



ASSESSMENT OF SURFACE WATER QUALITY AND POLLUTION CONTROL
STRATEGIES USING QUAL2Kw MODEL: A CASE STUDY OF TIKUR WUHA
RIVER; HAWASSA, ETHIOPIA

MSc THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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A THESIS SUBMITTED TO THE DEPARTMENT OF WATER SUPPLY AND
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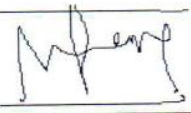
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I hereby declare that this MSc specialty or equivalent thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis / dissertation have been duly acknowledged.

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LIST OF ABBREVIATION AND ACRONYMS

APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
GPS	Global Positioning System
M.A.S.L	Mean above Seas Level
NTU	Nephelometric Turbidity Unit
PBAIS	Percentage of bais
pH	Power of Hydrogen
Q2E	QUAL2E
Q2K	QUAL2K
Q2Kw	QUAL2Kw
R ²	Coefficient Determination
TDS	Total Dissolved Solid
TSS	Total Suspended Solid
TWR	Tikur Wuha River
WHO	World Health Organization
WQ	Water Quality

TABLE OF CONTENTS

ACKNOWLEDGEMENT	i
LIST OF ABBREVIATION AND ACRONYMS.....	ii
TABLE OF CONTENTS.....	iii
LIST OF TABLE	vi
LIST OF FIGURE	vii
Abstract.....	viii
1. INTRODUCTION	1
1.1. Background	1
1.2. Statement of the Problem	5
1.3. Objective of the Study.....	6
1.3.1. General Objective	6
1.3.2. Specific Objective.....	6
1.4. Research Questions	7
1.5. Significance of the Study	7
1.6. Scope of the Study	7
2. LITERATURE REVIEW	8
2.1. General	8
2.2. Source of Surface Water Pollution.....	8
2.3. Surface Water Quality and its Parameter	10

2.3.1.	Parameters of river water quality tests.....	11
2.4.	Water Quality Modeling and Simulation	14
2.4.1.	General.....	14
2.4.2.	Water Quality Model Description.....	16
2.4.3.	Application of Water Quality Models	19
2.4.3.1.	Water Quality Models Application in Ethiopia.....	20
2.4.4.	Selection of Water Quality Model	22
2.4.5.	Description of QUAL2Kw Model	23
3.	MATERIAL AND METHODOLOGY	26
3.1.	Description of Study Area.....	26
3.2.	Data and Monitoring Station	27
3.3.	Sampling and Analysis.....	29
3.4.	Modeling Tool.....	31
3.4.1.	Application of Q2Kw Model	34
3.4.1.1.	River Discretization.....	34
3.4.1.2.	Input Data	34
3.4.1.3.	System Parameter	38
3.4.1.4.	Model Implementation	40
3.4.2.	Model Calibration	41
3.5.	Assessment of Strategies for Controlling Pollution in the Catchment.....	42
4.	RESULTS AND DISCUSSIONS.....	43

4.1. Analysis of TWR Water Quality Parameters	43
4.1.1. pH value	43
4.1.2. EC and TDS	44
4.1.3. Water temperature and DO	45
4.1.4. Phosphate (PO_4^{3-}).....	46
4.1.5. BOD ₅ and COD	47
4.1.6. Nitrate (NO_3^-) and Nitrite (NO_2^-).....	48
4.1.7. Ammonia nitrogen ($\text{NH}_3\text{-N}$)	49
4.2. Q2Kw Simulation Model	50
4.3. Surface Water Quality Control Strategies	54
5. CONCLUSION AND RECOMMENDATION.....	57
5.1. Conclusion.....	57
5.2. Recommendations	59
REFERENCE.....	60
APPENDIX.....	75
Appendix-A: Guideline Surface Water Quality Standards.....	75
Appendix-B: Model Output Parameters	76
Appendix-C: Image Showing Sampling Water and Experimental Analysis	79
Appendix-E: Coefficient Determination R^2 value between Simulated and Observed Data during Calibration	81

LIST OF TABLE

Table 2-1: Characteristics of some water quality models.....	18
Table 2-2: A survey of model based WQ and hydrology studies in Ethiopia	21
Table 2-3 Model simulate parameters	23
Table 3-1: Water quality parameters and determination methods and instruments used	30
Table 3-2: General performance ratings of the recommended statistics for a monthly time step.....	33
Table 3-3: Geographic characteristics of the monitoring station along the TWR.....	36
Table 3-4: Reach hydraulic characteristics of the monitoring stations along the TWR.....	36
Table 3-5: Monthly average meteorological parameters at Hawassa station	38
Table 3-6: Calibrated rate parameters for the TWR water quality modeling	39
Table 4-1: Water quality parameters measured along the TWR and tributary during the dry period.	51

LIST OF FIGURE

Figure 3-1: Location of study area and Monitoring Station	27
Figure 3-2: Mass balance constituents in a reach segment i.....	31
Figure 3-3: Discretization of the Tikur Wuha river.....	34
Figure 4-1: pH value in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR.....	43
Figure 4-2: EC and TDS concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR.....	44
Figure 4-3: Water T° and DO concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR.....	45
Figure 4-4: Phosphate (PO_4^{3-}) concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR.....	46
Figure 4-5: BOD and COD concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR.....	48
Figure 4-6: Nitrate (NO_3^-) and Nitrite (NO_2^-) concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR.....	48
Figure 4-7: Ammonia nitrogen concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR	49
Figure 4-8: Model calibration results for the water quality parameters in TWR using dry data.....	53

Abstract

River water pollution is caused by both natural and artificial activity, such as waste generated from urban area and agricultural lands. The water quality model using QUAL2Kw was conducted to assess the water quality status of Tikur Wuha River and pollution control strategies in Hawassa, Ethiopia. Water samples from this river were collected on March 2023 at different monitoring stations along the river, and their quality was analyzed. The study result indicated that all the measured parameters satisfied the guidelines of the WHO and Ambient Environment Standards for Ethiopia except BOD₅, TSS, and PO₄⁻³ in the study period. The concentration of DO were meet the permissible limit and two sampling station were below the minimum limit. The measured water quality of the river was appropriate for agricultural activity at all sampling points. The model was applied to simulate the water quality parameters such as flow rate, water temperature, EC, DO, BOD₅, pH, TSS, ammonia-N, nitrate-N, and phosphate. The model represented the measured data quite well with some exception. In this study, a stream water quality model, Q2Kw, was used to predict the river water quality using the data collected in dry season. The results from the calibrated model indicate that the model was able to appropriately predict the pollution of the river with |PBAIS| and R² values of 1.02% (0.999), (0.65), 8.87% (0.6), and 0.71%, respectively, for temperature, DO, EC, and pH. The model can be applied successfully to generate future scenarios for the study area and applicable to assess the effect of various pollution controls and supporting in-stream measures on key water quality parameters. In general, the study results indicate that proper waste management should be adopted to prevent the continued deterioration and improve the water quality condition of the Tikur Wuha River.

Key Words: QUAL2Kw; Tikur Wuha River; Water quality and Water quality model.

1. INTRODUCTION

1.1. Background

Water is a gift from nature and the most important resource for maintaining life in all economic activities, from agriculture to industry (Ye et al., 2013). Surface water bodies are vital natural resources that are vulnerable to pollution. Rivers are essential freshwater systems of strategic importance since they provide a majority of the world's freshwater resources for domestic, industrial, agricultural, and recreational uses. Rivers, which form the basis of human society, are essential for absorbing or carrying sewage from industrial, urban, and agricultural areas. The surface water is degraded by anthropogenic factors such as urbanization, industrialization, agricultural practices, and erosion (Basu & Lokesh, 2013).

Despite their limited availability, rivers are the most important inland water resources for domestic, industrial, and irrigation needs. Therefore, monitoring and assessment of water bodies is imperative to obtain reliable information on water quality for effective management. In addition to harming aquatic life and agricultural activity, contaminated water has a negative impact on people's health (Ibrahim et al., 2015). Urbanization, industrialization, land expansion along river basins, and rapid population growth have all contributed to water pollution and environmental degradation. In the majority of cities in developing countries, industrial effluents are discharged into rivers (Kori et al., 2013).

The decline in the quality and quantity of river water resources shows the pollution and improper management of the water resource (Tekile, 2023). Many rivers around the world are now being impacted by urbanization, industrialization, and agricultural activities. Urban rivers in developing countries are often considered carriers of organic

and inorganic nutrients and are becoming a threat to the community (Hamid et al., 2020). These water quality problems have implications for aquatic ecology as well as human health (Khouni et al., 2021).

In Ethiopia, the pollution of the urban river is related to the high and unplanned expansion of cities, uncontrolled agricultural and urban runoff, and improper domestic and solid waste released into the river (Yohannes & Elias, 2017). The study conducted by Prabu et al., (2011) on Huluka and Alaltu Rivers of Ambo in Ethiopia showed that all the measured ions are with an increasing trend from upstream to downstream and deterioration of the water quality of Huluka and Alaltu Rivers because those rivers are affected by a different source of pollution such as domestic, municipal sewage wastewater, solid waste disposal, and agricultural activities. Moreover, Gebreyohannes et al., (2015) study on Elala River in Ethiopia indicated the river water quality was contaminated due to the entry of domestic waste from urban areas and agricultural lands. Now a day's water pollution from the disposal of industrial wastewater is becoming an environmental concern in the shore of Hawassa town and affecting Tikur Wuha River and Lake Hawassa (Lencha, Tränckner, et al., 2021).

Streams from the eastern watershed that go to Lake Cheleleka are drained into the Tikur-Wuha River, which supplies water to Lake Hawassa. Several point sources have significantly impacted the water in this river (Lencha., et al., 2021). This is a threat to the people who rely on rivers, streams, and the lake for domestic and other purposes and to the survival of aquatic life as well. The multiple industries in the watershed have a significant impact on the Tikur Wuha River (Worako, 2015). Many researchers' studies on the tributaries and lower reaches of the Tikur Wuha River for assessing of the water quality of Lake Hawassa, but study along the river can more accurately determine the

quality of the river and its control mechanisms. Quality of water is necessary for sustainable growth. In semi-humid and semi-arid regions, water quality plays a crucial role in determining both the quantity and quality of grain production as well as human health (Oketola et al., 2013). The health of people, animals, and plants depends significantly on the quality of the water (Ibrahim et al., 2015). In terms of its physical, chemical, and biological properties, water quality is determined. An ecosystem that is balanced cannot exist in polluted surface waters. An ecosystem that is in equilibrium includes both living beings and the environment, which interact beneficially with one another (Gajbhiye et al., 2015).

Control of water contamination has reached essential significance in developed and a number of developing countries. The complex relationships between waste loads from various sources and the resulting water quality of the receiving waters should to be characterized. The most effective way to describe these relationships is the mathematical models (McIntyre et al., 2003). The complex relationships between waste discharge from different sources (point or nonpoint) and the resulting water qualities of the receiving waters are best described with mathematical models (Deksissa et al., 2004).

In order to prevent adverse effects on the state of water resources, stakeholders can provide suggestions using mathematical models (Marlina & Melyta, 2019). For rivers and streams, one-dimensional models are often used (Raeisi et al., 2022). There are various types of water quality models, and each one requires a particular degree of confidence in the model's predictions (Kannel et al., 2011). According to Mustafa et al., (2017), the United States Environmental Protection Agency (USEPA) created QUAL2E, which is the most widely used mathematical model for conventional pollutant impact

assessment. However, several limitations of the QUAL2E have been reported (Olowe & Kumarasamy, 2018). After modifying QUAL2E, Park and Lee (2002) created QUAL2K. Modifications include expanding computational structures and including more constituent interactions, such as algal BOD, denitrogenation, and DO variation caused by fixed plants. Pelletier and Chapra (2005) built the new QUAL2Kw model by modifying the original Q2K model that was first developed by Chapra and Pelletier in 2003. This model, which is a more modern version of Q2E, is useful for shallow rivers (Ghosh & Mcbean, 1998). Reaches that aren't equally spaced apart are used in the one-dimensional steady-state stream water quality model Q2Kw. Any reach can also take multiple loadings and abstractions, and the Microsoft Windows environment makes use of this flexibility. It is fully documented and easily accessible (Sharma et al., 2017). Q2Kw model is based on an automatic calibration system with new equations (Raeisi et al., 2022). It can also provide fundamental information for water quality evaluation, even with a small dataset (Kannel et al., 2007).

Q2Kw was chosen as a framework for the study of the Tikur Wuha River as a result. This study assessed the effects of waste discharge on receiving water bodies, discussed the model's use, and evaluated the river's water quality. The majority of water resources are easily contaminated by anthropogenic activity, especially in urban areas, according to studies in Hawassa city. Due to wastewater entering the river system either directly or indirectly through wastewater drains, the Tikur Wuha River in Hawassa has high levels of pollution from the discharge of untreated or poorly treated wastewater. However, there has been no published research on evaluating the Tikur Wuha River water quality using the Q2Kw model and pollution control techniques. The main objective of this research was to assess the Tikur Wuha River water quality using Q2Kw model and pollution control strategies.

1.2. Statement of the Problem

The quality of water resources degrades as a result of the waste produced by various industries being frequently dumped into bodies of water with or without treatment. Additionally, the use of inorganic fertilizers, pesticides, and herbicides in agricultural activities pollutes water resources, and the release of excessive nutrients into rivers could result in a rise in eutrophication (Yıldız & Karakuş, 2020). When compared to the upstream side, the middle and downstream portions of the river have greater concentrations of pollutants. This indicates that contamination levels raise while passing through the towns, due to such activities as washing clothes, having baths, and discharging domestic waste without any sort of treatment (Terfasa et al., 2021).

The Tikur Wuha River (TWR) is one of the surface water resources in the vicinity of Hawassa city and Tikur Wuha kebele that feeds Lake Hawassa. However, along the Tikur Wuha River, there are so many anthropogenic activities that are affecting the water quality like improper disposal of solid waste, improper disposal of liquid waste from urban areas, open defecation practice, and agricultural activity. Despite the increasing pollution in the river which augmented the pollution load, the local community uses the river for a variety of socioeconomic purposes, small-scale irrigation, bathing, cloth washing, animal watering, and recreation without any treatment. Water pollution in the River, like in most water bodies of the nation is a major problem. Industrial waste discharge into the TWR has led to deteriorating water quality and ecosystem health, including fish survival (Worako, 2015). In the interest of protecting the population from waterborne diseases and creating effective preventive measures, water quality monitoring and modeling are found to be essential.

Since both point and non-point sources have an impact on environmental systems like rivers and lakes, it's found to be essential and critical to comprehend the physico-chemical and biological characteristics for assessment and management. Many researchers' studies on the tributaries and lower reaches of the Tikur Wuha River, but study along the river can more accurately determine the quality of the river and its control mechanisms. The results must be interpreted using a water quality model since evaluating numerous water quality characteristics results in large and complex datasets. Water quality modeling, such as the QUAL2Kw model has been effectively used to better understand the water quality and ecological status of studied systems.

1.3. Objective of the Study

1.3.1. General Objective

The main objective of this study was to assess the water quality of Tikur Wuha River using QUAL2Kw model and pollution control strategies of the river.

1.3.2. Specific Objective

The specific objective of the research includes:

- ❖ To evaluate the water quality of selected physiochemical and biological parameters,
- ❖ To assess the impact of waste discharges on the river and
- ❖ To assess the control strategies for the priority parameters in the catchment and put forward the feasible one.

1.4. Research Questions

1. What does the physicochemical and biological water quality of Tikur Wuha River look like?
2. What are the impacts of waste discharge on the river?
3. How can we control the causes for pollution of TWR at a catchment level?

1.5. Significance of the Study

This study was providing scientific information regarding the water quality status of the Tikur Wuha River. The findings of this study may be significant for identifying the main pollution factors and assessing the river's water quality using the Q2Kw model. It also provides sufficient information to improve monitoring and management of Tikur Wuha river water against various national and international water quality standards.

1.6. Scope of the Study

The scope of the research is as follows:

This study is concerned with determination of the water quality status of TWR and also identifying the source of pollution that enters into the river using Q2Kw model. Analysis of the study was conducted only on 5 monitoring stations, one point source and one tributary because of cost limitations. Sampling starts from downstream at TWR mouth and ending upstream at BGI along River (Hawassa). The study was done during the dry season and the sample was conducted in March 2023 and analyzed the water quality parameters include flow rate, water temperature, electrical conductivity, TDS, TSS, turbidity, pH, DO, BOD₅, COD, nitrate as nitrogen (sum of NO₃⁻-N and NO₂⁻-N), ammonia nitrogen (NH₄-N), and phosphate. The study was conducted for a stretch of only 8.81 kilometers of the river from upstream to downstream.

2. LITERATURE REVIEW

2.1. General

Surface water can be exposed to contamination risks from agricultural, industrial, and domestic activities, which may include many types of pollutants such as heavy metals, pesticides, fertilizers, hazardous chemicals, and oils. Water quality can be classified into four types-potable water, palatable water, contaminated (polluted) water, and infected water (Hassan Omer, 2020). Rivers are the primary sources supplying water for municipal, agricultural and industrial uses. Consequently, there is public concern on water quality pollution of Rivers. Pollutant release is the primary reason for pollution of Rivers. Moreover, the management of pollution sources is often challenging and requires techniques that are useful for addressing the problems. Improved water quality prediction and protection techniques are important for successful management of pollution problems in these waters.

2.2. Source of Surface Water Pollution

Water pollution is a global challenge that has increased in both developed and developing countries, undermining economic growth as well as the physical and environmental health of billions of people. Although global attention has focused primarily on water quantity, water-use efficiency and allocation issues, poor wastewater management has created serious water-quality problems in many parts of the world, worsening the water crisis (Mateo-Sagasta et al., 2017). Anthropogenic activities related to extensive urbanization, agricultural practices, industrialization, and population expansion have led to water quality deterioration in many parts of the world (Bu et al.,

2014). The impact of water pollution is seen on human-being who have been directly or indirectly consuming the contaminated water like river (Amare et al., 2017).

There are many man-made pollutants that can contaminate water sources. With regard to their origin we recognize two categories of their sources, point and diffuse. Many infectious diseases of animals and humans are waterborne. The agents of these diseases are transferred by ingestion of water contaminated with human or animal feces that contain pathogenic bacteria, viruses and parasites (protozoa, eggs of parasites). They may survive in water for different periods of time depending on many factors (Sasakova et al., 2018).

Unsafe industrial waste disposal causes surface water contamination in many developing countries. Discharge of untreated industrial waste is a major problem for many communities dwelling near rivers basins through causing different health problems. Presently most industries do not treat their wastes if it contains no recyclable products which could be reprocessed or sold to generate additional revenue. Poor storage of industrial and other waste products also result in surface and ground water pollution (Ademe, 2014).

Pollution of water bodies may take place due to the discharge of domestic and industrial wastewater, toxic chemicals used for agriculture and other purposes, solid waste due to garbage, and cleaning of vehicles, drainage from farms and land surface, dust fall, wastes due to recreational use and much more such activities. Water pollution from nonpoint sources is one of the more critical pollution problems that have defied solution (Maschal Tarekegn & Truye, 2018). A nonpoint source of pollution is one whose surface water runoff carries a variety of pollutants that impair water quality (Mandelker, 1989). The major sources of river water pollution are classified as point sources through

which the polluting substance is emitted directly into the waterway (Yamuna et al., 2018).

The pollution of surface waters is a problem of global concern contributing to high morbidity and mortality rates from waterborne and food-borne diseases, such as typhoid fever, cholera and diarrhea (Chigor et al., 2012). Communities situated downstream or near to municipal sewage outfalls or contaminated water sources are at the highest risk of illness due to increased microbial pathogens and deteriorating physico-chemical parameters. Often the discharge of extremely turbid effluent in conjunction with dense algal blooms results in poor visibility within these water bodies thus creating dangerous situations for recreational users (Naidoo & Olaniran, 2013).

2.3. Surface Water Quality and its Parameter

The quality of water is identified in terms of its physical, chemical and biological parameters. The particular problem in the case of water quality monitoring is the complexity associated with analyzing the large number of measured variables and high variability due to anthropogenic and natural influences. Anthropogenic influences (urban, industrial and agricultural activities, increasing consumption of water resources) as well as natural processes (changes in precipitation inputs, erosion, weathering of crustal materials) degrade surface waters and impair their use for drinking, industrial, agricultural, recreation or other purposes (Simeonov et al., 2003).

The quality of water is highly important to understand the healthiness of a water body and its critical factor affecting human health and welfare. Water quality refers to the physical, chemical and biological characteristics of the water. Monitoring water quality is important in addressing water pollution problems through the formulation of suitable mitigation measures. Consequently, there has been an increasing demand for monitoring

the quality of environmental waters by regular measurements of various quality parameters. Among these, physicochemical characteristics of water are considered as important parameters that directly or indirectly affect water quality and consequently its sustainability (D. Tibebe et al., 2022).

2.3.1. Parameters of river water quality tests

Parameters that become benchmark for monitoring in the river include:

Temperature: Temperature is one of the most important factors for survival of aquatic life. The moderate change in temperature can seriously affect aquatic environment, including bacteria, algae, invertebrates and fish (Sadgir, 2015). It controls the rate of metabolic and reproductive activities and determines which fish species can survive. Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria and toxic chemicals in water. Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature. Thereby, the sedimentation and chlorination processes and biological oxygen demand (BOD) are temperature dependent. Most individuals find that water having a temperature between 10°C–15°C is most palatable (Peters, 2011).

pH: The concentration of hydrogen ions in a solution is subjectively called pH; it is the indicator of acidic or alkaline condition of water status and quantifies the basic or acidic nature of a solution. Standard range for any purpose such as survival of fish and its use as drinking water in-terms of pH is 6-9(EPA, 2003). Due to acid rain or discharges, pH changes which in turn increases the bacterial degradation thereby depleting the DO and hence the BOD requirement exponentially rises (Sadgir, 2015). A change in the pH can change the forms of some chemicals in the water. Therefore, it may affect aquatic plants and animals(Hassan Omer, 2020).

Electrical Conductivity: Electrical conductivity is a measure of the ability of an aqueous solution to carry an electric current and depends on the presence of ions, on their total concentration, mobility and temperature. It is associated with major water quality parameters due to dilution effect of stream flow and can be used as indicator in determining the suitability of water for irrigation. Electrical conductivity is also considered to be a rapid and good measure of dissolved solids which reflects the pollution status as well as trophic level of the aquatic body (Sadgir, 2015). Since the electrical current is carried by ions in solution, the conductivity increases as the concentration of ions increases (Hassan Omer, 2020).

Dissolved Oxygen: Dissolved oxygen (DO) is considered to be one of the most important parameters of water quality in streams, rivers, and lakes. Fish require oxygen concentration of 2 to 5 mg/l depending on species. In waters heavily contaminated with organic matter, dissolved oxygen disappears. It is a key test of water pollution. Oxygen is needed for aquatic life and the amount of oxygen dissolved in a water body is, therefore, an important water quality parameter. Low dissolved oxygen (DO) has been identified as a serious water quality problem (Xu, 2014). The amount of oxygen in water, to a degree, shows its overall health. That is, if oxygen levels are high, one can presume that pollution levels in the water are low. Conversely, if oxygen levels are low, one can presume there is a high oxygen demand and that the body of water is not of optimal health.

Biochemical Oxygen Demand: involving measurement of oxygen consumed by micro-organisms while stabilizing biologically decomposable organic matter under aerobic conditions and used to determine the pollution load of waste water. The untreated discharge of municipal and domestic waste in water bodies increases the amount of

organic content. Therefore, microbes present in water require more amount of oxygen for its degradation thus the BOD of water gets increased. BOD is the measure of the extent of pollutant in the water body (Sadgir, 2015).

Chemical Oxygen Demand: Chemical Oxygen Demand is an index of organic content of water because the most common substance oxidized by dissolve oxygen in water is organic matter having biological origin. It is a valuable parameter of water quality assessment which measures oxygen demand of biodegradable pollutants as well as non-biodegradable pollutants (Sadgir, 2015).

Nitrogen As Ammonia: Ammonia (NH_3) it is one of the most important pollutants in the aquatic environment because of its relatively highly toxic nature and its ubiquity in surface water systems. It is discharged in large quantities in industrial, municipal and agricultural waste waters.

Nitrates: Nitrate (NO_3^-) is a dynamic form of nitrogen and is the most dominant form of run-off, river input, ground water discharge and atmospheric deposition into the sea. Nitrate is produced from the complete oxidation process of nitrogen and ammonia compounds in water. Nitrogen found in surface water is a result of soil drainage and domestic wastewater.

Phosphate (PO_4^{3-}): Phosphate is a basic nutrient water quality parameter that affects the efficiency of natural water resources (Aydin et al., 2020). Household wastewater, runoff from agricultural areas, and the use of synthetic detergents are the primary source of high Phosphate concentration (Shishaye & Nagari, 2016). The increase in the concentration of phosphate in water bodies leads to eutrophication. This can result in the growth of various algae species, the reduction of carbon in the food web, and the reduction in the production of fish (Khatri & Tyagi, 2015).

2.4. Water Quality Modeling and Simulation

2.4.1. General

Water quality models are very important to predict the changes in surface water quality for environmental management in the world. The water quality models are the key tools to test the impact of various actions on the quality of water bodies. Moreover, any attempt for effective water resource management in a river basin could be supported by water quality modeling (Tsakiris & Alexakis, 2012). The water quality models are used in wider water quality management applications such as determination of the impact of point and nonpoint source loads on surface water quality (Angello et al., 2021). Water quality models can be effective tools to simulate and predict pollutant transport in water environment, which can contribute to saving the cost of labors and materials for a large number of chemical experiments to some degree (Wang et al., 2013).

Water quality models are important decision support system tools for water pollution control, study of the health of aquatic ecosystems and assessment of the effects of point and diffuse pollution. However, water quality models are usually comprehensive software, which are usually not easy to learn and apply (Erturk, 2010). Mathematical models can be used to predict changes in ambient water quality due to changes in discharges of wastewater. The one-dimensional water quality models have been widely accepted where simulated data are limited (Ye et al., 2013). Surface water quality models are critically important tools for managing our nations' surface waters as they help local communities and environmental managers better understand how surface waters change in response to pollution and how to protect them.

WQ decision-making based on monitoring approach alone has its limitations, though it is essential part of WQ management. The approach is not cost-effective and falls short of showing pollution scenarios on a basin scale for planning and decision-making purposes. In addition, damage will be done at the time of taking corrective action for a pollution problem identified during monitoring. In this case, investigators will know the standard violations in the receiving water body during monitoring; however, the approach is not good enough to prevent this from happening beforehand.

On the other hand, WQ modeling is cost-effective and has the ability to establish cause-and-effect relations between pollution sources and receiving aquatic environments based on scientific knowledge. Moreover, it can enhance policymakers' understanding of the assimilative capacity of water bodies. Thus, the approach can be used during the development stage of control measures and during the assessment of their effectiveness. In this regard, impact patterns due to various pollution scenarios can be established for developing and implementing appropriate pollution control measures. Monitoring and modeling approaches, when used in combination, give useful information to the regulator for effective environmental decision-making during planning and implementation (Borchardt et al., 2001). Therefore, mathematical models have enormous potential to address WQ problems and give rational solutions (Benedini, 2011).

2.4.2. Water Quality Model Description

WQ models are developed for specified objectives and under varied degrees of complexity in response to complex environmental problems. Water quality models can be classified as physical (laboratory) and mathematical (analytical) models (Ziemińska-Stolarska & Skrzypski, 2012). Besides, they can be categorized according to the complexity of computer simulation (1D, 2D, and 3D models), data requirements (extensive databases and minimum data requirements models), type of approach (physically based, conceptual, and empirical), pollutant type (nutrients, sediment, and salts, etc.), area of application (catchment, groundwater, river system, lake, coastal waters, integrated), nature (deterministic or stochastic), state analyzed (steady state or dynamic simulation), and spatial analysis (lumped, distributed) (Tsakiris & Alexakis, 2012).

Water quality software is usually classified according to model complexity, type of receiving water, and the water quality parameters (dissolved oxygen, nutrients, etc.) that the model can predict. The purpose of modeling is to solve problems of surface water pollution and to track water quality changes. Water quality models are applicable to analyze the existing phenomena, predict and compute effects of changes in the aquatic environment, set limits for pollutant discharge or load, identify the location of sources of pollution and causes of water quality deterioration on a given segment of the stream, and selecting an optimal approach for sustainable development (Tsakiris & Alexakis, 2012).

Water quality models can also be classified as simulation models or optimization models (Sharma et al., 2017). The simulation model defines and represents changes in water quality in some mathematical form. However, optimization models are commonly applied to find the smallest number of alternative data points before doing the model simulation. The models are typically classified with respect to model complexity, type of receiving water, and water quality parameters for which the model can be predicted.

In line with this, data requirements, mathematical computations (deterministic and stochastic), software requirements, dimensions of analysis (1-D, 2-D, and 3-D), assumptions, etc. of models may vary (Bahadur et al., 2013). Table 2_3 shows characteristics of some of the widely known models: AQUATOX, WQ Analysis Simulation Program (WASP), MIKE II, Soil and Water Assessment Tool (SWAT), SIMCAT, Q2E, and Q2Kw (Benedini, 2011). In this regard, 2-D and 3-D models require large amounts of data. They are complex models and therefore usually applied to large rivers (Cox, 2003).

Table 2-1: Characteristics of some water quality models.

Model	AQUATOX	Q2E	WASP	MIKE II	SWAT	SIMCAT	Q2Kw
Model type/ level of complexity	1-D, Dynamic state	1-D, Steady state/Dynam ic	1,2,3- D, Dynamic	2-D, Steady state, Dynamic	1-D, Quasi – Dynamic	1-D, Steady state	1-D, Steady state/Dynamic
Receiving type water	River, Lake, Reservoir	River	River, Lake, Reservoir, Estuary	River, Reservoir	River, Lake, Reservoir	River	Small river and stream
Modeling approach	Differential equations using 4 th and 5 th order, Runge- Kutta integration routines	The advection dispersion reaction equations, equal river reaches	The advection dispersion reaction equations	Implicit finite difference Scheme to Solve saint –Venant equation	Mass balance Equation	CSTRS	Mass balance Equation, Unequal river reaches
Model capabilities	DO, CBOD, NH ₃ , NO ₃ , OP,PO ₄ , Temperature Sediment	DO, BOD, NO ₄ _N, NO ₃ ,NO ₂ , OP, PO ₄ , Temperatur e Coliform, Bacteria	DO, CBOD, NH ₃ , NO ₃ , NO ₂ ,OP, PO ₄ , Temperature, Sediment, Metals, Toxics	DO,BOD, temperature, NO ₃ ,NH ₃ , sediments, coliform, bacteria	DO, BOD, NH ₃ , NO ₃ ,NO ₂ , OP,PO ₄ , Temperature, sediment, Toxics, Metal	DO,CBOD, NH ₃ , PO ₄	DO, BOD, NH ₃ , NO ₄ _N, NO ₂ ,OP, EC,pH,PO ₄ , Temperature, TP,TN, Metal ,Coliform, Bacteria,
Special water quality features	Algae, phytoplankt on, Planktonic, Benthic algae, Fish	Algae, phytoplankt on Planktonic, Benthic algae	Algae, phytoplankton Planktonic, pesticides	Algae , phytoplankton, Planktonic, Benthic algae	Surface and ground water interaction	NIL	Algae, phytoplankton, Planktonic, Benthic algae
Application Considerations	Limited Training/Pu blic Domain	Limited Training/ Public Domain	Substantial training/ Public Domain	Substantial training/ Significant Cost	Moderate training/ Public Domain	Limited Training/ Public Domain	Limited Training/ Public Domain

Source (Olowe & Kumarasamy, 2018)

2.4.3. Application of Water Quality Models

In many countries, river WQ assessment solely relies on physicochemical standards (Los, n.d.). Nevertheless, the need for integrated approach in river management was observed in international legislations such as the Clean Water Act of 1972 (Jeffery, 1987), the WQ Act of 1987 (US EPA, 2011) and the Water Framework Directive (WFD) (Schratter-Sehn et al., 1992). In this regard, US federal laws have a two-tier system in which sets effluent limitations based on available technology.

Integrated WQ assessment intends to evaluate physical, chemical and biological nature of water bodies in terms of their natural quality, intended use and human effects (Vaughan et al., 2009). Furthermore, the aforementioned legislations encourage the use of WQ models as decision support tools in which the legal emission limit values, pollution sources characteristics and recipient quality standards are considered. The role of WQ models in environmental decision-making is regarded essential because the models allow watershed based management approach, predictive capacity and cost-effectiveness (Gao & Li, 2014).

Consequently, they are applied in developed nations to remediation decision-making. This approach uses accurate and rich historical database maintained by scientific establishments and government agencies (Ongley, 1999).

2.4.3.1. Water Quality Models Application in Ethiopia

Application of WQ models for environmental decision-making is not common in developing countries. Their intended use is hampered by the absence of the necessary model input data in sufficient quantity and quality, as well as by a lack of experience in model-based WQ decision making (Ongley, 1999). Furthermore, in these countries, the monitoring approach is not implemented regularly, mostly due to financial limitations. The ability of regulators in environmental agencies to make decisions and implement them is constrained by this particular situation. Environmental agencies in developing countries like Ethiopia must start modeling activities as part of their management programs based on economical WQ monitoring techniques. Additionally, these countries can establish future parameters for the use of modeling tools in environmental decision-making (Tsegaye, 2019).

Although a number of literature works on watershed modeling about rivers, lakes and groundwater in Ethiopia were observed, they mostly deal with hydrology of the water bodies. The number of modeling works on WQ is very low even when compared to the not many hydrological modeling works on waterbodies in Ethiopia. Furthermore, specifically on the TWR, which is often regarded as one of the most polluted rivers in Hawassa, no WQ modeling works were found during the literature survey that were conducted on TWR and use the conventional modeling tools such as SWAT, Q2Kw and the likes. Q2Kw model was applied in the Little Akaki River, Addis Ababa (Zelalem et al., 2021).

Table 2-2: A survey of model based WQ and hydrology studies in Ethiopia

Water body	Studied waterbody	Objective	Model Used	Reference
River	Gilgel Abay River	Stream flow	SWAT	(Dile et al., 2013)
	Blue Nile river basin	Sediment transport	SWAT	(Betrie et al., 2013)
	Awash river basin	Water allocation	MODSIM	(Berhe et al., 2013)
	Didessa Sub-Basin	Water resources allocation	WEAP	(Adgolign et al., 2016)
	Omo-Geba river basin	Hydrological assessment	SWAT	(Eromo et al., 2016)
	Holetta river	Hydrological assessment	SWAT	(Tibebe et al., n.d.)
Lake	Lake Tana	Sustainable water use	SWAT	(Dargahi & Gebriye, 2011)
	Lake Ziway watershed	Hydrological assessment	SWAT	(Desta & Lemma, 2017)
Groundwater	Lake Tana basin	Groundwater-surface water flow interactions	MODFLOW	(Chebud & Melesse, 2009)
	Tana sub-basin Lake	Tana and groundwater interaction	SWAT	(Abiy et al., 2015)
	Central main Ethiopian rift lakes basin	Groundwater-surface water flow interactions	MODFLOW	(Ayenew, 2001)

2.4.4. Selection of Water Quality Model

Water quality models can be selected based on different criteria such as model complexity, availability of data, type of water body, water quality simulation capabilities, easy accessibility of the program code source, and the existence of good certification of the model (Olowe & Kumarasamy, 2018). Also, the model applicability, cost, familiarity, and support are criteria used for selecting suitable water quality models. Many water quality models are not widely used and are no longer being updated to comprise the latest developments. For deciding the most suitable models, it is essential to assess the existing water quality models.

Depending on their applicability, easy accessibility, cost effectiveness, freely availability, and model complexity and also depends on other various criteria as a one dimensional model; Q2Kw is one of the best tools for water quality simulations due to its flexibility, ease of use and free availability and Q2Kw model was suitable for assessing of the Tikur Wuha River water quality.

Q2Kw model is used to predict the water quality parameters and visualize the effect of different remedial measures to improve the river water quality. It also simulates several constituents that are not typically included in generally-available software. In particular, the model simulates pH, alkalinity, inorganic suspended solids, pathogenic bacteria, and bottom algae (Pelletier et al., 2006).

2.4.5. Description of QUAL2Kw Model

The mathematical model used to evaluate the water quality of the river was Q2Kw. Although Pelletier and Chapra developed the Q2Kw model in 2006, it is really just a modernized version of the Qual2E concept. This revised model is the most modern in the series of QUAL models that have been extensively used to simulate river water quality and have been recommended by the United States Environmental Protection Agency (USEPA) (Raesi et al., 2022). A typical Q2Kw working model simulates a river with a steady and irregular flow in one dimension. Pollution can be modeled in the flow simulation as either a point source or a non-point source (Kannel et al., 2007). More than fifteen different water quality parameters of the river, as shown in the Table 2-2 below, can be simulated by the Q2Kw model.

Table 2-3 Model simulate parameters

Variable	Symbol	Units*
Temperature		°c
Conductivity	s_1, s_2	µmhos
Inorganic suspended solids	$m_{i,1}, m_{i,2}$	mgD/L
Dissolved oxygen	o_1, o_2	mgO ₂ /L
Slow-reacting CBOD	$c_{s,1}, c_{s,2}$	mg O ₂ /L
Fast-reacting CBOD	$c_{f,1}, c_{f,2}$	mg O ₂ /L
Organic nitrogen	$n_{o,1}, n_{o,2}$	µgN/L
Ammonia nitrogen(NH ₃ –N)	$n_{a,1}, n_{a,2}$	µgN/L
Nitrate nitrogen(NO ₃ –N)	$n_{n,1}, n_{n,2}$	µgN/L
Organic phosphorus	$p_{o,1}, p_{o,2}$	µgP/L
Inorganic phosphorus	$p_{i,1}, p_{i,2}$	µgP/L
Phytoplankton	$a_{p,1}, a_{p,2}$	µgA/L
Detritus	$m_{o,1}, m_{o,2}$	mgD/L
Pathogen	x_1, x_2	cfu/100 MI
Generic constituent	gen_1, gen_2	user defined
Alkalinity	Alk_1, Alk_2	mgCaCO ₃ /L
Total inorganic carbon	$c_{T,1}, c_{T,2}$	mole/L
Bottom algae biomass	ab, ah	gD/m ²
Bottom algae nitrogen	IN_b	mgN/m ²
Bottom algae phosphorus	IP_b	mgP/m ²

The Q2Kw model, a one-dimensional steady state river and stream water quality model, utilizes reaches that are not equally spaced apart. The Q2Kw model is an updated version of the Q2K. It is helpful for shallow rivers and can be applied to rivers with approximately steady flows and pollutant loads (Sharma et al., 2017). The model is steady-state and therefore relatively easy to run. Dynamic models are more difficult to run because of the preparation of complex model input data sets that usually contain time series for model forcing and boundaries (Erturk, 2010). Microsoft Excel uses Q2Kw as its implementation. It was developed in Visual Basic for Applications (VBA). The graphical user interface for entering data, running the model, and seeing results is Excel. Small river basins can improve with the use of Q2Kw (Pelletier et al., 2006).

For the purpose of simulating various parameters and producing various management scenarios, the Q2Kw model and its earlier versions, Q2E, Q2E-UNCAS, and QUAL2K, have been applied to several watersheds. The QUAL series model has been successfully applied to the same research area, which suggests that the model is applicable globally and can still give fundamental information for assessing the quality of water even with a limited dataset (Sharma et al., 2017). Consequently, the model was successfully applied to rivers in different parts of the world: Tunggak River in Kuantan, Malaysia (Hossain et al., 2014), river Yamuna in India (Sharma et al., 2017), river Bagmati in Nepal (Kannel et al., 2007), a small karstic watershed in Brazil (Camargo et al., 2011) and plain of Chryssoupolis in Kavala, North Greece (Gikas, 2015).

Q2Kw is the newest version of the Q2K series, which was developed to cover the limitations of previous versions. Q2Kw can operate either as a steady state or as a dynamic model; this software is used as a tool for mathematical modeling and simulation of water quality. When operated as a steady-state model, it can be used to

study the impact of waste load on in-stream water quality. The main input data in the model can include geometric characteristics of the river (including channel slope, channel width, side slope, and Manning roughness coefficient), hydraulic characteristics, water quality data, and meteorological parameters. Therefore, in this study, Q2Kw model was selected for simulation of Tikur Wuha River water quality.

3. MATERIAL AND METHODOLOGY

3.1. Description of Study Area

The Tikur Wuha River is found in the southern region of Ethiopia, close to Hawassa Town, between the borders of Oromia and Sidama regional states. The Tikur Wuha River is a significant tributary of Lake Hawassa, draining from its eastern portion of Lake Hawassa watershed. It is located 275 kilometers to the south of Addis Ababa and 5 kilometer to the skirt of Hawassa town. The geographical locations are $6^{\circ} 49'-7^{\circ} 11'N$ and $38^{\circ} 28'-38^{\circ} 43'E$, respectively, and its elevation ranges from 1681 to 2976 meters above mean sea level. The main rainy season, with a mean annual precipitation of approximately 955 mm, occurs between July and September, while the months of April through October are wet and humid. The dry season's mean minimum precipitation is 17.8 millimeters in December, and the wet season's mean maximum is 119.8 millimeters in August (Lencha,et al., 2021).

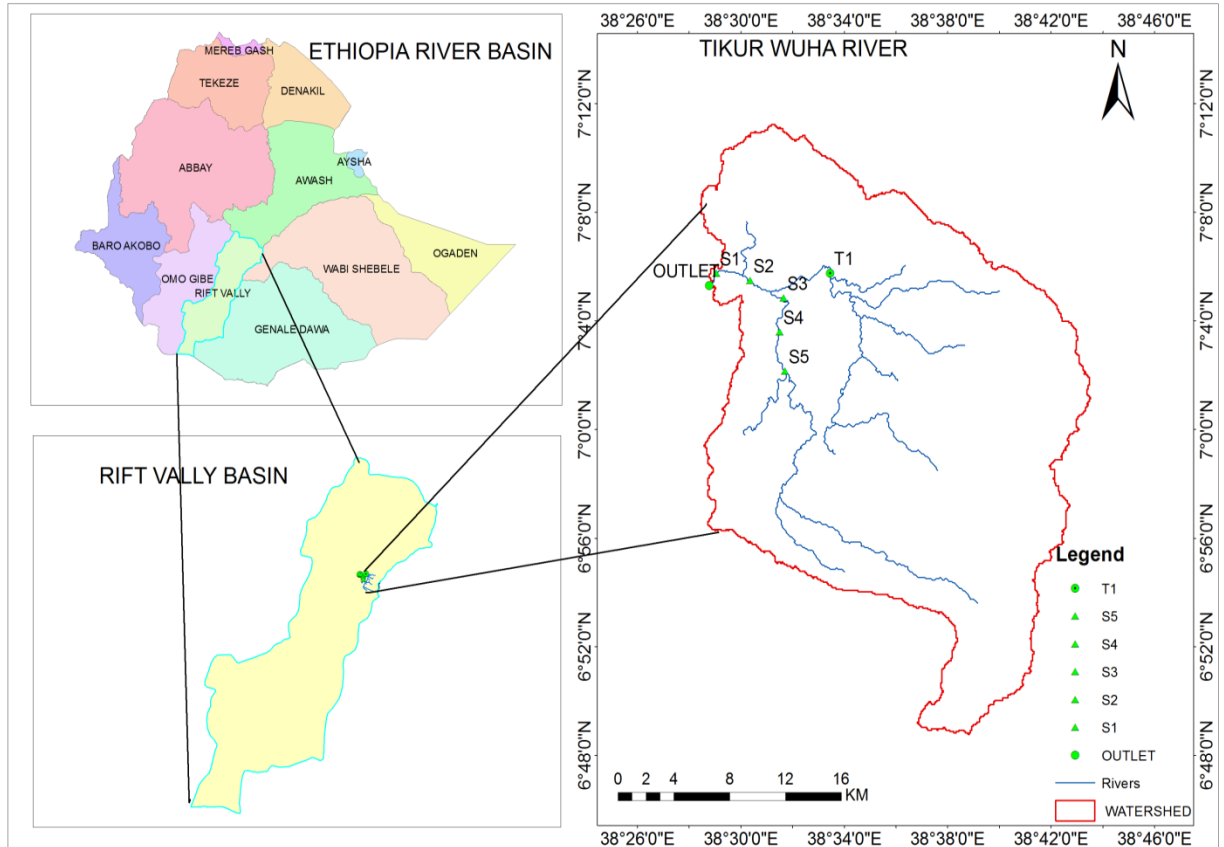


Figure 3-1: Location of study area and Monitoring Station

3.2. Data and Monitoring Station

The data were conducted on dry season (March, 2023) in Tikur Wuha River and its tributary as shown in (Table 4-1). The monitoring works were performed at low flow conditions of dry season for applicability of the steady flow model Q2Kw. The meteorological data, such as air temperature, dew point temperature and wind speed required for the modeling, were obtained from Hawassa station, part of the South Ethiopia Hydrology and Meteorology Agency. The monitoring station and sampling strategy were planned to cover a wide range of factors contributing to the water quality of the river, taking into account tributaries and point sources whose effluents end up in the river and have a substantial impact on the water quality of the river. Based on the topographical, nature of water flow, nature of river bed, and disposal of effluent and

considering the accessibility for sampling, a total of seven sampling points were selected covering 8.81km stretch of Tikur Wuha River for the present investigation.

The monitoring stations along Tikur Wuha river were station 1(TWR mouth, length 0.00km) at Tikur Wuha village near Lake Hawassa, Station 2 (Bee husbandary, length 4.0km) at Bee husbandary area just below wood bridge, Station 3 (Kerkera, length 7.2km) at just upstream of confluence with kerkera stream, Station 4 (Cheffe, length 8.42km) at just back to St. Mariam church street below concert bridge, Station 5 (BGI, length 8.81km) at just downstream of St. George Brewery factory and one tributary station is located along cheleleka wetland at Kerkera stream (water coming from Wesha River, Hallo River, Wedessa River) and one point source station was taking from Beer Georges Factory(BGI).

3.3. Sampling and Analysis

During the dry season, studies were conducted on March, 2023(daily) collecting data at sampling stations along the river and analyzed the parameters in this study were the flow rate, temperature, pH, dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD₅), chemical oxygen demand(COD), nitrate as nitrogen (sum of NO₃-N and NO₂-N), ammonia nitrogen (NH₃-N), phosphate, electrical conductivity, total dissolved solid, total suspended solid, turbidity, and also measured velocity, bottom width and water depth along the river at sampling location. Composite samples are taken at a selected location, depth, and time. The samples were collected at various locations along the river. The timings of samplings were varying. All the tasks, such as sample collection, preservation, transportation, and analysis, were carried out as per the standard methods APHA, (2012).

For physiochemical parameters, spectrophotometric determinations and TSS, samples were collected in 1L standard polyethylene plastic bottles and stored in iceboxes. Before collecting the samples, the bottles were carefully cleaned with distilled water and concentrated nitric acid to remove possible contaminants. The water samples were handled aseptically, labeled, maintained in sterile glass bottles, kept in a cooler and ice box, and delivered to the laboratory of Hawassa University Environmental Engineering.

Flow, water T⁰, pH, electrical conductivity (EC), DO, total suspended solids (TSS), Phosphates(PO₄⁻³), ammonia as N (NH₃-N), NO₃⁻ as N (sum of NO₃⁻-N and NO₂N), 5 days biochemical oxygen demand as O₂ (CBOD or BOD) and chemical oxygen demand as O₂ (COD) was measured. However, due to instrument problems, chemical limitations, and cost limitations other parameters were not yet analyzed throughout the study period. BOD and COD were selected to assess the presence of organic pollution.

NO₃ was selected to monitor non-point source pollution from agricultural land, urban drainage and residential lawns. Nitrite (NO₂⁻) and Ammonia (NH₃) were selected to monitor the toxic effect of water for human consumption and marine life. Recreational water suitability is based on turbidity, DO and BOD. EC and TDS were used to monitor the amount of total dissolved substances in water or effluent. pH was selected to survey acidity and alkalinity of water or effluent and temperature was selected as it is correlated negatively or positively with most of the water quality parameters. The test of physical parameters such as temperature, EC, TDS and turbidity was performed in-situ with a portable sensors and turbid meter respectively. Flow was measured with area-velocity method determining cross-sections and measuring velocities at three to five points along river cross sections.

The other parameters were analyzed in local laboratories at Hawassa University civil and environmental engineering laboratory and all the parameters were presented with their respective analytical methods and instruments used for analysis in Table 3-1 below.

Table 3-1: Water quality parameters and determination methods and instruments used

Parameter	Analytical Method and instruments
Turbidity	Nephelometric (Model T-100)
EC, pH, TDS, and T ⁰	Portable multi-parameter analyzer, HQ40d
DO	Winkler Titration Method
BOD	Nanometric, BOD Incubator
TSS	Filtration by standard glass fiber filter
COD	Photometric measurement (WAGTECH 7100 AT 600nm)
NH ₃ , NO ₃ ⁻ and PO ₄ ⁻³	Photometric, WAGTECH 7100 AT520nm,570nm,640nm)

3.4. Modeling Tool

The modeling tool includes a general mass balance for a constituent concentration (c_i) (fig. 3.2) in a reach's water column (excluding hyporheic exchange and the transport and loading terms are omitted from the mass balance equation for bottom algae modeling) that is expressed as (Pelletier et al., 2006).

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i} c_i - \frac{Q_i}{V_i} c_i - \frac{Q_{ab,i}}{V_i} + \frac{E'_{i-1}}{V_i} (c_{i-1} - c_i) + \frac{E'_{i+1}}{V_i} (c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i \quad (1)$$

Where Q_i = flow at reach i (L/day), $Q_{ab,i}$ = abstraction flow at reach i (L/day), V_i = volume of reach i (L), W_i = the external loading of the constituent to reach i (mg/day), S_i = sources and sinks of the constituent due to reactions and mass transfer mechanisms (mg/L/day), E_i = bulk dispersion coefficient between reaches i (L/day), E_{i-1} , E_i are bulk dispersion coefficients between reaches $i-1$ and i and i and $i + 1$ (L/day), c_i = concentration of water quality constituent in reach i (mg/L) and t = time (day).

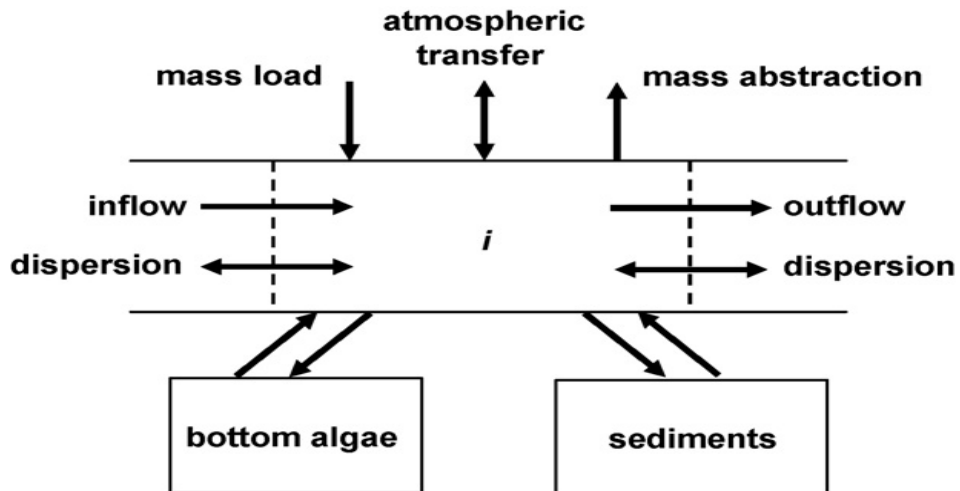


Figure 3-2: Mass balance constituents in a reach segment i

The model was utilizing a genetic algorithm (GA) for auto-calibration to maximize the goodness of fit of the model results compared with measured data by adjusting a large number of parameters. The fitness is calculated as the reciprocal of the weighted average of the normalized root mean squared error (RMSE) of the difference between the model predictions and the observed data for water quality constituents. GA maximizes the fitness function $f(x)$ as:

$$f(x) = \left[\sum_{i=1}^n w_i \right] \left[\sum_{i=1}^n \frac{1}{w_i} \right] \left[\left[\sum_{j=1}^m \frac{O_{ij}/m}{\sqrt{\sum (P_{ij}-O_{ij})^2 / m}} \right] \right] \quad (2)$$

Where O_{ij} = observed values, P_{ij} = predicted values, m = number of pairs of predicted and observed values, w_i = weighting factors, and n = number of different state variables included in the reciprocal of the weighted normalized RMSE (Pelletier et al., 2006). In the Q2Kw model the study river was divided in to several “reaches” and each reach was divided into segments.

During the calibration of water quality models, Although there are numerous statistical measures to assess the performance of water quality models, the performance indicators such as percentage bias or error (PBIAS), coefficient of determination (R^2), and Nash-Sutcliff (NSE) are frequently used. The model simulation is regarded as "very good" if $|PBAIS| < 25\%$, "good" if $25\% < |PBAIS| < 40\%$, "satisfactory" if $40\% < |PBAIS| < 70\%$, and "unsatisfactory" if $|PBAIS| > 70\%$, according to Bui et al. (2019).

Different water quality modelers use various performance evaluation strategies; however $|PBIAS| < 25\%$ (Amare et al., 2017), $R^2 > 0.5$ (Angello et al., 2021), and $NSE > 0.5$ (Moriassi et al., 2015) are the methods that are recommended.

$$\text{PBIAS} = \frac{\sum_{i=1}^n O_i - P_i}{\sum_{i=1}^n O_i} * 100 \quad (3)$$

$$R^2 = \left[\frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}} \right]^2 \quad (4)$$

However, it is often challenging to find all three criteria satisfying at the same time.

However, in the TWR, the performance of the Q2Kw model was assessed using both PBAIS and R^2 and the acceptable ranges are shown in Table 3-2.

Table 3-2: General performance ratings of the recommended statistics for a monthly time step.

Performance Evaluation						
Measure	Component	Very Good	Good	Satisfactory	Unsatisfactory	Reference
R^2	Constituents	>0.7	$0.6 < R^2 \leq 0.7$	$0.3 < R^2 \leq 0.6$	< 0.3	(Amare et al., 2017)
	Flow	>0.8	$0.7 \leq R^2 < 0.8$	$0.5 < R^2 < 0.7$	≤ 0.5	
PBIAS	Constituents	$< \pm 15$	$\pm 15 < \text{PBIAS} < \pm 20$	$20 \leq \text{PBIAS} < \pm 30$	$\geq \pm 30$	(Moriasi et al., 2015)
	Flow	$< \pm 5$	$\pm 5 < \text{PBIAS} < \pm 10$	$\pm 10 \leq \text{PBIAS} \leq \pm 15$	$\geq \pm 15$	

3.4.1. Application of Q2Kw Model

3.4.1.1. River Discretization

The total study length of 8.81km from the confluence of the river with the Tikur Wuha River mouth to the Cheleleka wetland was discretized into 12 reach segments with a length of 0.8km in each reach except reach 1 and 2. Figure 3-3 shows the river segmentation system and the location of the tributary input. River discretization was used to assess the waste discharge into the river. The model uses the headwater data to define upstream boundary conditions. The portion of the river including sampling station 1 was treated as headwater. The option of internal calculation was selected for the downstream boundary condition.

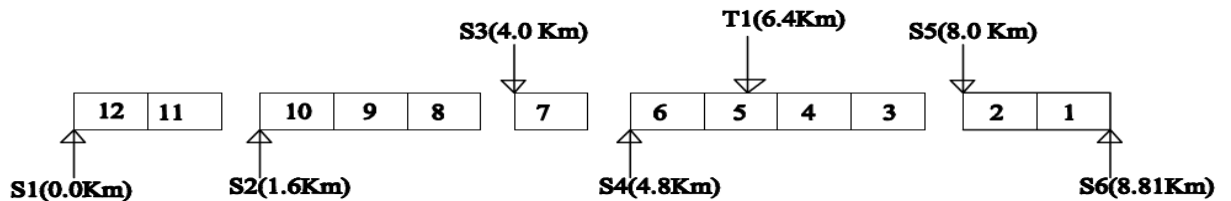


Figure 3-3: Discretization of the Tikur Wuha river

3.4.1.2. Input Data

After collecting the data, all the necessary parameters for the qualitative simulation were entered into the Q2Kw model. The data included interpolations and some hydraulic characteristics of rivers (channel slope, bottom width, manning roughness coefficient), geographic characteristics (elevation, longitude, and latitude), meteorological data (air temperature, wind speed, and dew point temperature), and water quality data of rivers and point sources required for the model input data.

❖ Hydraulic characteristics

The model accepts input data for the hydraulic characteristics of the various reaches, which are represented in Table 3-3. It is hypothesized that each reach in the river is idealized as a trapezoidal channel. The Manning's equation was used to determine mean velocity and depth under steady flow as a function of stream width, bottom slopes, and the Manning's roughness coefficient. The Tikur Wuha River is a naturally occurring stream channel with weeds, windings, and pools. After partitioning, certain more essential information was selected from the reference material and all the fields near the river sections, including Manning's coefficient. As a result, the authors estimated the coefficient to be approximately 0.05 (Chapra et al., 2014).

$$Q = \frac{S_0^{1/2} A_c^{5/3}}{n P^{2/3}} \quad (5)$$

Where Q is the flow rate (m^3/s), S_0 is the bottom slope (m/m), n is the Manning roughness coefficient, A_c is the cross-sectional area (m^2), and P is the wetted perimeter (m). The measured river geometries and water velocities were used to determine the hydraulic characteristics at each sampling locations. Mean depth and velocities was measured in dry season. In this study, the reach segment lengths and geographic longitude and latitude were calculated using Google Earth. Table 3-4 shows the number of reaches between the five primary monitoring stations (0-2, 3-6, 7, 8-10, and 11-12) along with their relative hydraulic properties.

Table 3-3: Geographic characteristics of the monitoring station along the TWR

Downstream	Elevation		Downstream					
Location	Upstream	Downstream	Latitude			Longitude		
(km)	(m)	(m)	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
8.81	-	1691	7	3	8	38	31	23
8.42	1691	1690.4	7	3	35	38	31	12
8.0	1690.4	1690.12	7	3	17	38	31	26
7.2	1690.12	1689.8	7	3	56	38	31	22
6.4	1689.8	1689.5	7	4	21	38	31	27
5.6	1689.5	1689.2	7	4	47	38	31	22
4.8	1689.2	1689.2	7	4	52	38	31	20
4.0	1689.2	1688.9	7	5	6	38	31	6
3.2	1688.9	1688.6	7	5	14	38	30	41
2.4	1688.6	1688.28	7	5	30	38	30	24
1.6	1688.28	1687.98	7	5	42	38	29	58
0.8	1687.98	1687.06	7	5	45	38	29	6
0.0	1687.06	1686.76	7	5	30	38	28	56

Table 3-4: Reach hydraulic characteristics of the monitoring stations along the TWR

Location	Reach	Manning Formula			Flow
		Channel	Manning	Bot Width	
(km)		Slope	N	M	m ³ /sec
8.81	0-2	0.023	0.05	4.1	0.557
8.0	3-6	0.048	0.05	4.5	0.873
4.8	7	0.041	0.05	9.8	0.901
1.6	8-10	0.041	0.05	6.48	0.935
0	11-12	0.078	0.05	13.7	0.592

❖ **Water quality data and flow rate**

The water quality input parameters included in the model were flow rate, water temperature, electrical conductivity, pH, DO, BOD, ammonium nitrogen, nitrate (nitrite + nitrate) nitrogen, total suspended solid and TDS. The data on organic and inorganic nitrogen, organic phosphorus and inorganic phosphorus, inorganic suspended solids, slow and fast CBOD, phytoplankton, detritus and pathogen were not measured and the inputs were left blank. The water qualities for the wastewater and river tributaries were the other point pollutions input to the model. Table 4-1 shows the input water quality parameters for each station.

As the model simulates ultimate BOD, the measured 5day BOD was transferred to ultimate BOD (BOD_u) using the following relationship (k = the BOD decomposition in the bottle, 1/day): The bottle rates for sewage derived organic carbons are on the order of 0.05–0.3 day^{-1} (Raj et al., 2007).

$$BOD_u = \frac{CBOD_5}{1 - e^{-5k}} \quad (6)$$

In the headwater boundary condition sheet of the model, the required parameters such as flow rate, temperature, conductivity, dissolved oxygen, ultimate carbonaceous biochemical oxygen demand, ammonia nitrogen, nitrate nitrogen, and pH are given as inputs. The other parameters were not measured, and the inputs were left blank. During sampling, it was observed that the maximum surface of the river bed was covered by algae; therefore, the algae were assumed to be 100% for stations 1 and 2, and the other stations were 50%. The sediment/hyporheic zone thickness, sediment porosity, and hyporheic exchange flow were left blank because the hyporheic exchange simulation was chosen "no" to bypass the calculation of mass transfer between the water column and the hyporheic pore water and water quality kinetics in the hyporheic zone.

❖ Meteorological data

The meteorological data include solar radiation, wind speed, dew point temperature, air temperature, the percentage of cloud cover and shade. Table 3-5 shows the monthly average values of several meteorological parameters at Hawassa station for the researched region.

Table 3-5: Monthly average meteorological parameters at Hawassa station

Parameter	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Air temperature	17	18.8	19.2	22	15.4	16	20	18.5	12.6	17.5	18.9	23
Dew point tem	12	13	17.6	10	11.56	9.73	12	11	14.8	17.6	21	15.4
Wind speed(m/s)	2.1	1.73	2	2	1.89	2	1.95	2	2	2	2.03	2.09

3.4.1.3. System Parameter

The ranges of rate parameters required by Q2Kw were obtained from various literatures, including the Q2Kw user manual and documentation for the enhanced stream water quality models QUAL2E and QUAL2E-UNCAS (Chapra et al., 2014). The exponential model was chosen for oxygen inhibition for CBOD oxidation, nitrification, denitrification, phytorespiration, and bottom algae respiration. The wind effect was considered negligible. The other parameters were set as defaults in the Q2Kw model. The model was calibrated using dry-season data. The calibrated and validated dry season data produce the minimum RMSE value of important parameters such as dissolved oxygen and biochemical oxygen demand. Hence, the dry season calibrated model was used for further study, and the calibrated system rate parameters for dry season data were presented in Table 3-6.

Table 3-6: Calibrated rate parameters for the TWR water quality modeling

Parameter	Value	Units	Symbol	Min value	Max value
Carbon	40	gC	gC	30	50
Nitrogen	7.2	gN	gN	3	9
Phosphorus	1	gP	gP	0.4	2
Dry weight	100	gD	gD	100	100
Chlorophyll	1	gA	gA	0.4	2
Inorganic suspended solids: Settling velocity	0.02128	m/d	v_i	0	2
Oxygen inhabitation parameter CBOD oxidation	0.60	L/mgO2	K_{socf}	0.60	0.60
Oxygen inhabitation model nitrification	Exponential				
Oxygen inhabitation parameter nitrification	0.60	L/mgO2	K_{sona}	0.60	0.60
Oxygen enhance model denitrification	Exponential				
Oxygen enhance parameter denitrification	0.60	L/mgO2	K_{sodn}	0.60	0.60
Oxygen inhabitation model phyto respiration	Exponential				
Oxygen inhabitation parameter phyto respiration	0.60	L/mgO2	K_{sop}	0.60	0.60
Oxygen enhance parameter bot alg respiration	0.60	L/mgO2	K_{sob}	0.60	0.60
Fast CBOD: Oxidation rate	0.5447	/d	k_{dc}	0	5
Temp correction	1.047		θ_{dc}	1	1.07
Ammonium: Nitrification	0.0002	/d	k_{na}	0	10
Temp correction	1.07		θ_{na}	1	1.07
Nitrate: Denitrification	1.92802	/d	k_{dn}	0	2
Temp correction	1.07		θ_{dn}	1	1.07
Sediment denitrification transfer coeff	0.88217	m/d	v_{di}	0	1
Temp correction	1.07		θ_{di}	1	1.07

3.4.1.4. Model Implementation

The measuring data on dry season was used for calibration. The solution of integration was done with Euler's method, as Euler's method is suggested as the default because it usually yields sufficiently accurate results at a moderate computational price. For the pH modeling, we used the Newton–Raphson method, as it is considered being the best method. The calculation step used for the calculations was fixed at 5.625 minutes to avoid instability in the model.

The goodness of fit was performed with different weights have been assigned to various parameters, so as to minimize the error between observed and simulated values. These values have been obtained using various trials considering rate parameters and default values in the model. The weight for dissolved oxygen was given as 5 and is justifiable as it is the most influential parameter. Weight 5 was given for temperature, CBOD, COD and pH. Weight 1 was given for other parameters. The model was run until the system parameters were appropriately adjusted and the reasonable agreement between model results and field measurements were achieved. In order to test the ability of the calibrate model to predict water quality conditions under dry conditions, the model was run using a complete different data set without changing the calibrate parameters. Then, the model was used to simulate water quality conditions during the critical period in dry season. In this study, the default rate parameters in the “Rate” sheet were taken for the auto calibration purpose (Pelletier et al., (2006). The genetic algorithm was run for a population size of 100, with 100 generations of evolution, until we obtained only minor differences between the simulated results and the observed data. According to Pelletier et al., (2006), a population of 100 performs better than smaller numbers and nearly as well as a population of 500.

3.4.2. Model Calibration

During the calibration stage, Hydraulic characteristics, meteorological, and water quality data were processed for dry periods. Then, simulated data and observed data were compared. Using optimization techniques, the major objective of calibration was to reduce the difference between model output and observed data. Nevertheless, the final model should reflect as many realities as possible. Typically, there are two general calibration methods used in practice: (a) the manual approach of trial and error; and (b) the automatic model (systemic) technique. In the first approach, the user enters every parameter based on physical observations, and after that, they offer suggestions as part of a series of preliminary testing. The Q2K model is capable of carrying out this procedure. The second approach reduces the dichotomy using the Q2Kw model between the computational results and the observed ones by using the finite difference method. For this purpose, the square deviation using the root mean square error as a selection criterion is the most practical manual regression method (Pelletier et al., 2006). So, here the second (automatic calibration technique) was applied. For evolutionary processes, the use of genetic algorithms is effective.

3.5. Assessment of Strategies for Controlling Pollution in the Catchment

Many countries have developed a water management plan in which a set of management options has been studied or implemented through some projects to solve water problems. These management options are various in terms of their budget and outcome quality. Logically, the most expensive option would be expected to result in the best quality outcome. However, that outcome may not always be true when the problem is complicated and related to a set of qualitative and quantitative criteria (Almaarofi et al., 2017). For instance, delaying the implementation of an expansive management options through implementing simple nutrient or sediment control options at appropriate locations in the catchment can save time and money.

There are different management remediation options that apply in river water catchments to treat point and non-point source of pollutants. Decision makers are required to select the most appropriate management remediation options to address water quality and other issues within their unique catchments. The recommended remediation strategies advocated by river custodians include: vegetation filter strips, wetland filters, riparian filter strips, animal contamination prevention, and community awareness programs. According to the National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution guideline (USEPA, 2005), constructed wetland and riparian filter strips were selected in the TWR catchment to improve water quality.

4. RESULTS AND DISCUSSIONS

4.1. Analysis of TWR Water Quality Parameters

The water quality parameters was measured along the TWR, industrial effluent and its tributary during the dry period shows in Table 4-1 and the units are mg/L except flow (m^3/sec), temprature ($^{\circ}\text{c}$), EC ($\mu\text{S}.\text{cm}^{-1}$), and pH unitless.

4.1.1. pH value

In the current study, the pH value varied slightly between sampling points during the dry season. The pH values ranged from 7.4(PS) to 8.45(S2) were observed in the study period. Monitoring station S2 recorded the greatest pH value. According to the study of (Yusuf, 2020), high pH value occur due to the presence of high quantities of dissolved carbon dioxide in the water, high levels of photosynthetic activity, and low water levels. The pH value is within the recommended value of guideline Ambient Environment Standards For Ethiopia (6 to 9) at all station point (EPA, 2003).

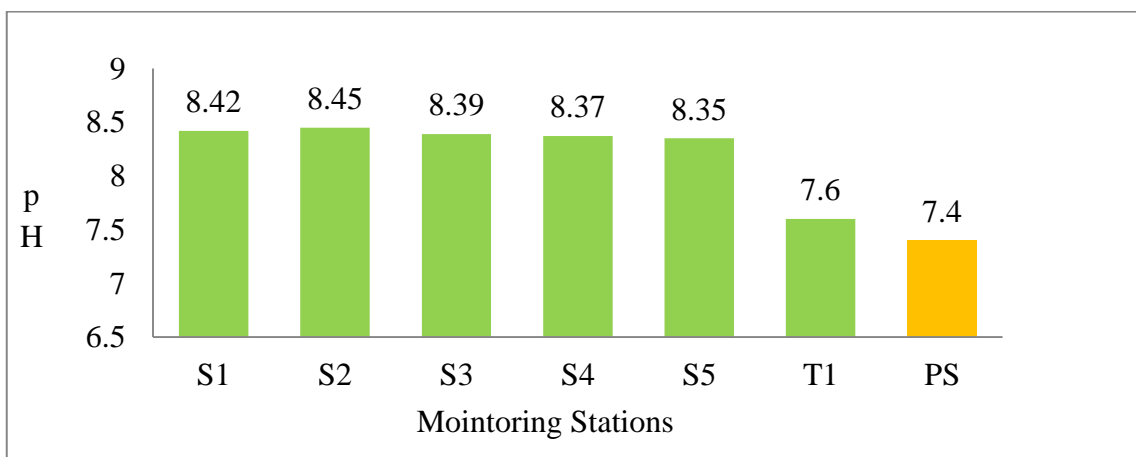


Figure 4-1: pH value in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR

4.1.2. EC and TDS

The concentrations of EC and TDS varied from 200 $\mu\text{s}/\text{cm}$ (T1) to 3728 $\mu\text{s}/\text{cm}$ (PS) and 100mg/L (T1) to 1574mg/L (PS) respectively, were observed. The concentration of EC and TDS showed an increasing trend to the downstream of the river except S5 for EC and S3 for TDS except T1 and PS. The maximum value of EC and TDS were recorded at PS may be due to the improper disposal of effluent discharge from BGI. The lowest values of EC and TDS were measured at sampling point T1 during the study period may be due to low anthropogenic activity present around the sample point and self-purification capacity of the water. According to Leta & Dibaba, (2019) study from the Awetu River in Ethiopia, the concentration of TDS and EC during the dry season was reduced by the low dissolved constituents present in ionic form. The measured TDS and EC values in the current investigation were within the permitted ranges except PS for EC value.

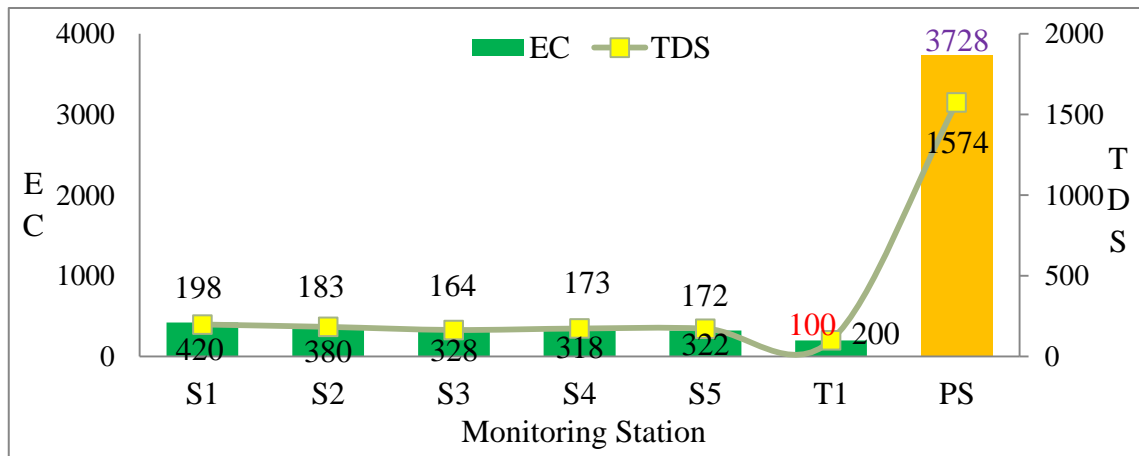


Figure 4-2: EC and TDS concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR

4.1.3. Water temperature and DO

The current investigation showed the variation in the DO value of Tikur Wuha River ranged from 3.6 to 5.1 mg/L and point source(PS) was 1.6mg/L and the highest value was recorded at S1 (5.1) in the lower reaches of the river and the lowest value was recorded at PS (1.6) in BGI effluent discharge. The result in the river showed that the water quality meet the minimum requirement of DO concentration of 4 mg/L except for S4 and S5 in the river and PS in the BGI effluent discharge and may negatively impact biological community survival and aquatic life. The DO value of S4 and S5 in the river and PS in the BGI effluent discharge were well below the standard value. This indicates that the discharge of industrial and domestic effluents has resulted in serious organic pollution of these rivers, as the decrease of DO was mainly caused by the decomposition of organic compounds. Moreover, an extremely low DO content usually indicates the degradation of an aquatic system (Lencha, Ulsido, et al., 2021). The major cause for lowering of DO was the point sources having the DO value of 1.6 mg/L. The findings of this study comparable with the previous studies conducted by (Lencha, et al., 2021). Temperature was negatively correlated with DO concentration and maximum at PS due to industrial discharge effluent.

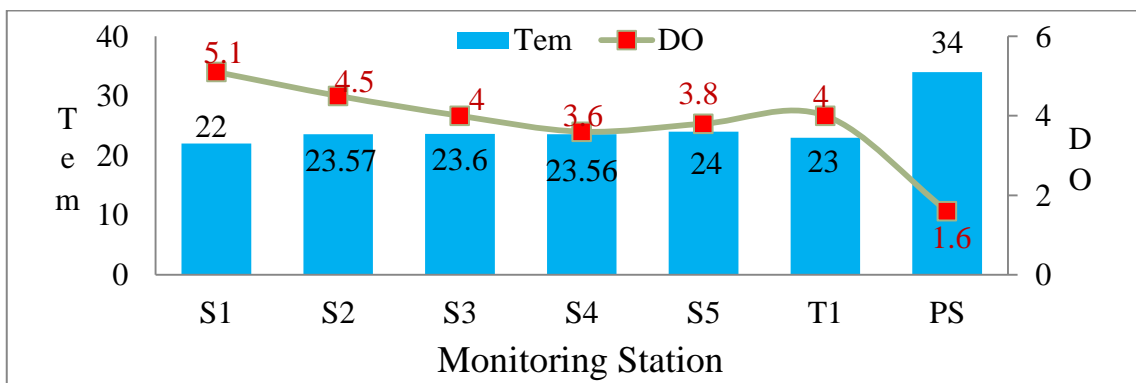


Figure 4-3: Water T° and DO concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR

4.1.4. Phosphate (PO_4^{3-})

Phosphate (PO_4^{3-}) in rivers is usually the result of domestic waste discharged from the town and runoff from agricultural fields sprayed with fertilizers (Yawar et al., 2015). The concentration of phosphate value ranged from 1.2 mg/L to 18.7 mg/L was measured. Similar findings were also reported on the studies of (Yawar et al., 2015), the highest concentration of phosphate was observed at sampling point T1 and PS during the dry season may be caused by agricultural activity, the use of detergent and soaps for cloth, discharge effluent from BGI, and also detected due to the low flow of water which reduces the dilution capacity of the river. The lowest mean value of phosphate was measured at sampling point S5 during the dry season. As described by Selemani et al., (2017) at Pangani River in Tanzania, the minimum phosphate value in the dry season was associated with the entry of fewer nutrients from non-point sources of pollution due to the absence of surface runoff. The determined values of phosphate were within the permissible limit of irrigation water set by the FAO standard (2 mg/L) except S2, T1 and PS sampling points.

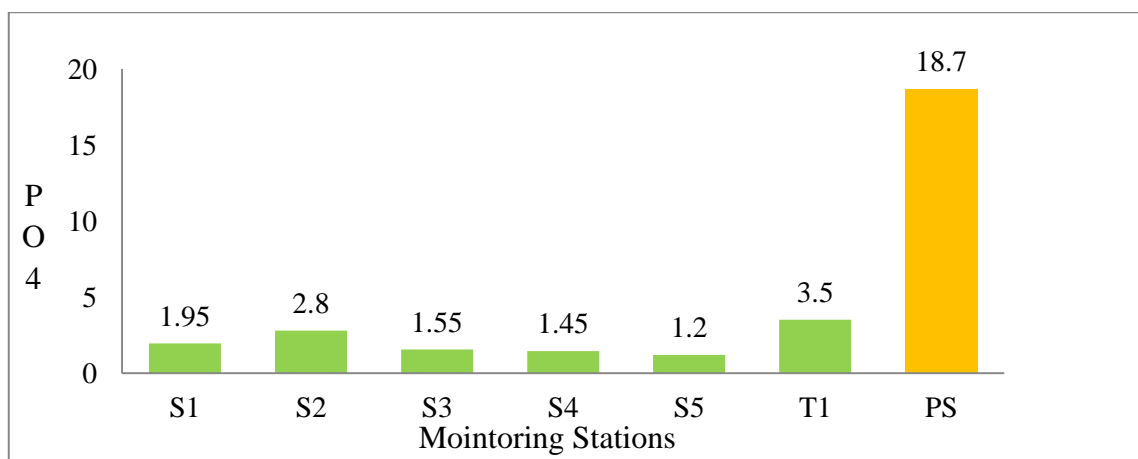


Figure 4-4: Phosphate (PO_4^{3-}) concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR

4.1.5. BOD₅ and COD

The concentration of BOD₅ and COD obtained from the experiment showed that the maximum value was recorded at all monitoring stations. The BOD₅ analysis for rivers ranges from 46.5mg/L to 57mg/L and point source were 62 mg/L. The COD analysis for river ranges from 217 mg/L to 266 mg/L and point source were 274mg/L. The measured values of BOD₅ and COD were above the acceptable limits. The maximum value of BOD₅ was measured at sampling point S2 and PS due to the presence of leaves, woody debris, dead plants, and animal manure around the river and discharge effluent from BGI. There are enormous anthropogenic activities along the river in the form of nonpoint source of pollution from the recreational activities, agricultural runoff and animal waste.

The COD values were higher in monitoring stations indicating the presence of higher organic matter impeding the TWR water quality. BOD > 5.0 mg/L and COD >20 was recorded in all monitoring stations signposting possible pollution (Alobaidy et al., 2010). Releasing liquid wastewater with higher BOD causes impairments in water quality such as DO decline and fish kills in the receiving water bodies (Lencha, Tränckner, et al., 2021). The concentration of BOD₅ in the area under investigation is above the permissible limits of WHO and EPA guidelines (<5 mg/L) for human consumption and aquatic life in the study river; which indicates the water in the river is highly polluted by organic matter.

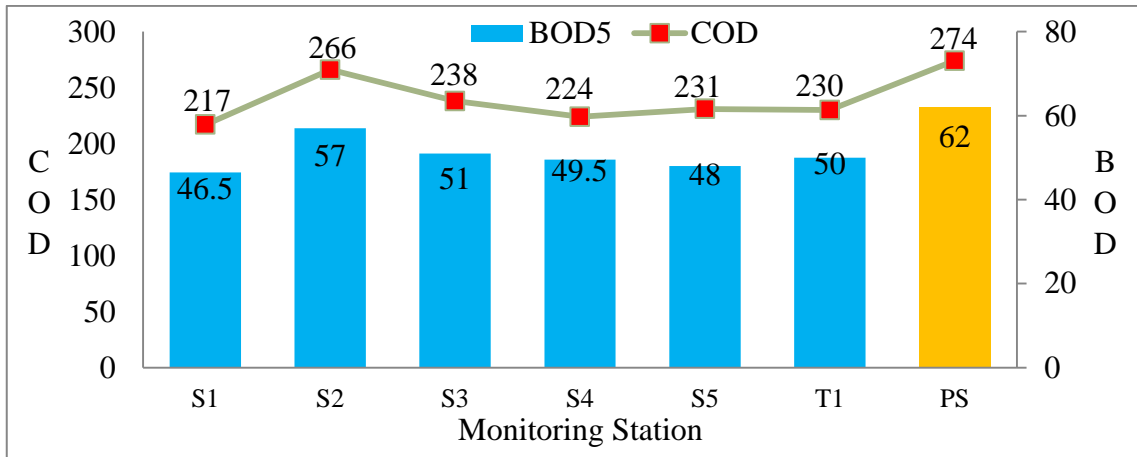


Figure 4-5: BOD and COD concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR

4.1.6. Nitrate (NO_3^-) and Nitrite (NO_2^-)

The WHO guideline recommends 50 mg/L for nitrate ion and 3 mg/L of nitrite ion for safe human consumption. The concentration of nitrate ion and nitrite ion were lowest because of less surface runoff and does meet permissible limit for fish survival (EPA, 2003).

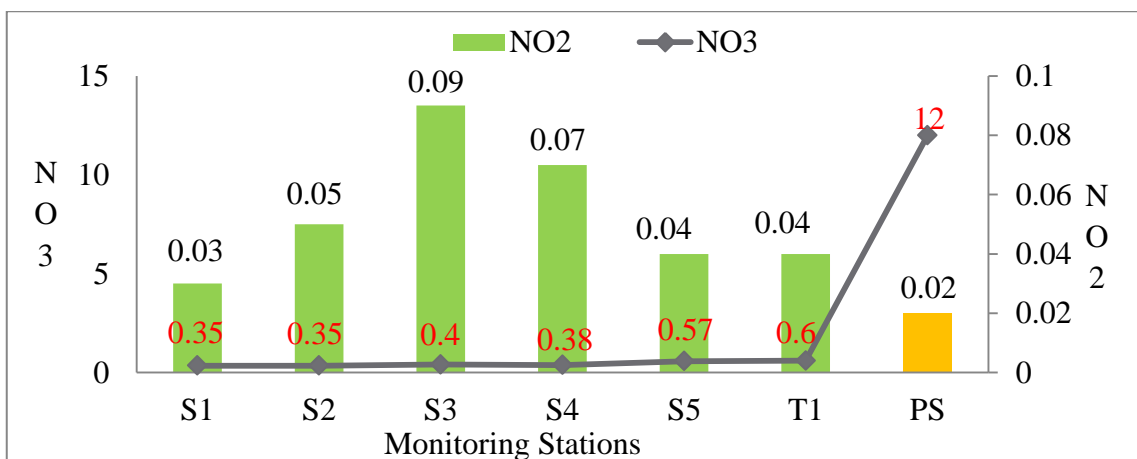


Figure 4-6: Nitrate (NO_3^-) and Nitrite (NO_2^-) concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR

4.1.7. Ammonia nitrogen (NH₃-N)

A good quality water body must have an ammonia levels less than 0.05 mg/L and when this level goes beyond 2 mg/L fish are killed (Francis-Floyd et al., 2022). Nonetheless, in the river under investigation, the mean ammonia ranges from 0.27mg/L (S5) to 1.45mg/L (S2), 0.2mg/L was tributaries (T1) and point sources were 7.2mg/L and these values are higher than the recommended value. In addition, point sources were contributing larger amounts of ammonia to the river. The findings are in line with the previous studies conducted by (Lencha, et al., 2021) on the eastern catchment of Lake Hawassa. Ammonia is an indicator for elevated pollution from organic substances producing noxious odors and are often indicative of sewage pollution and agricultural runoff (Damo & Icka, 2013).

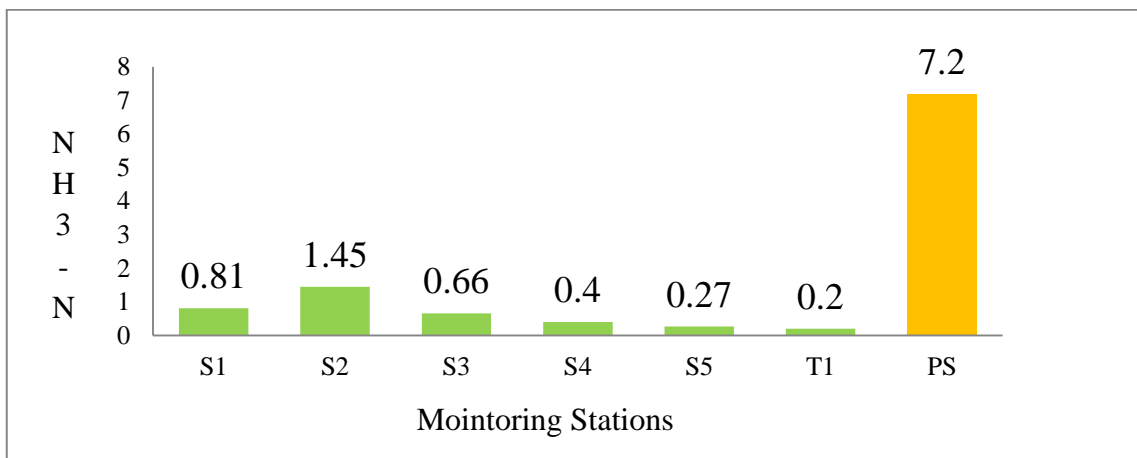


Figure 4-7: Ammonia nitrogen concentrations in the water and wastewater sample collected over 7 monitoring stations with wastewater sample labeled yellow at the TWR

4.2. Q2Kw Simulation Model

In the TWR, the Q2Kw model was calibrated by adjusting and minimizing the error between the observed and model- simulated values using a monitored water quality constituent and flow and by adjusting the parameters that controlled the pollutants and nutrient dynamics. The detritus, inorganic suspended solids, phytoplankton, and pathogens were not simulated due to data limitations, and a default value of 100 mg/L was used for alkalinity as calcium carbonate. The calibrated parameter values in the model are presented in Table 3-6 and the field water quality measurements was conducted on March, 2023, during the dry season are summarized in Table 4.1. The model calibration results for the water quality data at five monitoring locations based on four selected calibration parameters are shown in Fig 4-1. The horizontal axis of each graph indicates the distance (km) upstream of the river (distance 0km is downstream). The simulated results are presented as continuous lines and the observed data as symbols.

Table 4-1: Water quality parameters measured along the TWR and tributary during the dry period.

Station	Flow	T ^o	EC	DO	BOD ₅	COD	NH ₃ -N	NO ₂ ⁻	NO ₃ ⁻	pH	TSS	TDS	PO ₄ ⁻³
S1	0.59	22	420	5.1	46.5	217	0.81	0.03	0.35	8.42	109	198	1.95
S2	0.94	23.57	380	4.5	57	266	1.45	0.05	0.35	8.45	81	183	2.8
S3	0.9	23.6	328	4	51	238	0.66	0.09	0.4	8.39	63.5	164	1.55
S4	0.87	23.56	318	3.6	49.5	224	0.4	0.07	0.38	8.37	56	173	1.45
S5	0.56	24	322	3.8	48	231	0.27	0.04	0.57	8.35	48.2	172	1.2
T1	0.89	23	200	4	50	230	0.2	0.04	0.6	7.6	55	100	3.5
PS	0.45	34	3728	1.6	62	274	7.2	0.02	12	7.4	58	1574	18.7

The model calibration results are in well agreement with the measured data, with some exceptions showing in figure 4.1. The calibration result in the river showed that the water quality meet the minimum requirement of DO concentration of 4 mg/L except for S1 and S2 in the river and may negatively impact biological community survival and result in the death of most fish. In the downstream part of the river, DO concentration is above 5 mg/L, an indication of better quality of water. The model simulated for DO was in good agreement on most of the monitoring stations, with an overall coefficient of determination (R^2) value between the observed and simulated values of 0.65 during calibration. This value indicates the effectiveness and interrelationships between the observed and simulated values.

Other parameters, such as the water temperature and EC, were very well simulated by Q2Kw in TWR during calibration, with a |PBAIS| and R^2 of 1.02% (0.999) and 8.87% (0.6), respectively. The |PBAIS| of pH during the model calibration was 0.71%, which is acceptable for developing countries. High value of |PBAIS| for DO and Low values R^2 for pH was observed and thus not presented. For the simulated and observed dataset for DO, Tem, and EC at all monitoring stations and for all study periods, a very good R^2 value was observed. In general, with the exception of the pH parameter, the Q2Kw model simulated the water quality parameters with an R^2 ranging from 0.55 to 0.999, which could be sufficient to interpret the model output for the development of water quality management programs and pollution control in TWR. For instance, (Kannel et al., 2007) and (Sharma et al., 2017) considered R^2 value that is greater than 0.5 as acceptable, especially for developing countries where financial resources are often limited for regular monitoring stations and greater accuracy in data analysis.

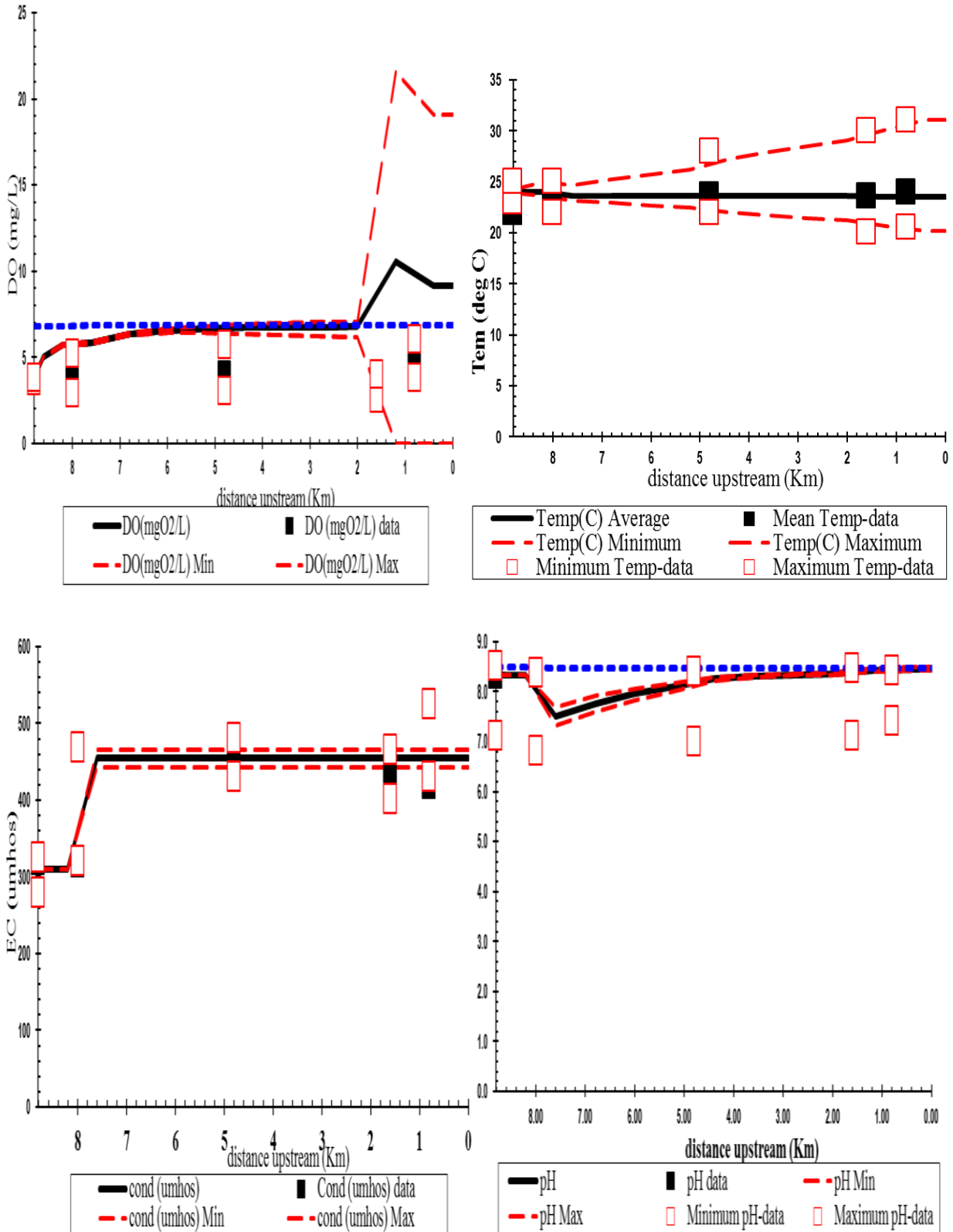


Figure 4-8: Model calibration results for the water quality parameters in TWR using dry data

4.3. Surface Water Quality Control Strategies

Different surface water quality management remediation strategies are includes: vegetation filter strips, wetland filters, riparian filter strips, animal contamination prevention, and community awareness programs. According to the National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution guideline (USEPA, 2005), constructed wetland and riparian filter strips were selected and the evidence of wetland filters effectiveness shows a reduction of TSS by 76–97%, nitrates by 86%, nitrites by 47%, and phosphorus by 48%. The riparian filter strips have been found to reduce TSS by 84–90%, nitrates by 79–93%, nitrite by >80%, and phosphorus by 80%. The role of wetlands and riparian areas include water quality improvement; stream shading; flood attenuation; shoreline stabilization; ground water exchange; and habitat for aquatic, semiaquatic, terrestrial, migratory, and rare species. Wetlands and riparian areas typically occur as natural buffers between uplands and adjacent water bodies. Loss of these systems allows for a more direct contribution of non-point source pollutants to receiving waters (Correll, 1984). Riparian forests, for example, have been found to contribute to the quality of aquatic habitat by providing cover, bank stability, and a source of organic carbon for microbial processes like denitrification(Ames et al., 2005). Constructed wetlands have been considered for use in urban and agricultural settings where some sort of engineered system is suitable for non-point source pollution reduction.

The use of natural coagulants for the clarification of water and wastewater has been recorded throughout human history since ancient times and it is still current today. Natural organic polymers have been used for more than 2000 years in India, Africa, and China as effective coagulants (Abirami.M & Rohini, 2017). Natural coagulants are divided into three categories; plant, microorganism or animal-based (Subramani et al., 2017). However, available sources of plant-based coagulants are much more widespread than animal-based coagulants, thus plant based coagulants could be potential alternatives to chemical coagulants and have gradually gained in importance over the years. The use of plant-based materials as water treatment agents has long history, particularly the wood charcoal as an excellent adsorbent like *Moringa oleifera* (Bryan, 2019).

Moringa Oleifera is a tropical plant from the family of Moringaceae, a single family of shrubs with 14 known species. *Moringa oleifera* is native from India but is now found throughout the world. *Moringa Oleifera* is non-toxic natural organic polymer, a medicinal plant. It is drought tolerant and has nutritional and medicinal value (Neethu et al., 2017). Many plants have been used to clarify water. These include *Moringa oleifera*, *Moringa stenopetala*, and *Vicia faba* (Chonde, 2017). Among the most studied natural coagulants *Moringa oleifera* is one of them. *Moringa oleifera* seeds are also used as a primary coagulant in wastewater treatment due to the presence of a water-soluble cationic coagulant protein able to reduce the turbidity, COD, and TDS of the wastewater treated (Feihrmann et al., 2017). *Moringa oleifera* seeds stand out due to high efficiency in turbidity removal in river waters and for not producing significant changes in pH and alkalinity of the treated water (Feria et al., 2018).

Moringa oleifera is used as a primary coagulant and does not carry any impact on human health, and has a high efficiency up to 99% in the removal of turbidity from surface water and up to 98% in the removal of heavy metals from surface water (Ghawi, 2017). *Moringa oleifera* seeds possess antimicrobial, buffering capacity and also contains natural antioxidant compounds which are biodegradable, environmentally safe to humans and essential to the human's system (Sulaiman et al., 2017).

In general, wetland systems and riparian filter strips can be successfully applied for the treatment of non-point source pollution in surface water runoff and are effective at removing suspended solids and pollutants that attach to solids and soil particles to prevent the entry of the TWR. Moreover, the use of natural coagulants like *Moringa oleifera* can substantially save money on the cost of chemical materials, reduce to a minimum the amount of sludge produced, and, hence, require fewer disposals. Therefore, *Moringa oleifera* was selected to reduce the TSS, COD, and TDS of the wastewater treated before discharging directly into the TWR depending on several advantages, such as being inexpensive, non-corrosive, non-toxic, having a high level of biodegradability, having a lower cost, treating water without extreme pH, having good color and turbidity removal, and also promoting the removal of bacteria.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this study, the water quality analysis results examined from different stations of the river showed that most of the parameters were higher during the study period. According to the assessment of river water quality at different sampling points in the dry seasons, most of the physico-chemical water quality parameters are within guideline of Ambient Environment Standards For Ethiopia, WHO and FAO standard, whereas some of the parameters are exceeded from the standard limit. A very high concentration of BOD₅ was found in all sampling locations and it is above the permissible limit of WHO guidelines. A high BOD indicates organic pollution, which depletes the oxygen in rivers. TSS level was above WHO guidelines in all sampling points except at sampling points S5. High TSS values limit photosynthesis and respiration in aquatic organisms by reducing light penetration in the water. In addition, the concentration of phosphate was within the permissible limit of FAO at all sampling points except at sampling points S5 and T1. The concentration of DO meets the minimum requirement of 4 mg/L except for S4 and S5 in the river and may negatively impact biological community survival and result in the death of most fish. On the other hand, the concentration of water temperature, EC, and pH value was within the permissible limit.

In this study, a stream water quality model, Q2Kw, was calibrated for the Tikur Wuha River using the data collected in 2023. In calibration, the percentage bias |PBAIS| and coefficient determination R² (inside bracket) values between the simulated and observed data for water temperature, DO, EC, and pH are 1.02% (0.999), (0.65), 8.87% (0.6), and 0.71%, respectively, indicating that the performance of the Q2Kw model is satisfactory

and the model can be applied successfully to generate future scenarios for the study area.

The simulation of the QUAL2Kw for flow and constituents has shown that the model is sufficient for the interpretation of water quality in the river. The QUAL2Kw simulated the water quality constituents with relatively good accuracy having an R^2 ranging from 0.55 to 0.99 and |PBAIS| from 0.71% to 8.8%. Hence, the model is applicable to assess the effect of various pollution controls and supporting in-stream measures on key water quality parameters. The water quality model, QUAL2Kw, is a useful tool for managing river pollution, especially in developing countries where financial resources are often limited for regular monitoring stations and greater accuracy in data analysis. The results can be properly interpreted for early pollution prevention and management strategies. Additionally, the model has the ability to provide support for decision-making when designing, carrying out, and managing initiatives for river improvement in the study area.

5.2. Recommendations

As per the guideline of the WHO and Ambient Environment Standards for Ethiopia, the present water quality of the river is not acceptable as drinking water source and survival of fish. Therefore proper waste management should be adopted to prevent the continued deterioration in water quality. Then recommended that:

- ❖ In order to protect the pollution of Tikur Wuha River water, wetland systems and riparian filter should be applied for the treatment of non-point source pollution in the river catchment.
- ❖ To protect the Tikur Wuha River water from the adverse effects of wastewater effluent from BGI should be applied natural coagulants like *Moringa oleifera* around the catchment area.
- ❖ Public awareness programs and strict enforcement against domestic and municipal wastewater disposal into the river water should be adopted.

REFERENCE

- Abirami.M, & Rohini, C. (2017). A Comparative Study on the Treatment of Turbid Water Using MoringaOleifera and Alum as Coagulants. 41–48.
- Abiy, A. Z., Demissie, S. S., & Macalister, C. (2015). Groundwater Recharge and Contribution to the Tana Sub-basin , Upper Blue Chapter 22 Groundwater Recharge and Contribution to the Tana Sub-basin , Upper Blue Nile Basin , Ethiopia. November. <https://doi.org/10.1007/978-3-319-18787-7>
- Ademe, A. S. (2014). Source and Determinants of Water Pollution in Ethiopia: Distributed Lag Modeling Approach. Intellectual Property Rights: Open Access, 2(2). <https://doi.org/10.4172/2375-4516.1000110>
- Adgolign, T. B., Rao, G. V. R. S., & Abbulu, Y. (2016). WEAP modeling of surface water resources allocation in Didessa. Sustainable Water Resources Management, 2(1), 55–70. <https://doi.org/10.1007/s40899-015-0041-4>
- Almaarofi, H., Etemad-Shahidi, A., & Stewart, R. A. (2017). Strategic evaluation tool for surface water quality management remedies in drinking water Catchments. Water (Switzerland), 9(10). <https://doi.org/10.3390/w9100738>
- Alobaidy, A. H. M. J., Abid, H. S., & Maulood, B. K. (2010). Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq. Journal of Water Resource and Protection, 02(09), 792–798. <https://doi.org/10.4236/jwarp.2010.29093>

- Amare, S. K., Zebene, K., & Agizew, N. E. (2017). Evaluating water quality of Awash River using water quality index. *International Journal of Water Resources and Environmental Engineering*, 9(11), 243–253. <https://doi.org/10.5897/ijwree2017.0736>
- Ames, M. D. T., Dosskey, M. G., James, D. E., & Helmers, M. J. (2005). PLACEMENT OF RIPARIAN FOREST BUFFERS TO IMPROVE WATER QUALITY. June.
- Angello, Z. A., Behailu, B. M., & Tränckner, J. (2021). Selection of optimum pollution load reduction and water quality improvement approaches using scenario basedwater quality modeling in little akaki river, Ethiopia. *Water (Switzerland)*, 13(5). <https://doi.org/10.3390/w13050584>
- APHA. (2012). Standard methods for the examination of water and wastewater (Vol. 10). American public health association Washington, DC.
- Aydin, H., Ustaoglu, F., Tepe, Y., & Soylu, E. N. (2020). Assessment of water quality of streams in northeast Turkey by water quality index and multiple statistical methods. *Environmental Forensics*, 0(0), 1–18. <https://doi.org/10.1080/15275922.2020.1836074>
- Aynew, T. (2001). NUMERICAL GROUNDWATER FLOW MODELING OF THE CENTRAL MAIN ETHIOPIAN RIFT LAKES BASIN. 24(2), 167–184.
- Bahadur, R., Amstutz, D. E., & Samuels, W. B. (2013). Water Contamination Modeling—A Review of the State of the Science. *Journal of Water Resource and Protection*, 05(02), 142–155. <https://doi.org/10.4236/jwarp.2013.52016>

- Basu, S., & Lokesh, K. S. (2013). Spatial and temporal variations of river water quality :
A case study of River Kabini at Nanjangud in Karnataka. 5(10), 591–596.
<https://doi.org/10.5897/IJWREE12.130>
- Benedini, M. (2011). Water Quality Models for Rivers and Streams . State of the Art
and Future Perspectives. *European Water*, 34(1), 27–40.
- Berhe, F. T., Melesse, A. M., Hailu, D., & Sileshi, Y. (2013). Catena MODSIM-based
water allocation modeling of Awash River Basin , Ethiopia. *Catena*, 109, 118–128.
<https://doi.org/10.1016/j.catena.2013.04.007>
- Betrie, G., Griensven, A. Van, Brussel, V. U., Mohamed, Y. A., & Popescu, I. (2013).
Linking SWAT and SOBEK Using Open Modeling Interface (OpenMI) for
Sediment Transport Simulation in the Blue Nile River Basin T ECHNICAL N
OTE : L INKING SWAT AND SOBEK U SING O PEN M ODELING I
NTERFACE (O PEN MI) FOR S EDIMENT T RANSPORT. February 2014.
<https://doi.org/10.13031/2013.39847>
- Borchardt, D., Reichert, P., & Rauch, W. (2001). River Water Quality Model No . 1
Edited by IWA Task Group on River Water Quality Modelling Mogens Henze. 1.
- Bryan, M. (2019). Terminalia catappa (talisay) leaves as coagulant for preliminary
surface water treatment. *International Journal of Biosciences | IJB | ISSN*, 14(5),
324–329. <https://doi.org/10.12692/ijb/14.5.324-329>
- Bu, H., Meng, W., & Zhang, Y. (2014). Spatial and seasonal characteristics of river
water chemistry in the Taizi River in Northeast China. *Environmental Monitoring
and Assessment*, 186(6), 3619–3632. <https://doi.org/10.1007/s10661-014-3644-6>

- Camargo, R. D. A., Calijuri, M. C., Federal, U., & Preto, D. O. (2011). Water quality prediction using the QUAL2Kw model in a small karstic watershed in Brazil. *Water quality prediction using the QUAL2Kw model in a small karstic watershed in Brazil*. February 2017. <https://doi.org/10.4322/actalb.2011.012>
- Chapra, S., Pelletier, G., & Tao, H. (2014). Steve Chapra, Greg Pelletier and Hua Tao. 1–91.
- Chebud, Y. A., & Melesse, A. M. (2009). Numerical modeling of the groundwater flow system of the Gumera sub-basin in Lake Tana basin , Ethiopia. *3704(December)*, 3694–3704. <https://doi.org/10.1002/hyp>
- Chigor, V. N., Umoh, V. J., Okuofu, C. A., Ameh, J. B., Igbinosa, E. O., & Okoh, A. I. (2012). Water quality assessment: Surface water sources used for drinking and irrigation in Zaria, Nigeria are a public health hazard. *Environmental Monitoring and Assessment*, *184(5)*, 3389–3400. <https://doi.org/10.1007/s10661-011-2396-9>
- Chonde, S. (2017). Treatment of Dairy Wastewater By Moringa Oleifera Seeds. *World Journal of Pharmaceutical Research*, September, 1484–1493. <https://doi.org/10.20959/wjpr20178-9015>
- Correll, W. T. . P. and D. L. . (1984). *Nutrient Dynamics in an Agricultural Watershed : Observations on the Role of A Riparian Forest Author (s) : William T . Peterjohn and David L . Correll Published by : Wiley on behalf of the Ecological Society of America Stable URL : https://www.jstor.org. 65(5), 1466–1475.*
- Cox, B. A. (2003). A review of currently available in-stream water-quality models and their applicability for simulating dissolved oxygen in lowland rivers. *Science of the Total Environment*, *314–316(03)*, 335–377. [https://doi.org/10.1016/S0048-9697\(03\)00063-9](https://doi.org/10.1016/S0048-9697(03)00063-9)

- Damo, R., & Icka, P. (2013). Evaluation of water quality index for drinking water. *Polish Journal of Environmental Studies*, 22(4), 1045–1051.
- Dargahi, B., & Gebriye, S. (2011). Combined 3D hydrodynamic and watershed modelling of Lake Tana , Ethiopia. *Journal of Hydrology*, 398(1–2), 44–64. <https://doi.org/10.1016/j.jhydrol.2010.12.009>
- Deksissa, T., Meirlaen, J., Ashton, P. J., & Vanrolleghem, P. A. (2004). SIMPLIFYING DYNAMIC RIVER WATER QUALITY MODELLING : A CASE STUDY OF INORGANIC NITROGEN DYNAMICS IN THE. 303–320.
- Desta, H., & Lemma, B. (2017). Journal of Hydrology : Regional Studies SWAT based hydrological assessment and characterization of Lake. *Journal of Hydrology: Regional Studies*, 13(September), 122–137. <https://doi.org/10.1016/j.ejrh.2017.08.002>
- Dile, Y. T., Berndtsson, R., & Setegn, S. G. (2013). Hydrological Response to Climate Change for Gilgel Abay River , in the Lake Tana Basin - Upper Blue Nile Basin of Ethiopia. 8(10), 12–17. <https://doi.org/10.1371/journal.pone.0079296>
- EPA. (2003). Guidline Ambient Environment Standards for Ethiopia. Prepared By: The Environmental Protection Authority And The United Nations Industrial Development Organization, V 1.1(August), 103.
- Eromo, S., Adane, C., Santosh, A., & Pingale, M. (2016). Assessment of the impact of climate change on surface hydrological processes using SWAT : a case study of Omo-Gibe river basin , Ethiopia. *Modeling Earth Systems and Environment*, 2(4), 1–15. <https://doi.org/10.1007/s40808-016-0257-9>

- Erturk, A. (2010). A simple stream water quality modelling software for educational and training purposes. *Turkish Journal of Fisheries and Aquatic Sciences*, 10(1), 61–70. <https://doi.org/10.4194/trjfas.2010.0109>
- Feihrmann, A. N. C., Baptista, A. T. A., Lazari, J. P., Silva, M. O., Vieira, M. F., & Vieira, A. M. S. (2017). Evaluation of coagulation/floculation process for water treatment using defatted cake from *Moringa oleifera*. *Chemical Engineering Transactions*, 57, 1543–1548. <https://doi.org/10.3303/CET1757258>
- Feria, D. J. J., Garrido, L. V., & Mercado, W. R. (2018). Coagulant Activity from *Moringa oleifera* seed for Raw Water Treatment from Reservoirs. *International Journal of Applied Engineering Research*, 13(8), 6419–6423. <http://www.ripublication.com>
- Francis-Floyd, R., Watson, C., Petty, D., & Pouder, D. (2022). Ammonia in Aquatic Systems. *Edis*, 2022(4), 1–6. <https://doi.org/10.32473/edis-fa031-2022>
- Gajbhiye, S., Sharma, S. K., & Awasthi, M. K. (2015). Application of Principal Components Analysis for Interpretation and Grouping of Water Quality Parameters. *International Journal of Hybrid Information Technology*, 8(4), 89–96. <https://doi.org/10.14257/ijhit.2015.8.4.11>
- Gao, L., & Li, D. (2014). A review of hydrological/water-quality models. *Frontiers of Agricultural Science and Engineering*, 1(4), 267–276. <https://doi.org/10.15302/J-FASE-2014041>
- Gebreyohannes, F. , Gebrekidan, A., Hadera, A.and Estifanos, S. (2015). Investigations of Physico-Chemical Parameters and its Pollution Implications of. 7(2), 240–257. <https://doi.org/http://dx.doi.org/10.4314/mejs.v7i2.7> Investigations

- Ghawi, H. A. (2017). USING NATURAL COAGULANT TO REMOVE TURBIDITY AND HEAVY METAL FROM SURFACE WATER TREATMENT PLANT IN IRAQ Domestic Wastewater unit View project , January 2017. www.ijetsi.org
- Ghosh, N. C., & Mcbean, E. A. (1998). Water quality modeling of the Kali River, India. *Water, Air, and Soil Pollution*, 102(1–2), 91–103. <https://doi.org/10.1023/A:1004912216834>
- Gikas, G. D. (2015). Water Quality of Drainage Canals and Assessment of Nutrient Loads Using Water Quality of Drainage Canals and Assessment of Nutrient Loads Using QUAL2Kw. September. <https://doi.org/10.1007/s40710-014-0027-5>
- Hamid, A., Bhat, S.U., & Jehangir, A. (2020). Local determinants influencing stream water quality. *Applied Water Science*, 10(1), 1–16. <https://doi.org/10.1007/s13201-019-1043-4>
- Hassan Omer, N. (2020). Water Quality Parameters. *Water Quality - Science, Assessments and Policy*, 1–18. <https://doi.org/10.5772/intechopen.89657>
- Hossain, M. A., Sujaul, I. M., & Nasly, M. A. (2014). Application of QUAL2Kw for water quality modeling in the Tunggak River ,. 6–14.
- Ibrahim, A., Juahir, H., Sultan, U., Abidin, Z., & Toriman, M. E. (2015). Advances in Environmental Biology Surface Water Quality Assessment of Terengganu River Basin Using Multivariate Techniques *Advances in Environmental Biology Surface Water Quality Assessment of Terengganu River Basin Using Multivariate Techniques*. January.

- Kannel, P. R., Kanel, S. R., Lee, S., Lee, Y. S., & Gan, T. Y. (2011). A Review of Public Domain Water Quality Models for Simulating Dissolved Oxygen in Rivers and Streams. *Environmental Modeling and Assessment*, 16(2), 183–204. <https://doi.org/10.1007/s10666-010-9235-1>
- Kannel, P. R., Lee, S., Kanel, S. R., Lee, Y. S., & Ahn, K. H. (2007). Application of QUAL2Kw for water quality modeling and dissolved oxygen control in the river Bagmati. *Environmental Monitoring and Assessment*, 125(1–3), 201–217. <https://doi.org/10.1007/s10661-006-9255-0>
- Kasa, T., Lukas, A., Tilahun, G., Amele, Z., & Reddythota, D. (2022). Heliyon Investigation of Wabe River water fitness for agricultural and industrial purposes. *Heliyon*, 8(August), e11865. <https://doi.org/10.1016/j.heliyon.2022.e11865>
- Khatri, N., & Tyagi, S. (2015). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science*, 8(1), 23–39. <https://doi.org/10.1080/21553769.2014.933716>
- Khouni, I., Louhichi, G., & Ghrabi, A. (2021). Use of GIS based Inverse Distance Weighted interpolation to assess surface water quality: Case of Wadi El Bey , Tunisia. *Environmental Technology & Innovation*, 24, 101892. <https://doi.org/10.1016/j.eti.2021.101892>
- Kori, B. B., Shashidhar, T., & Mise, S. (2013). APPLICATION OF AUTOMATED QUAL2Kw FOR WATER QUALITY MODELING IN THE RIVER KARANJA, INDIA. 2(2), 193–203.

- Lencha, S. M., Tränckner, J., & Dananto, M. (2021). Assessing the water quality of lake hawassa Ethiopia—Trophic state and suitability for anthropogenic uses—applying common water quality indices. *International Journal of Environmental Research and Public Health*, 18(17). <https://doi.org/10.3390/ijerph18178904>
- Lencha, S. M., Ulsido, M. D., & Muluneh, A. (2021). Evaluation of seasonal and spatial variations in water quality and identification of potential sources of pollution using multivariate statistical techniques for Lake Hawassa Watershed, Ethiopia. *Applied Sciences (Switzerland)*, 11(19). <https://doi.org/10.3390/app11198991>
- Leta, M. K., & Dibaba, W. T. (2019). Assessment of Physico-Chemical Parameters of Awetu River, Jimma, Oromia, Ethiopia. *Journal of Water Sustainability*, 1(November), 13–21. <https://doi.org/10.11912/jws.2019.9.1.13-21>
- Mandelker, D. R. (1989). Controlling nonpoint source water pollution: Can it be done. *Chicago-Kent Law Review*, 65(2), 479–502.
- Marlina, N., & Melyta, D. (2019). Analysis Effect of Cloud Cover, Wind Speed, and Water Temperature to BOD and DO Concentration Using QUAL2Kw Model (Case Study In Winongo River, Yogyakarta). *MATEC Web of Conferences*, 280, 05006. <https://doi.org/10.1051/matecconf/201928005006>
- Maschal Tarekegn, M., & Truye, A. Z. (2018). Causes and impacts of shankila river water pollution in Addis Ababa, Ethiopia. *Environ Risk Assess Remediat*, 2(4), 21–30.

- Mateo-Sagasta, J., Zadeh, S. M., Turrall, H., & Burke, J. (2017). Water Pollution from Agriculture: A Global Review. The Food and Agricultural Organization., 1–35.
- McIntyre, N. R., Wagener, T., Wheeler, H. S., & Chapra, S. C. (2003). Risk-based modelling of surface water quality: A case study of the Charles River, Massachusetts. *Journal of Hydrology*, 274(1–4), 225–247. [https://doi.org/10.1016/S0022-1694\(02\)00417-1](https://doi.org/10.1016/S0022-1694(02)00417-1)
- Moriasi, D. N., Gitau, M. W., Pai, N., & Daggupati, P. (2015). Hydrologic and water quality models: Performance measures and evaluation criteria. *Transactions of the ASABE*, 58(6), 1763–1785. <https://doi.org/10.13031/trans.58.10715>
- Naidoo, S., & Olaniran, A. O. (2013). Treated wastewater effluent as a source of microbial pollution of surface water resources. *International Journal of Environmental Research and Public Health*, 11(1), 249–270. <https://doi.org/10.3390/ijerph110100249>
- Neethu, P., Navami, D., & Anitha, K. (2017). Treatment of dairy wastewater by *Moringa oleifera* as natural coagulant. *Int. J. Adv. Res. Innovative Ideas Educ.*, 3(4), 1448–1453.
- Oketola, A. A., Adekolurejo, S. M., & Osibanjo, O. (2013). Water Quality Assessment of River Ogun Using Multivariate Statistical Techniques. *Journal of Environmental Protection*, 04(05), 466–479. <https://doi.org/10.4236/jep.2013.45055>
- Olowe, K. O., & Kumarasamy, M. vellaisamy. (2018). Assessment of some existing water quality models. *Nature Environment and Pollution Technology*, 17(3), 939–948.

- Ongley, E. D. (1999). Water Quality Management: Design, Financing and Sustainability Considerations. In Proceedings of the African Water Resources Policy Conference, Nairobi, May 26-28, 1999., 1–12.
- Pelletier, G. J., Chapra, S. C., & Tao, H. (2006). QUAL2Kw - A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. *Environmental Modelling and Software*, 21(3), 419–425. <https://doi.org/10.1016/j.envsoft.2005.07.002>
- Peters, R. W. (2011). Water and wastewater engineering: Design principles and practice, 1ST edition. In *Environmental Progress & Sustainable Energy* (Vol. 30, Issue 3). <https://doi.org/10.1002/ep.10602>
- Prabu, P. C., Wondimu, L., & Tesso, M. (2011). Assessment of water quality of Huluka and Alaltu Rivers of Ambo, Ethiopia. *Journal of Agricultural Science and Technology*, 13(1), 131–138.
- Raeisi, N., Moradi, S., & Scholz, M. (2022). Surface Water Resources Assessment and Planning with the QUAL2KW Model: A Case Study of the Maroon and Jarahi Basin (Iran). *Water (Switzerland)*, 14(5). <https://doi.org/10.3390/w14050705>
- Raj, P., Lee, S., Lee, Y., Kanel, S. R., Pelletier, G. J., & Box, P. O. (2007). Application of automated QUAL2Kw for water quality modeling and management in the Bagmati River, Nepal. 2, 503–517. <https://doi.org/10.1016/j.ecolmodel.2006.12.033>
- S. Mustafa, A., O. Sulaiman, S., & H. Shahooth, S. (2017). Application of QUAL2K for Water Quality Modeling and Management in the lower reach of the Diyala river. *Iraqi Journal of Civil Engineering*, 11(2), 66–80. <https://doi.org/10.37650/ijce.2017.134910>

- Sadgir, P. (2015). Assessment of Multi Parameters of Water Quality in Surface Water Bodies-A Review. October.
- Sasakova, N., Gregova, G., Takacova, D., Mojzisova, J., Papajova, I., Venglovsky, J., Szaboova, T., & Kovacova, S. (2018). Pollution of Surface and Ground Water by Sources Related to Agricultural Activities. *Frontiers in Sustainable Food Systems*, 2(July). <https://doi.org/10.3389/fsufs.2018.00042>
- Schratter-Sehn, A. U., Schmidt, W. F. O., Kielhauser, R., Langer, H., & Karcher, K. H. (1992). Pravention Lokaler Schleimhautlasionen Wahren Oropharynx-Bestrahlung Durch Einen Plombenschutz. *Strahlentherapie Und Onkologie*, 168(1), 35–38.
- Selemani, J. R., Zhang, J., Muzuka, A. N. N., Njau, K. N., Zhang, G., Mzuza, M. K., Maggid, A., Zhang, J., Muzuka, A. N. N., Njau, K. N., Zhang, G., & Mzuza, M. K. (2017). Nutrients ' distribution and their impact on Pangani River Basin ' s ecosystem Tanzania. *Environmental Technology*, 0(0), 1–15. <https://doi.org/10.1080/09593330.2017.1310305>
- Sharma, D., Kansal, A., & Pelletier, G. (2017). Water quality modeling for urban reach of Yamuna river, India (1999–2009), using QUAL2Kw. *Applied Water Science*, 7(3), 1535–1559. <https://doi.org/10.1007/s13201-015-0311-1>
- Shishaye, H. A., & Nagari, and A. (2016). Hydrogeochemical Analysis and Evaluation of the Groundwater in the Haramaya Well Field ,Eastern Hararghe Zone, Ethiopia. *Journal of Hydrogeology & Hydrologic Engineering*. <https://doi.org/10.4172/2325-9647.1000148>

- Simeonov, V., Stratis, J. A., Samara, C., Zachariadis, G., Voutsas, D., Anthemidis, A., Sofoniou, M., & Kouimtzis, T. (2003). Assessment of the surface water quality in Northern Greece. *Water Research*, 37(17), 4119–4124. [https://doi.org/10.1016/S0043-1354\(03\)00398-1](https://doi.org/10.1016/S0043-1354(03)00398-1)
- Subramani, T., Rajkumar, V., & Priyanka, S. (2017). Treatment of dairy wastewater from Salem Aavin using natural coagulants. *International Journal of Application or Innovation in Engineering & Management*, 6(5), 263–273.
- Sulaiman, M., Andrawus Zhigila, D., Mohammed, K., Mohammed Umar, D., Aliyu, B., & Manan, F. A. (2017). Moringa oleifera seed as alternative natural coagulant for potential application in water treatment: A review. *Journal of Advanced Review on Scientific Research Journal Homepage*, 30(1), 1–11. www.akademiabaru.com/arsr.html
- Tekile, A. K. (2023). Suitability Assessment of Surface Water Quality for Irrigation : A Case Study of Modjo River , Ethiopia. *Journal of Environmental and Public Health*, 2023. <https://doi.org/https://doi.org/10.1155/2023/1482229>
- Terfasa, F., Daba, A. T., & Pandian, M. (2021). Assessments of the Total Heterotrophic Bacterial Population Density From Wabe River, South-Central Ethiopia. June. <https://doi.org/10.21276/IJIPSR.2019.07.01.765>
- Tibebe, D., Tesfaye, Y., & Anteneh, B. M. (2022). The Impact of Sewage Effluents on Water Quality of Lake Hawasa. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4061458>
- Tibebe, M., Assefa, M., & Zemadim, B. (n.d.). CHAPTER 7 Runoff Estimation and Water Demand Analysis for Holetta River , Awash subbasin , Ethiopia using SWAT and CropWat models.

- Tsakiris, G., & Alexakis, D. (2012). Water quality models : An overview. *European Water*, 37, 33–46.
- Tsegaye, M. Y. (2019). Water Quality Assessment Using Optimal Multi- Objective Waste-Load Allocation Approach: The Case of Little Akaki River. April, 1–174.
- US EPA. (2011). A National Evaluation of the Clean Water Act Section 319 Program. November, 197.
- USEPA. (2005). National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution.
- Vaughan, I. P., Diamond, M., Gurnell, A. M., Hall, K. A., Jenkins, A., Milner, N. J., Naylor, L. A., Sear, D. A., Woodward, G., & Ormerod, S. J. (2009). Integrating ecology with hydromorphology: A priority for river science and management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 19(1), 113–125. <https://doi.org/10.1002/aqc.895>
- Wang, Q., Li, S., Jia, P., Qi, C., & Ding, F. (2013). A review of surface water quality models. *The Scientific World Journal*, 2013. <https://doi.org/10.1155/2013/231768>
- Worako, A. W. (2015). Evaluation of the water quality status of Lake Hawassa by using water quality index , Southern Ethiopia. 7(4), 58–65. <https://doi.org/10.5897/IJWREE2014>.
- Xu, Z. (2014). Dissolved Oxygen Dynamics and Modeling - A Case Study in A Subtropical Shallow Lake. Elsevier Science Ltd, 22, 114.
- Yamuna, R., Idris, S., Abdu, Y. A., & Saini, G. (2018). Assessment of Surface Water Quality Using Qual2k Software : A Case Study Assessment of Surface Water Quality Using Qual2k Software: A Case Study of River Yamuna , India.

2018(March 2017), 16–23.

- Yawar, M., Khan, A., Gani, K. M., & Chakrapani, G. (2015). Assessment of surface water quality and its spatial variation . A case study of Ramganga River , Ganga Basin , India. September 2016. <https://doi.org/10.1007/s12517-015-2134-7>
- Ye, H., Guo, S., Li, F., & Li, G. (2013). Water quality evaluation in Tidal River reaches of Liaohe River Estuary, China using a revised QUAL2K model. *Chinese Geographical Science*, 23(3), 301–311. <https://doi.org/10.1007/s11769-013-0586-9>
- Yıldız, S., & Karakuş, C. B. (2020). Estimation of irrigation water quality index with development of an optimum model: a case study. *Environment, Development and Sustainability*, 22(5), 4771–4786. <https://doi.org/10.1007/s10668-019-00405-5>
- Yohannes, H., & Elias, E. (2017). Contamination of Rivers and Water Reservoirs in and Around Addis Ababa City and Actions to Combat It. *Environment Pollution and Climate Change*, 01(02). <https://doi.org/10.4172/2753-458x.1000116>
- Yusuf, Z. H. (2020). Phytoplankton as bioindicators of water quality in Nasarawa reservoir , Katsina State Nigeria. *Acta Limnological Brasiliensia*, 32. <https://doi.org/https://doi.org/10.1590/S2179-975X3319>
- Zelalem, A. A., Behailu, B. M., & Tränckner, J. (2021). Quality Modeling in Little Akaki River , Ethiopia.
- Ziemińska-Stolarska, A., & Skrzypski, J. (2012). Review of mathematical models of water quality. *Ecological Chemistry and Engineering S*, 19(2), 197–211. <https://doi.org/10.2478/v10216-011-0015-x>

APPENDIX

Appendix-A: Guideline Surface Water Quality Standards

Parameters	WHO limit(2017 & 2021)	FAO limits(1994)
pH	6.5-8.5	8.5
TDS	1000	2000
EC	2500	3000
TSS	50	50
NH ₄ -N	70	60
DO	4	5
PO ₄ ³⁻	0.2	2
NO ₃ ⁻ -N	50	10
BOD ₅	5	Null

Appendix-B: Model Output Parameters

River water quality output data

Reach Label	x(km)	cond (umhos)	DO (mgO2/L)	CBOD (mgO2/L)	NH ₄ -N (ugN/L)	NO ₃ ⁻ -N (ugN/L)	Alk	pH
Headwater	8.81	310.30	3.80	48.00	270.00	570.00	100.00	8.35
MS 0.78	8.62	310.30	5.03	47.84	270.17	569.59	100.00	8.34
	8.21	310.30	5.75	47.67	270.40	569.28	100.01	8.33
MS 3.29	7.60	454.14	5.87	26.65	3304.13	1366.69	100.01	7.51
	6.80	454.14	6.35	26.53	3299.30	1366.17	100.01	7.76
	6.00	454.14	6.57	26.42	3293.76	1365.71	100.02	7.96
	5.20	454.14	6.66	26.30	3287.75	1365.27	100.02	8.09
MS 3.94	4.40	454.14	6.76	26.13	3273.59	1364.66	100.04	8.26
	3.60	454.14	6.76	25.99	3264.19	1364.14	100.05	8.31
	2.80	454.14	6.77	25.85	3254.76	1363.61	100.06	8.34
	2.00	454.14	6.77	25.71	3245.37	1363.08	100.07	8.36
Last Segment	1.20	454.14	10.57	25.59	3221.32	1347.20	100.14	8.42
	0.40	454.14	9.16	25.46	3196.65	1331.40	100.21	8.44
Terminus	0.00	454.14	9.16	25.46	3196.65	1331.40	100.21	8.44

Output data of river Hydraulics Characteristics

Reach	Downstream		Hydraulics Characteristics						
Label	Label	Distance	Q, m ³ /s	E', m ³ /s	H, m	B, m	Ac, m ²	U, mps	Slope
Headwater	Headwater	8.81	0.58	0.29	0.16	4.10	0.67	0.86	0.023000
MS 0.78		8.62	0.58	0.28	0.16	4.10	0.67	0.86	0.023000
		8.21	0.58	0.20	0.16	4.10	0.67	0.86	0.023000
MS 3.29		7.60	1.03	0.51	0.17	4.50	0.79	1.30	0.048000
		6.80	1.03	0.51	0.17	4.50	0.79	1.30	0.048000
		6.00	1.03	0.51	0.17	4.50	0.79	1.30	0.048000
		5.20	1.03	0.51	0.17	4.50	0.79	1.30	0.048000
MS 3.94		4.40	1.03	0.51	0.11	9.80	1.10	0.93	0.041000
		3.60	1.03	0.51	0.15	6.48	0.94	1.09	0.041000
		2.80	1.03	0.51	0.15	6.48	0.94	1.09	0.041000
		2.00	1.03	0.51	0.15	6.48	0.94	1.09	0.041000
Last Segment		1.20	1.03	0.51	0.08	13.70	1.04	0.99	0.078000
		0.40	1.03	0.51	0.08	13.70	1.04	0.99	0.078000

Temperature output

Distance	Temp(C)	Temp(C)	Temp(C)
x(km)	Average	Minimum	Maximum
8.81	24	24	24
8.615	23.99755	23.80777	24.46458
8.21	23.99491	23.60447	24.95102
7.6	28.27853	27.82648	29.38021
6.8	28.17873	27.49962	29.82407
6	28.08109	27.18048	30.24899
5.2	27.98552	26.86884	30.65495
4.4	27.78636	26.2234	31.46091
3.6	27.65831	25.81056	31.95683
2.8	27.5337	25.41108	32.41723
2	27.41234	25.02444	32.84252
1.2	27.16907	24.25924	33.63415
0.4	26.93792	23.5425	34.32335
0	26.93792	23.5425	34.32335

Appendix-C: Image Showing Sampling Water and Experimental Analysis



Image shows measuring the DO by titration and insert sample in oven for determining TSS



Image showing test the sample water parameter COD, $\text{NH}_4\text{-N}$, NO_3^- , and PO_4^-



Image showing sample taking with lab technician from the river along cheffe kebele



Image showing measuring of river depth and width in-situ

Appendix-E: Coefficient Determination R^2 value between Simulated and Observed Data during Calibration

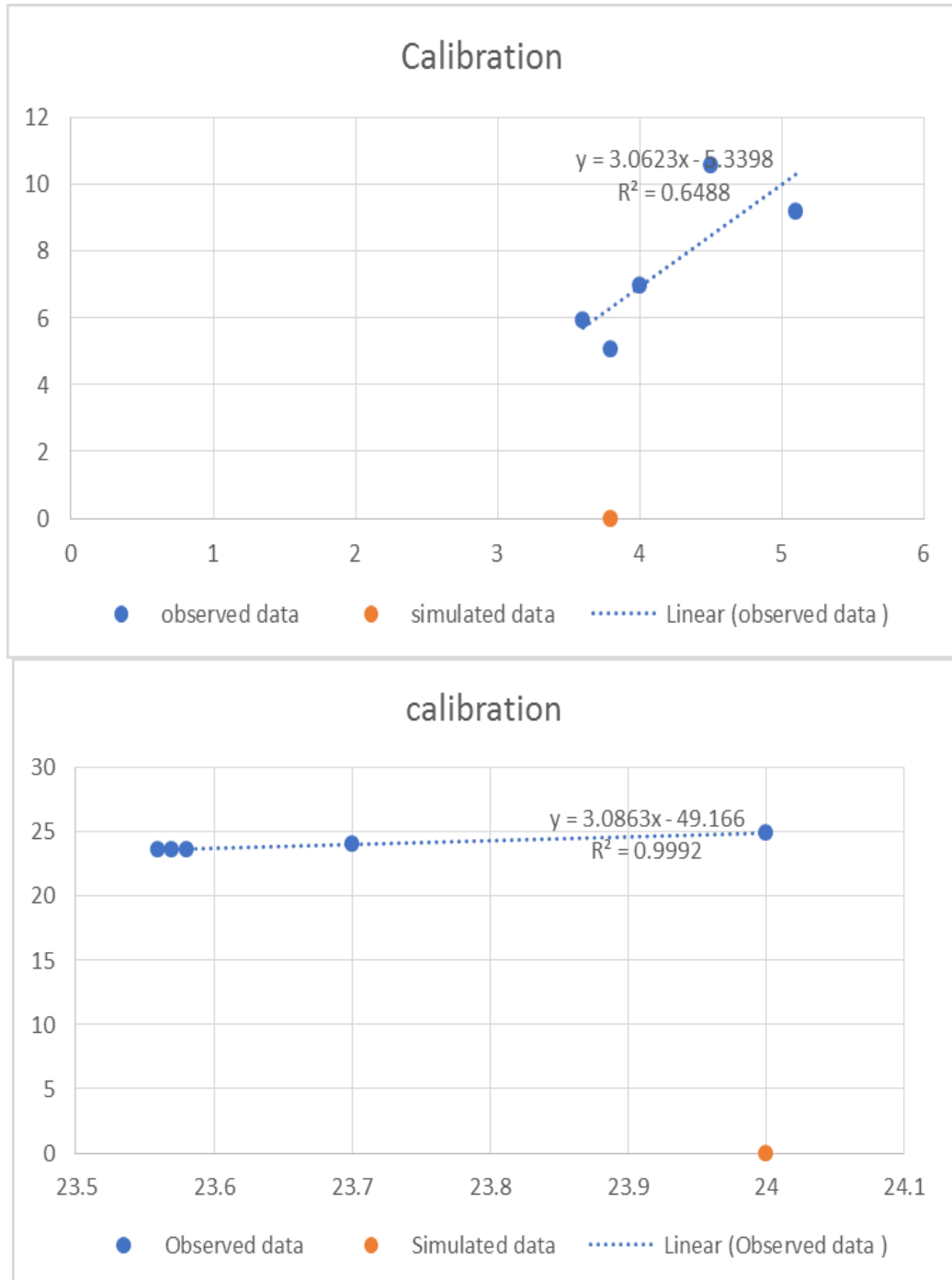


Image showing R^2 value of the simulated and observed data of DO and water temperature

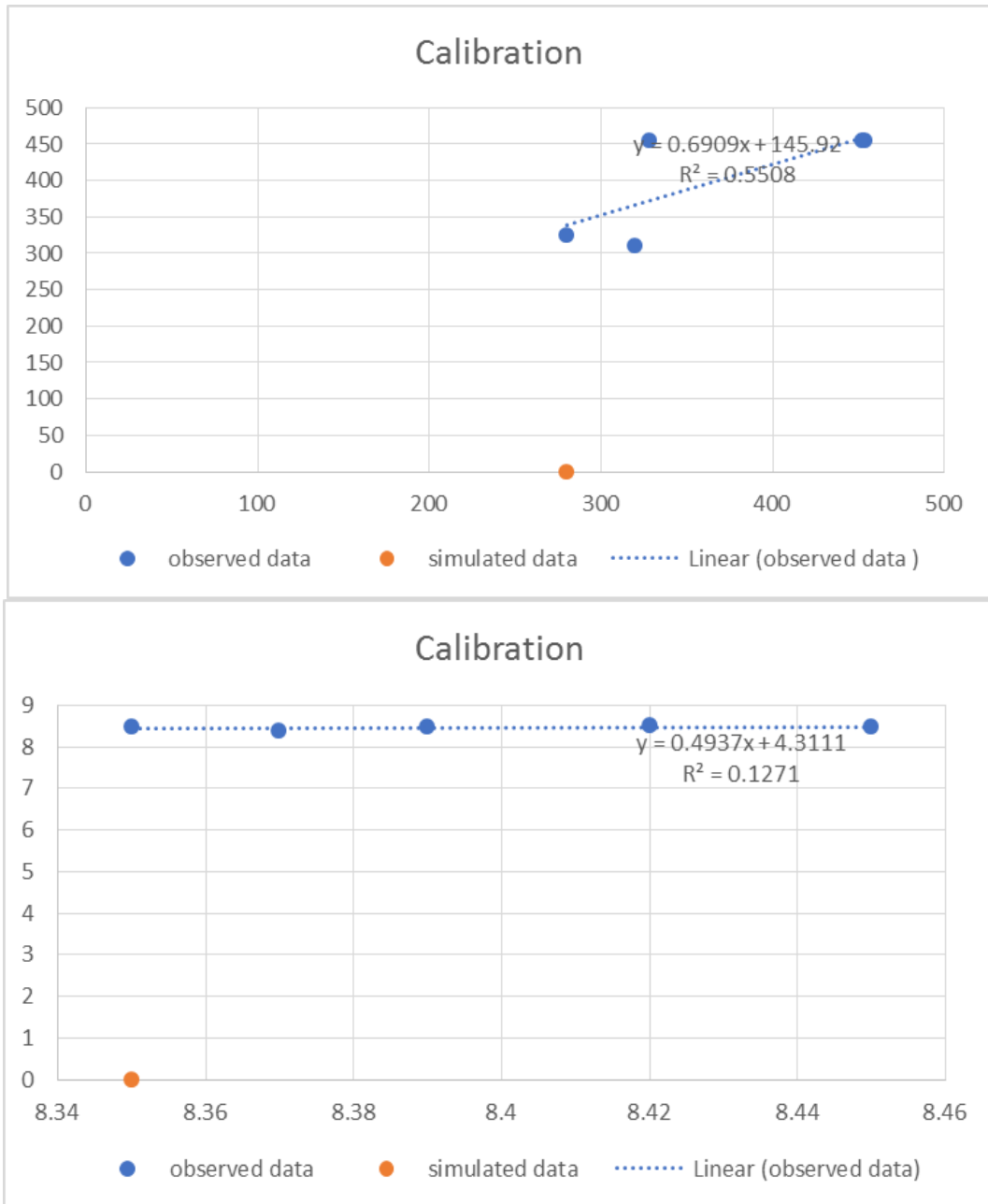


Image showing R^2 value of the simulated and observed data of EC and pH