28	13.90	8.07	2.26	140.53

APPENDIX

C

Appendix C:

Table C.1 : Roughness coefficient values for each channel surface material (Te Chow et al., 1988)

Material	**n**
Man-made channels	
Concrete	0.012
Gravel bottom with sides:	
Concrete	0.020
mortared stone	0.023
Riprap	0.033
Gravel bottom with sides:	
Clean, straight	0.025-0.04
Clean, winding and some weeds	0.03-0.05
Weeds and pools, winding	0.05
Mountain streams with boulders	0.04-0.10
Heavy brush, timber	0.05-0.20

APPENDIX

D

Appendix D:

Table D.1 : Model state variable (Chapra et al.,2012).

Variable	Symbol	Unit
Conductivity	S	µmhos
Inorganic suspended solids	m_i	mgD/l
Dissolved oxygen	O	mgO_2/L
Slowly reacting CBOD	c_s	mgO_2/l
Fast reacting CBOD	c_f	mgO_2/l
Organic nitrogen	n_o	µgN/l
Ammonia nitrogen	n_a	µgN/l
Nitrate nitrogen	n_n	µgN/l
Organic phosphorus	p_o	µgP/l
Inorganic phosphorus	p_i	µgP/l
Phytoplankton	a_p	µgA/l
Phytoplankton nitrogen	IN_p	µgN/l
Phytoplankton phosphorus	IP_p	µgP/l
Detritus	m_o	mgD/l

Pathogen	X	cfu/100 ml
Alkalinity	AIK	$mgCaCO_3/l$
Total inorganic carbon	c_T	mole/l
Bottom algae biomass	a_b	mgA/m^2
Bottom algae nitrogen	IN_b	mgN/m^2
Bottom algae phosphorus	IP_b	mgP/m^2
Constituent i		
Constituent ii		
Constituent iii		

الخلاصة

منذ أن تطورت الأنشطة الصناعية والبشرية بطرق مختلفة في العراق، تراجعت نوعية المياه على طول نهر الحلة، وهو المصدر المائي الوحيد في مدينة الحلة لمياه الشرب. في هذا البحث تم استكشاف ومحاكاة نوعية المياه لطول نهر الحلة المار بمركز مدينة الحلة باستخدام نموذج يسمى "نموذج QUAL2K" وهو إطار نمذجة عددي لمراقبة نوعية المياه في الأنهار بالاعتماد على الجودة الهيدروليكية وجودة المياه. تم جمع البيانات على طول 6.8 كم لاستخدامها كمدخلات بواسطة النموذج. تم قياس مكونات جودة المياه بما في ذلك الأوكسجين المذاب (DO), والطلب على الأوكسجين البيولوجي الكربوني (CBOD), ودرجة الحموضة, والتوصيل الكهربائي (EC), والقلوية (ALK), ودرجة الحرارة (درجة الحرارة) في تسع محطات أخذ عينات تقع على طول هذا النهر في أكتوبر 2022 (موسم التدفق المنخفض) وينايـر 2023 (موسم التدفق العالي). كشفت مقارنة النتائج التجريبية مع المعايير أن متوسط قيمة DO, CBODu, pH, EC, ALK, ودرجة الحرارة كانت ضمن المعايير العراقية ومعايير منظمة الصحة العالمية ويمكن اعتبارها قيمة مقبولة. تمت معايرة النموذج والتحقق من صحته لكلا الموسمين لضمان الدقة أولاً. أشارت الأخطاء الإحصائية للتنبؤات النموذجية لـ (DO, CBODu, pH, EC, ALK, ودرجة الحرارة) مقارنة بالقياسات الميدانية إلى وجود توافق جيد خلال كل من موسم الجفاف والمطر.

أظهرت النتائج أن معدل تدفق نهر الحلة يؤثر على نموذج المحاكاة للأوكسجين المذاب عن طريق خفض مستواه على طول النهر قليلاً لأن التدفق يصل إلى المدينة مع ارتفاع الطلب على الرواسب والمواد المغذية من المناطق الزراعية أعلى النهر. ومع ذلك، فإن سلوك التخفيض هذا يعتمد بشكل أساسي على ظروف النهر المائية وجودة المياه مثل تصريف مصدر التلوث، وغياب الطحالب، والنشاط البكتيري، وتحلل المواد العضوية، والرواسب السفلية. ونتيجة لذلك، أظهر ناتج النموذج سلوك التخفيض لتوزيع CBODu حيث يقلل التدفق العالي من قيم CBODu. أظهرت نتائج محاكاة نموذج الاتحاد الأوروبي أنه في حالة زيادة معدل تدفق المياه، تزداد موصلية المياه بسبب زيادة الأيونات في مياه النهر. بالنسبة لمحاكاة نماذج pH و Alk، أدت زيادة معدل تدفق النهر إلى زيادتها أيضًا.

تم إجراء تحليل حساسية النموذج لاستكشاف جودة مياه النهر ولتسليط الضوء على كيفية تأثير بعض العوامل على محاكاة النموذج، ثانيًا. من أجل دراسة تأثير تغير ظروف النهر على محاكاة النموذج، تنوعت المدخلات الرئيسية للنموذج الذي تمت معايرته والتحقق من صحته بشكل كبير. تم تنفيذ ذلك عن طريق تغيير أحد مدخلات النموذج والاحتفاظ بالمدخلات الأخرى دون تغيير. بعد ذلك، تم عرض نتائج محاكاة النموذج لاستكشاف نتائج التغيير المحددة هذه. يعد هذا التحليل مهمًا لأنه يعطي إشارة للمستخدم حول كيفية تأثير بعض المتغيرات على محاكاة النموذج واستقراره. تم فحص تأثير معامل معدل الأكسدة CBOD لكل من المواسم الجافة والرطبة. هذه الميزة مهمة لتشغيل النموذج بشكل عام. ويمكن استخدامه لمعايرة النموذج. بالنسبة لـ CBODu، كان

تـــأثير معـــدل أكســـدة CBODu طفيفًـــا بســـبب انخفـــاض تركيـــز CBODu فـــي النهـــر. ومـــع ذلـــك، عـــانى النهـــر مـــن انخفـــاض فـــي قـــيم الاوكســـجين المـــذاب عنـــدما ارتفـــع معـــدل أكســـدة CBOD إلى 0.2 يوم-1 وأصبح أكثر لمدة 0.5 يوم-1.

وقـــد يزيـــد معـــدل الأكســـدة هـــذا بســـبب التفـــاعلات الكيميائيـــة؛ علـــى ســـبيل المثـــال، يمكـــن لأكســـدة المركبـــات غيـــر العضـــوية مثـــل الحديـــد أو الكبريـــت أن تســـتهلك أيضًـــا الأوكســـجين المـــذاب. بالإضـــافة إلـــى ذلـــك، فـــإن معامـــل معـــدل إعـــادة التهويـــة مهـــم لتشـــغيل النمـــوذج بشـــكل عـــام. ويمكـــن اســـتخدامه لمعـــايرة النمـــوذج. تـــم دمـــج العديـــد مـــن المخططـــات داخـــل النمـــوذج. وتعتمـــد معظـــم هـــذه المعـــادلات علـــى دراســـات ميدانيـــة لتيـــارات أو قنـــوات مختبريـــة مختـــارة. ومـــع ذلـــك، يمكـــن تحديـــد معامـــل معـــدل إعـــادة التهويـــة فـــي النمـــوذج عـــن طريـــق تحديـــد قيمـــة محـــددة. ومـــع ذلـــك، فقـــد وجـــد أن معادلـــة معـــدل إعـــادة التهويـــة الداخليـــة قابلـــة للتطبيـــق فـــي هـــذه الدراســـة. عـــلاوة علـــى ذلـــك فـــإن تـــأثير معامـــل الخشـــونة علـــى ســـرعة ميـــاه النهـــر كـــان معنويـــا. ونتيجـــة لـــذلك فـــإن زيـــادة معامـــل الخشـــونة مـــن 0.08 إلـــى 0.09 و0.1 أدت إلـــى خفـــض متوســـط السرعة بنسبة 7.41% و12.96% على التوالي.

أخيـــرًا، تـــم إجـــراء تحليـــل قـــدرة إدارة نمـــوذج QUAL2K لدراســـة تـــأثير مصـــادر نقـــاط التلـــوث علـــى مســـتوى DO لنهـــر الحلـــة نظـــرًا لأن وجـــود مصـــادر نقـــاط التلـــوث علـــى طـــول النهـــر يمكـــن أن يكـــون لـــه العديـــد مـــن التـــأثيرات الســـلبية علـــى النظـــام البيئـــي للنهـــر وجـــودة مياهـــه. أشـــارت النتـــائج إلـــى أن وجـــود مصـــادر نقـــاط التلـــوث هـــذه أدى إلـــى انخفـــاض مســـتوى الأوكســـجين المـــذاب أســـفل مواقـــع المصـــب، اعتمـــادًا علـــى تركيـــز الملوثـــات المصـــدر وتصـــريفها. إن وجـــود مصـــدر ملـــوث واحـــد مـــن BOD_5 عنـــد نقطـــة 2.8 كـــم بتركيـــز ملـــوث 100 و 150 و 200 ملجـــم / لتـــر وتصـــريف 1 م3 / ثانيـــة أدى إلـــى انخفـــاض الأوكســـجين المـــذاب فـــي النهـــر ولكـــن الانخفـــاض فـــي حالـــة 200 ملجـــم / لتـــر كـــان ضـــخمة وأكبـــر مـــن تلـــك التـــي تبلـــغ 100 و 150 ملغـــم / لتـــر. أدت إضـــافة المزيـــد مـــن المصـــادر النقطيـــة إلـــى تقليـــل الأوكسجين المذاب أكثر من حالة مصدر نقطي واحد.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة بابل

كلية الهندسة

قسم الهندسة البيئية

النمذجة العددية لمراقبة نوعيه المياه في نهر الحلـه، العـراق: محاكـــاة وسينـــاريوهات أدارة المياه

رسالة

مقدمة الى قسم الهندسة البيئية / كلية الهندسة في جامعة بابل كجزء من متطلبات نيل

درجة الماجستير في الهندسة / الهندسة البيئية

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