

**Republic of Iraq  
Ministry of High Education and Scientific Research  
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College of Engineering  
Department of Environmental Engineering**



**Assessment of Al-Abbasiyah River Water Quality for  
Drinking and Irrigation Uses by Applying Water Quality  
Indices and GIS Technology**

*A Thesis*

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

*By*

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**1445 AH**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

(( وَجَعَلْنَا مِنْ أَلْمَاءِ كُلِّ شَيْءٍ حَيًّا ))

صَدَقَ اللَّهُ الْعَلِيُّ الْعَظِيمُ

سورة الأنبياء، آية 30

## **SUPERVISOR CERTIFICATION**

I certify that the preparation of this thesis entitled "**Assessment of Al-Abbasiyah River Water Quality for Drinking and Irrigation Uses by Applying Water Quality Indices and GIS Technology**" was done by "**Mustafa Abdulkareem Obayes Al Yousif**" and under my supervision at the Department of Environmental Engineering / College of Engineering/ University of Babylon, as partial fulfillment of the requirements for the degree of Master in Engineering/ Environmental Engineering.

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Date:        /        / 2023

## **DEDICATION**

To Imam Mahdi (God fasten his reappearance), who will fill the earth with justice after it has been filled with tyranny and oppression.

To my supervisor, who helped and supported me in all stages of completing this thesis.

To my parents, who encouraged me to be the best I can be. They always provided me with the best opportunities in life.

To my brother and sister, my friends, and my colleagues, who have always been an inspiration and strength for me.

**Mustafa**

**2023**

## الخلاصة:

الأنهار هي المصدر الرئيسي للمياه العذبة في العراق، حيث تستخدم للشرب والري وكافة الاستعمالات الأخرى. ساهمت العديد من العوامل، بما في ذلك النمو السكاني، والتوسع في الأنشطة الاقتصادية، وتغير المناخ، في انخفاض كبير في كل من نوعية وكمية المياه في السنوات الأخيرة. وبالتالي كان من الضروري تقييم جودة مياه الأنهار ومراقبة مستوى تلوثها واتخاذ الاحتياطات اللازمة للحفاظ عليها.

تهدف هذه الدراسة إلى تقييم جودة مياه نهر العباسية (أحد فروع نهر الفرات في وسط العراق) لاستخدامات الشرب والري باستخدام مؤشرات جودة المياه (WQIs) وتكنولوجيا نظم المعلومات الجغرافية (GIS). تم قياس ثمانية عشر متغيراً في موسمي الصيف والخريف لعام 2022 وموسمي الشتاء والربيع لعام 2023 بأخذ عينات من مياه الأنهار من ثمانية مواقع على طول النهر. المتغيرات المقاسة هي درجة الحرارة، ودرجة الحموضة، والموصلية الكهربائية، والمواد الصلبة الذائبة الكلية، والمواد الصلبة العالقة، والعمارة، والاكسجين المذاب، والطلب على الأكسجين الكيميائي الحيوي، والقلوية الكلية، والصلابة الكلية، وايونات البيكربونات، والكالسيوم، والمغنيسيوم، والكلوريد، والنترات، والكبريتات، والصوديوم، والبوتاسيوم.

تم استخدام برنامج Visual Basic لإنشاء ثلاث تطبيقات حاسوبية لحساب طرق WQI المستخدمة في هذه الدراسة. الهدف الرئيسي من هذه التطبيقات هو تسهيل العمليات الحسابية وتوفير نافذة بسيطة لإعطاء نتيجة مباشرة لقيمة WQI لأي عينة مياه وأيضاً باستخدام اي عدد من المعلمات وفي أي وقت.

لتقييم جودة مياه النهر لاستخدامات الشرب، تم استخدام مؤشر جودة المياه الحسابي (WA-WQI) ومؤشر مجلس الوزراء الكندي لجودة المياه (CCME-WQI) باستخدام جميع متغيرات جودة المياه المقاسة مرة وباستخدام جميع المتغيرات باستثناء العمارة مرة أخرى. حيث أظهرت نتائج المتوسط السنوي لـ WA-WQI (مع العمارة) و-CCME WQI (مع وبدون العمارة) أن تصنيف جودة مياه نهر العباسية لاستخدامات الشرب تراوح

بين "ضعيف" و "ضعيف جدا". أظهرت نتائج المتوسط السنوي لـ WA-WQI (بدون العكارة) أن تصنيف نهر العباسية كان "ضعيف" في جميع المواقع على طول النهر. من ناحية أخرى، لتقييم جودة مياه النهر لاستخدامات الري، تم استخدام مؤشر جودة المياه للري (WQIFIR) ومؤشرات أخرى مثل (نسبة امتزاز الصوديوم (SAR)، مؤشر كيلي (KI)، نسبة الصوديوم (SSP)، ومؤشر النفاذية (PI)). أظهرت نتائج WQIFIR أن تصنيف جودة مياه نهر العباسية لاستخدامات الري تراوحت بين "تقييد منخفض (LR)" و"تقييد معتدل (MR)" لجميع المواقع والمواسم. أما وفقاً للمؤشرات الأخرى، فقد كان تصنيف جودة المياه "ممتاز" "جيد" "متوسط" في جميع المواقع والمواسم وفقاً لـ SAR و KI و PI على التوالي، بينما تراوح بين "جيد" و "مقبول" وفقاً لـ SSP.

في هذه الدراسة تم أيضاً إنشاء نماذج الانحدار الخطي لتقدير جودة مياه النهر لاستخدامات الشرب والري بواسطة برنامج SPSS بناءً على نتائج WQIs المحسوبة. أظهرت النماذج التي تم إنشاؤها مقبولة وقيم  $R^2$  عالية. كانت قيم  $R^2$  هي 97%، و 91% و 75% لأفضل النماذج التي تم الحصول عليها لتقدير WA-WQI (مع العكارة)، WA-WQI (بدون العكارة) و WQIFIR، على التوالي.

علاوة على ذلك، تم تنفيذ طريقة الوزن العكسي للمسافة (IDW) في ArcGIS 10.8 لإنشاء خرائط التوزيع المكاني لجودة مياه نهر العباسية لاستخدامات الشرب والري لجميع الفصول بناءً على نتائج WQIs المحسوبة.

وأخيراً وفقاً للنتائج المتحققة في هذه الدراسة، فإنه الاستنتاجات أظهرت ان مياه نهر العباسية كانت ملوثة وغير صالحة للشرب المباشر طوال فترة الدراسة ويجب أن تخضع للمعالجة قبل الاستخدام نتيجة التخلص غير السليم من النفايات، والكميات الكبيرة من الجريان السطحي الزراعي والحضري، ومياه الصرف الصحي، والاستخدام المفرط للأسمدة غير العضوية. أما لاستخدامات الري، كانت مياه النهر مناسبة لري النباتات مع بعض القيود بسبب ارتفاع الملوحة في بعض المواقع بسبب الخصائص الجيولوجية المحلية وأنشطة الري الزراعي.



جمهورية العراق  
وزارة التعليم العالي والبحث العلمي  
جامعة بابل  
كلية الهندسة  
قسم الهندسة البيئية

## تقييم نوعية مياه نهر العباسية لاستخدامات الشرب والري باستخدام مؤشرات جودة المياه وتكنولوجيا نظم المعلومات الجغرافية

رسالة مقدمة الى قسم الهندسة البيئية / كلية الهندسة في جامعة بابل وهي جزء من  
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Praise Allah his Majesty before anything and after anything and to the prophet "Mohammed and Ahl-Al-Bait" for the strength, courage, and wisdom that Allah gave me to complete this humble work.

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## **ABSTRACT**

Rivers are the primary source of fresh water in Iraq. Many factors, including population growth, and climate change, have contributed to a significant decline in both the quality and quantity of water in recent years. Consequently, it is necessary to assess the quality of river water and take the necessary precautions to preserve it.

This study aims to assess the water quality of the Al-Abbasiyah River, one of the branches of the Euphrates River in the center of Iraq, for both drinking and irrigation uses by applying the water quality indices (WQIs) together with GIS technology. Eighteen parameters were measured in the summer and autumn seasons of 2022 and the winter and spring seasons of 2023 by taking samples of river water from eight locations along the river length. The measured parameters are temperature (T), electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), alkalinity, total hardness (TH), hydrogen ions (pH), calcium ( $\text{Ca}^{+2}$ ), sulfate ( $\text{SO}_4^{-2}$ ), chloride ( $\text{Cl}^-$ ), Bicarbonate ( $\text{HCO}_3^-$ ), magnesium ( $\text{Mg}^{+2}$ ), nitrate ( $\text{NO}_3^-$ ), sodium ( $\text{Na}^+$ ), and potassium ( $\text{K}^+$ ).

Visual Basic software was used to create three computer applications to calculate the WQI methods used in this study. The main objective of these applications is to facilitate the calculations and to provide a simple window to give a fast indication of the WQI value for any surface water and also for any selected number of parameters at any time.

To assess the status of the river water quality for drinking usage, the Weighted Arithmetic-Water Quality Index (WA-WQI) and the Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI) were adopted using eighteen collected surface water parameters, and using all parameters except turbidity again. The results of the annual average of WA-WQI (with turbidity) and CCME-WQI (with and without turbidity) showed that

the water quality rating (WQR) of Al-Abbasiyah River for drinking uses ranged between “poor” and “very poor”. The results of the annual average of the WA-WQI (without turbidity) showed that the WQR of the Al-Abbasiyah River was “poor” in all locations along the river.

For irrigation purposes, the WQI for Irrigation (WQIFIR) and other indices such as (Sodium Adsorption Ratio (SAR), Kelly’s Index (KI), Sodium Percentage (SSP), and Permeability Index (PI)) were applied to evaluate the river water quality that uses for irrigation. The results of the WQIFIR showed that the WQR of Al-Abbasiyah River for irrigation uses ranged between “low restriction (LR)” and “moderate restriction (MR)” for all locations and seasons. According to the other irrigation indices, the WQR was “Excellent” “Good” and “Moderate” in all locations and seasons according to SAR, KI, and PI methods, respectively, while it ranged between “Good” and “Permissible” according to SSP method.

Linear regression models were also created in SPSS software to determine the suitability of the RWQ to be employed in drinking and irrigation. The created models showed acceptability with high coefficient of determination ( $R^2$ ) values. The  $R^2$  values were 97%, 91%, and 75% for the best estimating models for WA-WQI (with turbidity), WA-WQI (without turbidity), and WQIFIR, respectively.

Moreover, The Inverse Distance Weighting (IDW) method has been implemented in ArcGIS10.8 to create spatial distribution maps of Al-Abbasiyah River water quality for drinking and irrigation uses for all seasons based on the results of the calculated WQIs.

It was concluded that the water of the Al-Abbasiyah River was polluted and not suitable for direct drinking throughout the study period and must be subject to treatment before use as a result of improper waste disposal, large amounts of agricultural and urban runoff, sewage, and excessive use of inorganic fertilizers. However, for irrigation uses, the river water was suitable

for plant irrigation with some restrictions due to high salinity in some locations due to local geological characteristics and agricultural irrigation activities.

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## List of Abbreviations and Symbols

Abbreviation	Description
<b>WQ</b>	Water Quality
<b>RWQ</b>	River Water Quality
<b>WQI</b>	Water Quality Index
<b>WHO</b>	World Health Organization
<b>ODEQ</b>	Oregon Department of Environmental Quality
<b>GIS</b>	Geographical Information System
<b>ArcGIS</b>	Arc Geographical Information System
<b>IDW</b>	Inverse Distance Weighting
<b>SPSS</b>	Statistical Package for the Social Sciences
<b>PCA</b>	Pearson's Correlation Analysis
<b>r</b>	Correlation Coefficient
<b>R<sup>2</sup></b>	Coefficient of determination
<b>FC</b>	Fecal Coliforms
<b>WQP</b>	Water Quality Parameters
<b>WQR</b>	Water Quality Rating
<b>NSF-WQI</b>	National Sanitation Foundation-Water Quality Index
<b>CCME-WQI</b>	Canadian Council of Ministers of the Environment-Water Quality Index
<b>O-WQI</b>	Oregon Water Quality Index
<b>WA-WQI</b>	Weighted Arithmetic Water Quality Index
<b>WQIFIR</b>	Water Quality Index for Irrigation
<b>SAR</b>	Sodium Adsorption Ratio
<b>KI</b>	Kelly Index
<b>SSP</b>	Sodium Percentage
<b>PI</b>	Permeability Index
<b>Temp.</b>	Temperature
<b>pH</b>	Hydrogen Ions
<b>EC</b>	Electrical Conductivity
<b>TDS</b>	Total Dissolved Solids
<b>TSS</b>	Total Suspended Solid
<b>Turb.</b>	Turbidity
<b>DO</b>	Dissolved Oxygen
<b>BOD</b>	Biochemical Oxygen Demand
<b>HCO<sub>3</sub></b>	Bicarbonate Ions
<b>Alk.</b>	Total Alkalinity
<b>TH</b>	Total Hardness
<b>Ca</b>	Calcium Ions
<b>Mg</b>	Magnesium Ions
<b>Cl<sup>-</sup></b>	Chloride Ions

<b>NO<sub>3</sub></b>	Nitrate Ions
<b>SO<sub>4</sub></b>	Sulfate Ions
<b>Na</b>	Sodium Ions
<b>K</b>	Potassium Ions
<b>E-WQ</b>	Excellent Water Quality
<b>G-WQ</b>	Good Water Quality
<b>P-WQ</b>	Poor Water Quality
<b>VP-WQ</b>	Very Poor Water Quality
<b>UUH-WQ</b>	Unsuitable Uses for Human Water Quality
<b>NR</b>	No Restriction
<b>LR</b>	Low Restriction
<b>MR</b>	Moderate Restriction
<b>HR</b>	High Restriction
<b>SR</b>	Severe Restriction
<b>C<sub>i</sub></b>	Measured Value of Each Parameter
<b>q<sub>i</sub></b>	Sub-Index for Each Parameter
<b>w<sub>i</sub></b>	Weight of Each Parameter
<b>S<sub>i</sub></b>	Allowable Standard Limits
<b>°C</b>	Degrees Celsius
<b>mg/L</b>	Milligram per Liter
<b>meq</b>	Milli-equivalent
<b>µS/cm</b>	Micro Siemens per centimeter
<b>NTU</b>	Nephelometric Turbidity Unit
<b>LRMs</b>	Linear Regression Models
<b>SDM</b>	Spatial Distribution Maps
<b>MSE</b>	Mean Square Error
<b>RMSE</b>	Root Mean Square Error

## 1.1 General

Water is one of the many abundant natural resources used by all living things, including humans, animals, plants, and other organisms. The water demand is rising as a result of the growing population, expanding economic activity, and urban expansion. The decrease in water levels and the degradation of their quality, the overuse of surface water, which considers the most important of water resources, is threatening human life and its surrounding environment (Massoud, 2012). In many nations, the declining quality of surface water is becoming a severe problem (Witek & Jarosiewicz, 2009) and one of the main goals of water resource conservation policy is monitoring water quality (Simeonov, 2002). As a result, developing countries have recently increased their efforts to focus on evaluating the water quality of rivers (Kannel et al., 2007).

Surface water quality assessment is a comprehensive process that involves using several variables that can have significant impacts on the overall quality of the water. Evaluating water quality (WQ) by testing many parameters, each separately and for several samples, is a complex process, and it is not possible to get a final decision on the water quality based on it (Almeida et al., 2007). Therefore, Various methods have been considered to analyze water quality such as statistical assessments of individual parameters and water quality indices (Venkatesharaju et al., 2010).

The water quality index (WQI) is a mathematical expression that converts the result values of several variables entered into a single value to indicate the water quality (Bordalo et al., 2006). Several indicators of water quality have been developed around the world to enable researchers and those interested in the field of water sources to make an easy and clear judgment about the overall water quality in each study area quickly and effectively (Stambuk, 1999).

Recently, technological advancements have led to the development of new techniques and methodologies to contribute to evaluating water quality. These techniques and methodologies have included Geographical Information Systems (GIS), which are used to monitor water quality to shorten the time of the calculating process, cost, monitoring, and improve the accuracy of results (Pavelsky and Smith, 2009).

The GIS has a highly important role to play in all spatial and geographic characteristics to manage different water resources and create maps interested in this field. This technique includes powerful analytical and visualization tools that can be used to describe, examine, and simulate the processes and functions of natural systems (Chabuk et al., 2020).

In Iraq, particularly in the previous three decades, Iraq's water resources have seen a significant change in terms of shortage of water quantity and degradation of water quality due to a variety of factors, including large numbers of dams on the rivers of Tigris and Euphrates in Turkey and Syria, severe local decreases in annual rates of precipitation, and incorrect management and unsound planning of water use (Rahi and Halihan, 2010).

Iraqi researchers are paying a great deal of attention to the rivers because of the harm caused by pollutants released from treated and untreated wastewater of domestic and industrial along rivers, as well as pollutants from agricultural land extending along the river and on both sides of riverbanks.

In this study, the water quality of the Al-Abbasiyah River, which is one of the branches of the Euphrates River, which branches in the south of Babylon Governorate and passes most of its length through Najaf and Qadisiyah governorates, will be assessed for drinking and irrigation uses by applying water quality indices and GIS software.

## 1.2 Study Significance and Problem Statement

Al-Abbasiyah River feeds large agricultural areas within the Governorates of Najaf and Qadisiyah, and it is the main source to supply water for drinking uses for many cities, towns, and villages that lie on both sides of the river. In addition, this river is considered the main source of feeding many small streams that branch from it to irrigate huge agricultural areas which are located on both sides of the main river and its branches.

As a result of these many uses of the river and the large number of cities through which it passes, it has been exposed to many points and non-point sources of pollution, and pollution levels in some places can reach high levels. Therefore, evaluating the WQIs for drinking and irrigation uses in the Al-Abbasiyah River using the WQI methods and creating spatial distribution maps along the river using GIS software is very necessary to show the levels of pollution in any part of the river and knowing the suitability of the river water for different uses, and to compensate for the shortage of studies related to the water quality in this river.

## 1.3 Study Aims

The major aims of the current study are as follows:

1. Evaluating water quality of Al-Abbasiyah River for drinking uses using water quality index for one year and four seasons.
2. Use the water quality index for Irrigation uses to evaluate water quality for this purpose in the Al-Abbasiyah River by measuring parameters for one year and four seasons.
3. Creating spatial distribution maps in the GIS software for drinking and irrigation water quality along the Al-Abbasiyah River.
4. Creating linear regression models to estimate the values of the WQIs for drinking and irrigation uses using the SPSS software.

## 1.4 Study Structure

The thesis is divided into five chapters as follows:

### **Chapter One: Introduction**

An introduction to the thesis, study problem, the study aims, and study structure.

### **Chapter Two: Theoretical Concepts & Literature Review**

The theoretical concept and literature review include a definition of the most famous methods used to assess the WQ for drinking and irrigation uses, the equations of each method, and an overview of its origins. Moreover, this chapter includes a general definition of GIS technology and its methods for creating spatial distribution maps. In addition, a general review of previous studies and research related to the topic of the thesis.

### **Chapter Three: Experimental Work and Methodology**

This chapter describes the study area and experimental work which includes all the performed field works (determination of sampling locations, and sampling), tools, apparatus, and equipment used to perform the field, and laboratory tests and explains the analysis. Moreover, it includes the implementation of WQ assessment methods for drinking and irrigation uses.

### **Chapter Four: Results & Discussions**

This chapter includes the presentation of Figures and Tables of the results of the WQ assessment for drinking and irrigation uses for different seasons of the year. Furthermore, producing spatial distribution maps in the GIS of the WQ for the Al-Abbasiyah River. It also includes a discussion of the results and the reasons for the variation in river water quality from one location to another, and from one season to another.

### **Chapter Five: Conclusions & Recommendations**

Include conclusions of all findings from this study and recommendations for future works.

## 2.1 Introduction

Pure water is colorless, tasteless, and odorless. Water is able to dissolve most of the substances it comes in contact with, so there is no completely pure water in nature. Hence, water always contains various impurities and chemicals (Qasim et al., 2000).

Increasing the concentration of these chemicals and biological impurities in the water of a particular water body above the acceptable limits leads to a deterioration of the water quality (WQ) in that water body, and consequently increase the potential risks to humans, animals, plants, and the environment generally.

Monitoring the water quality of water bodies as well as knowing the spatial distribution of various biological, chemical, and physical variables is essential in water environmental studies as well as water resources management (Meer and Jong, 2006). Therefore, this chapter presents the basic theories related to WQ and the techniques used in mapping the spatial distribution of rivers' water quality that were adopted in the current thesis as shown in the following sections.

## 2.2 Water Quality Constituents

Inorganic and organic substances may be present in a dissolved and suspended form in natural water bodies. These substances could be derived from natural sources or through the leaching of waste deposits. A variety of organic and inorganic contaminants are also caused by municipal and industrial wastes. The weathering and leaching of rocks, soils, and sediments produce inorganic compounds. The main inorganic components are the bicarbonate, chloride, sulfate, nitrate, and phosphate salts of calcium, magnesium, sodium, and potassium. The decomposing plant and animal manure, as well as agricultural runoffs, are where the organic compounds come from. The organic compounds range from natural humid materials to synthetic organics used as detergents,

pesticides, herbicides, and solvents. These constituents and their concentrations influence the quality and use of natural water resources (Qasim et al., 2000).

### 2.3 Water Quality Indices

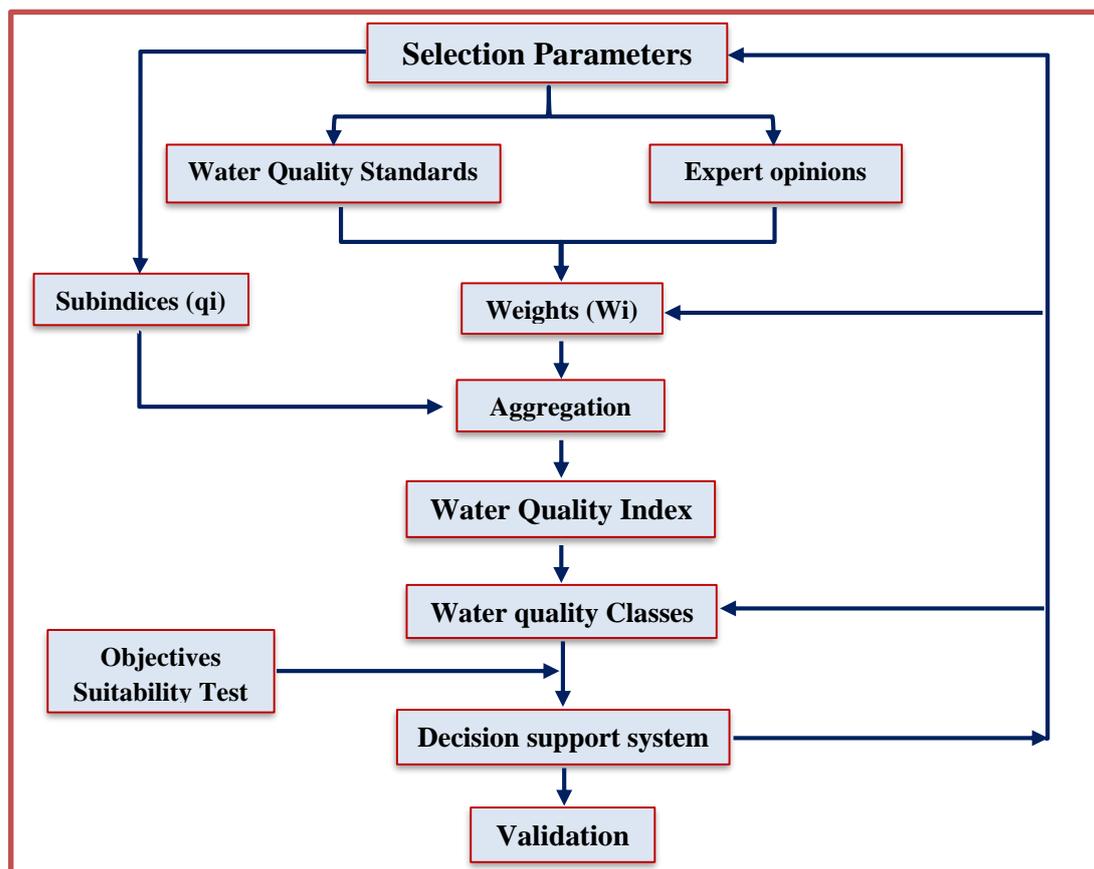
For agricultural and industrial activities, as well as human daily demands, WQ is just as crucial as water quantity. Both human activity and natural processes have an impact on water quality (WQ). Each year, between 300 and 400 million tons of toxic materials are dumped into the water bodies. In developing nations, 80% of sewage is discharged directly into water bodies without treating them (WHO-UN, 2010). Numerous local and international organizations had established guidelines and criteria for concentrations level of parameters in water bodies to ensure acceptable WQ. As a result, the World Health Organization (WHO) has established WQ guidelines for biological, chemical, and physical variables that are regularly modified to follow the changes in concentration of parameters due to many external and internal factors (WHO, 2017). Most countries have created local standard limits for parameters in water bodies to meet their needs (US EPA, 2017).

It is difficult to give a clear assessment of water quality based on a large number of variables measured for each sample, as some of these variables exceed the standard limits and some are within the limits (Li et al., 2014). Considering this, the water quality index (WQI), which is used to simplify the complicated set of rivers WQ variables in one value, is regarded as a crucial component of sound water resource management (Sun et al., 2016). WQI is often a dimensionless number that aggregates together various parameters for any water body to evaluate its water quality. The WQI methods significantly reduce the amount of data and streamline and describe the state of the quality of water in a single number (Kachroud et al., 2019).

The WQI methods' goal is to categories water bodies according to their chemical, physical, and biological features, identify potential uses of them, and manage soundly (Boyacioglu, 2007). WQI methods can be considered as models

to evaluate WQ, where reliable standards are adopted and given suitable weighting for each parameter and aggregate the factors are established (**Figure 2.1**). Four standard steps are employed in all WQI methods to implement their calculating process (Abbasi and Abbasi, 2012):

- i. Choice of wanted variables.
- ii. Transformation of these variables, which initially have different dimensions, according to a common scale.
- iii. Creating subindices by giving each transformed variable a weighting factor.
- iv. The process of calculating a final index score by aggregating subindices. The following part includes the history of WQ indicators and an overview of the most important indicators used in evaluating WQ around the world.



**Figure (2.1):** Basic steps to develop a WQ index (Kachroud et al., 2019).

### 2.3.1 A Brief History of WQI Methods

Water quality indicators have historically been used for WQ assessment by a variety of organizations and researchers from various nationalities. In the past ten years of the 20<sup>th</sup> century, this matter has become more obvious. The water quality index (WQI) was initially created by Horton (Horton, 1965) in the United States by choosing the ten parameters often used to assess WQ such as Cl, DO, conductivity, pH, coliforms, alkalinity, etc. Therefore, WQI has since gained widespread acceptance in European, Asian, and African nations. The allocated weight for a parameter had a significant impact on the index value and showed the importance of a parameter for specific usage.

Later, Brown et al. (1970) developed a new WQI and selected nine parameters (DO, pH, BOD, FC, total nitrate and phosphate, temperature, turbidity, and TDS). They were based on the 142 water experts to assess the WQ. It was done by adopting five categories for water quality rating: blue for excellent, green for good, yellow for average, orange for poor, and red for very poor. They also calculated each variable's weighting. Brown et al.'s index had an arithmetic form, but they thought later that a geometric aggregation was preferable to an arithmetic aggregation since it was more sensitive to outliers in a single variable (Brown et al., 1973). Their index was given the moniker 'NSFWQI' because the National Sanitation Foundation financed these initiatives.

Then, during the last thirty years of the twentieth century, many indices of WQ appeared in various countries of the world. In Europe, another index based on standards for WQ was proposed by (Prati et al., 1971). Nemerow & Sumitomo (1970) presented three specific-use WQ indices that, when combined, produce a general WQI. Bhargava (1983) presented a new WQI in India where the combination of variables showed the pollution load was more specific. He described the WQI formula according to water use and afterward determined the variables that would be used. Another WQI was presented by (Tiwari & Mishra, 1985) based on the same concepts as those of (Horton, 1965 and Brown et al.,

1970), but they changed the weighting approach by adding the normative values of the key water parameters. To maintain harmonicity in the magnitude of the sub-indices, logarithm, and antilogarithm have been applied in their aggregation.

New indices began to emerge in the twenty-first century, significantly streamlining the formulas already in use and defining the index's field of application. For instance, depending on the measurement and classification of each variable, the overall Index of pollution was evaluated by several WQ variables (Sargaonkar et al., 2003).

In recent years, many researchers have continued to find and develop new indices of water quality. The number of WQ criteria employed and the method by which they are implemented vary widely across the indices.

### **2.3.2 The Significance of Utilizing WQI Methods**

To interpret water results meaningfully, WQI methods are used to assess the WQ by monitoring data in the first place, especially when the pollutant concentrations are below the WQ standards. In general, WQI can completely ignore the importance of the sampling frequency used to assess WQ (Brown et al., 1973), but should measure the samples seasonally. WQI methods give administrative decision-makers the ability to assess the effectiveness of regulatory programs and present WQ information to the audience in a straightforward and accessible way. Additionally, they help experts incorporate monitoring data into a wider framework (Sutadian et al., 2016). Practically all monitoring program goals, such as environmental planning, water quality monitoring, assessment, and treatment, are accomplished using the WQIs (Li et al., 2014).

### 2.3.3 Categories of WQI

In general, there are four basic categories for water quality indices (Vinod et al., 2013) are as follows:

**First, public indices:** These indices employ general WQ measurements rather than considering the type of water usage, such as the **National Sanitation Foundation Water Quality Index (NSF-WQI)** (Ott, 1978).

**Second, particular consumption indices:** In this case, water is categorized according to the type of utilization and application (industrial, drinking, ecosystem preservation, etc.). **The indices of British Columbia and Oregon** are the most significant and applicable of these indicators (DEQ, 2003).

**The third category is indices of designing or planning:** Where these indices are an instrument that supports planning and decision-making in WQ management initiatives.

**Fourth, statistical indices:** Where statistical techniques are applied, rather than individual viewpoints. Here, the data are assessed using statistical methods. Another crucial component of the statistical method is the statistical validation of certain assumptions about observations data of WQ.

The first three indices are subjected to the methodology of the experts' opinions (Harkins, 1974). The various ratings provided by the experts still have a chance of lowering objectivity and comparability. As a result, many alternative indices are created. However, applying statistical methods can help to reduce the subjectivity assumptions adopted when constructing the indices. The statistical methods can also be used to pinpoint crucial elements that determine a water body's quality and the degree to which they matter (Terrado et al., 2010).

### 2.3.4 Selection of Water Quality Systems

The most important part of every WQI method is its WQ parameters. As stated by (Sutadian et al., 2016), the parameter selection procedure can be

applied to three different systems; therefore, the definitions of these systems are as follows:

- i. Fixed system:** The selecting WQI parameters in this system are considered the most appropriate and essential set required for computing the final degree of the index. In this system, it is not allowed to add new parameters even if essential, but it is restricted to fixed parameters only. This restriction causes a prevalent problem for most employers.
- ii. Open system:** This system gives the free choice for users to select their parameters. An open system has great flexibility compared with a fixed system. When it comes to comparing the findings of WQI that resulted from various sites, there are limitations. It is unacceptable to apply the comparison in this system when a user uses different parameters.
- iii. Mixed system:** This system integrates a fixed system and an open system. In the Mixed system, the final index value is computed based on fixed parameters desired, in addition to optional extra parameters that the user can input.

## 2.4 Some of the Most Used WQI Methods for Drinking Use

Over the years, several different organizations (local or international) sought to develop many indices of water quality, which have been used to evaluate the WQ in various particular circumstances. For any water body on a worldwide level, no one index can describe its total WQ. Nevertheless, the development of WQI is necessary to measure variations in WQ over time and location as well as to assess the set goals of international agreements aimed at conserving water resources (Paun et al., 2016). Some common indices will be described among a large number of WQI methods as follows:

### 2.4.1 National Sanitation Foundation Water Quality Index (NSF-WQI)

Brown et al. (1970) set up the WQI that was supported by the National Sanitation Foundation to be defined as "NSF-WQI". The NSF-WQI has the highest degree of acceptance for use in assessing water quality in the United States, despite the level of criticism of this method due to a lack of sufficient assessment of all regions in the U.S.A.

This method was built based on the Dalkey technique by choosing parameters carefully. They created a standard scale after that, giving suitable weights for them. Nine parameters have been adopted for assessing the WQ, including temperature, pH, turbidity, fecal coliform, DO, BOD, PO<sub>4</sub>, NO<sub>3</sub>, and TDS (Tyagi et al., 2013).

To calculate a statistical score  $Q_j$  from the received WQI, a graph of the weighting curve is employed. The weight of each parameter calculated by the NSF-WQI can be shown in **Table (2.1)**.

**Table (2.1):** Parameters and their Weights for parameters entered in the NSF-WQI method (Kachroud et al., 2019).

Parameter	Weight	Parameter	Weight
DO	0.17	PO <sub>4</sub>	0.10
Fecal Coliforms	0.16	Temperature	0.10
pH	0.11	Turbidity	0.08
BOD	0.11	TDS	0.07
NO <sub>3</sub>	0.10	<b>Total</b>	<b>1.00</b>

The main formula of NSF-WQI is calculated as follows (Brown et al., 1970):

$$\text{NSF\_WQI} = \sum_j^n Q_j W_j \quad (2.1)$$

Where: **n**: parameters number; **Q<sub>j</sub>**: category of quality for the  $j^{\text{th}}$  parameter; **W<sub>j</sub>**: relative weight for the  $j^{\text{th}}$  parameter ( $\sum W_j = 1$ ). The rating of water quality according to NSF-WQI is given in **Table (2.2)**.

**Table (2.2):** The rating of water quality according to NSF-WQI (Paun et al., 2016).

NSF-WQI Value	WQR
91 - 100	Excellent
71 - 90	Good
51 - 70	Medium
26 - 50	Bad
0 - 25	Very bad

The advantage of this method is that it summarizes the data in the value of one index in an objective, rapid, and repeatable manner. Furthermore, easy to use by ordinary people and is not restricted to experts.

For its disadvantages, it gives a general quality of water without giving importance to the potential water use. It is also considered a fixed system and other parameters cannot be added to it as needed (Paun, et al., 2016).

#### 2.4.2 Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI)

The Canadian Council of Ministers introduced a comprehensive assessment of the appropriateness of river systems to maintain life in water bodies at specific control locations in Canada. The CCME-WQI used relevant WQ standards as reference points to connect the water quality data with different beneficial uses of water. Each index is determined for each monitoring location during a selected predefined period.

Many water quality parameters are examined by water samples measured during a selected time. Each parameter measured values are compared to the relevant water quality standard. Three factors employed in the computation of the index include the proportion of parameters and tests that do not comply with the guidelines, as well as the deviation from the standards for tests that do not comply with the standards. These three factors are called scope ( $F_1$ ), frequency ( $F_2$ ), and amplitude ( $F_3$ ) (CCME, 2005).

$$F_1 = \frac{\text{No. of failed parameters}}{\text{Total No. of parameters}} \times 100 \quad (2.2)$$

Scope (F1): the ratio of failed parameters to all parameters that are not compatible with the standards of water quality at any site during a selected time.

$$F2 = \frac{\text{No. of failed tests}}{\text{Total No. of tests}} \times 100 \quad (2.3)$$

Frequency (F2): the proportion of individual tests that don't satisfy the standards of water quality.

The test is considered failed when any parameter value of the sample is higher than the standard limit. The total tests' number that failed during the selected time includes all parameter values in each sample that failed. The total number of tests for a particular site is done by multiplying the total samples' number measured during the selected time by the number of the mean parameters for each sample (Paun et al., 2016).

Amplitude (F3): The average deviation of failed test values from their standards is represented by the amplitude factor.

$$F3 = \frac{nse}{0.01 nse + 0.01} \quad (2.4)$$

An excursion is the relative value of deviation for a failed test from the standard value, and it is computed as follows:

When the test value should be within the allowable limit of standards:

$$\text{excursion}_i = \left( \frac{\text{failed test value}_i}{\text{standard value}_i} \right) - 1 \quad (2.5)$$

When the test value should not be lower than the standards:

$$\text{excursion}_i = \left( \frac{\text{standard value}_i}{\text{failed test value}_i} \right) - 1 \quad (2.6)$$

The following formula is used to compute the overall value for specific tests that are out of conformance:

$$nse = \frac{\sum \text{excursion}_i}{\text{total number of tests}} \quad (2.7)$$

where: nse represents the entire sum of all normalized excursions from the standards. Equation (2.8) is used to determine the CCME-WQI as follows:

$$CCME\_WQI = 100 - \left( \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (2.8)$$

where (1.732) is represented as the factor that is used to convert the resulting values of the CCMEWQI method into a scale of 0 - 100.

The preceding formula generates a CCME-WQI value between (0 and 100) and gives the water quality a digital value. A value near 100 indicates excellent water quality, whereas zero indicates water quality is very poor. It requires professional judgment and expectations of public water quality. **Table (2.3)** shows the water quality rating (WQR) according to CCME-WQI.

**Table (2.3):** WQR according to CCME-WQI (Paun et al., 2016).

CCME-WQI Value	WQR
95 - 100	Excellent
80 - 94	Good
60 - 79	Fair
45 - 59	Marginal
0 - 44	Poor

The advantages of this method are the flexibility in choosing the desired parameters and the ability to adapt to the standard specifications of the area in which it is used, as well as the desired water use. Complicated datasets are analytically simplified. It gives a diagnosis, and correctness, in addition to understanding stakeholders and the community in general, and is considered an appropriate technique to evaluate the WQ, as it is easy to calculate.

One of the drawbacks of this method is the lack of instructions about the variables to be used. Give equal importance to all parameters. F1 does not work properly when too few variables are considered or when there is too much variation between them (Paun et al., 2016).

### 2.4.3 Oregon Water Quality Index (O-WQI)

Another WQI widely used in the public field is the O-WQI. This method was established by the Oregon Department of Environmental Quality (ODEQ) in the last years of the 1970s, and it has since undergone numerous updates (Cude, 2001). Nevertheless, due to the significant resources needed to calculate and publish the results. Due to improvements in computer systems, new

techniques for collecting data and analysis, as well as a better knowledge of the QW, the O-WQI method was modified in 1995. The original subindices were modified, temperature and total phosphorus subindices were added, and the aggregation calculation was improved (Paun et al., 2016).

The O-WQI evaluates and expresses 8 different WQ elements. The parameters covered in this method are temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, ammonia and nitrate nitrogen, total phosphorus, total solids, and fecal coliform (Dinius, 1987).

It offered Oregon's streams' ambient water quality for broad recreational use. Thus, it should be used with caution when applying to other geographic areas or water bodies. Since the O-WQI was introduced in the 1970s, the science of water quality has significantly advanced (Dunn, 1995). The original O-WQI was modeled after the NSF-WQI, which chose variables using the Delphi approach (Dalkey, 1969). The recreational water quality index was developed using the Delphi technique. This approach can be characterized as a means of assembling information from a variety of experts so that consensus can be achieved regarding the most up-to-date information on how to manage a challenging circumstance (Rowe & Wright, 1999). The findings of the water quality variables were transformed into subindex values using logarithmic operations by both indices. The advantage of logarithmic transforms is that a change in magnitude at lower levels of impairment has a larger effect than a change in magnitude at higher levels of impairment. The following formula is provided by (Poonam et al., 2013):

$$O\_WQI = \sqrt{\frac{m}{\sum_{j=1}^m \frac{1}{STI_j^2}}} \quad (2.9)$$

Where: m: the subindices number; STI: the subindex of each parameter. **Table (2.4)** presents the WQR using the O-WQI values.

**Table (2.4):** WQR according to O-WQI (Paun et al., 2016).

O-WQI Value	WQR
90 - 100	Excellent
85 - 89	Good
80 - 84	Fair
60 - 79	Poor
0 - 59	Very poor

One advantage of this method is that the aggregation method used to integrate the sub-indices gives the most affected parameters, the highest impact on the final WQI. The equation is also sensitive to the changing conditions and significant effects on water quality.

The disadvantage of this method is that it does not take into account changes in the concentrations of toxins or habitats. Without taking into account all pertinent physical, chemical, and biological data, it is impossible to establish the quality of water for a particular purpose or to employ it to deliver conclusive data about the WQ (Paun et al., 2016).

#### 2.4.4 The Weighted Arithmetic Water Quality Index (WA-WQI)

The WA-WQI method is superior to other methods to compute the WQI since it involves a single fundamental mathematical equation for many quality parameters and can assess the quality of both surface water and groundwater (Călmuc et al., 2018). Numerous Physicochemical variables are employed for both the analysis of information for each station and their potential value to human use.

In this method, different water quality parameters are multiplied by a weighting factor. Then, they are aggregated using the simple arithmetic mean. The weight ( $W_i$ ) for various parameters is inversely proportional to the recommended standard ( $S_i$ ) for the corresponding parameter.  $W_i$  values are calculated from the following formula (Tyagi et al., 2013):

$$W_i = \frac{1}{S_i} \quad (2.10)$$

Where  $S_i$  is the allowable standard value of the  $i^{\text{th}}$  parameters. Then, Equation (2.11) is used to calculate the relative value of quality ranging ( $q_i$ ) for each parameter in water bodies and compare it with upper standard limits as follows:

$$q_i = \frac{X_i - X_o}{S_i - X_o} \times 100 \tag{2.11}$$

Where  $q_i$  is the relative value of quality ranging for each parameter in water.  $X_i$ : the measured value for each parameter.  $X_o$ : the measured value for each parameter in pure water.  $S_i$ : the allowable standard value for each parameter.

For all parameters, the ideal value ( $X_o$ ) = 0, while for pH and DO parameters the ( $X_o$ ) is equal to 7 and 14.6 respectively. The main formula to calculate WA-WQI is as follows (Tyagi et al., 2013):

$$WA\_WQI = \frac{\sum_{i=1}^n W_i \times q_i}{\sum_{i=1}^n W_i} \tag{2.12}$$

**Table (2.5)** shows the WQR according to WA-WQI.

**Table (2.5):** WQR according to WA-WQI (Brown et al., 1970).

WA-WQI Value	WQR
0 - 25	Excellent
26 - 50	Good
51 - 75	poor
76 - 100	Very poor
> 100	Unsuitable uses for human

The advantages of this method are that it allows the use of a smaller number of water quality parameters based on the user's desire. Give different weights to each variable depending on its importance. It describes the suitability of surface and groundwater for human use and is useful for giving comprehensive information on WQ to the worried public.

One of the disadvantages of this method is the excessive or eclipse in emphasizing the value of one parameter that is not valid. An index can't accommodate all applications for data of WQ (Paun et al., 2016).

## 2.5 Some of the Most Used WQI Methods for Irrigation Use

### 2.5.1 The Irrigation Water Quality Index (WQIFIR)

Meireles et al. (2010) introduced the mathematical method to calculate the water quality index for irrigation uses (WQIFIR). This method can be estimated by using equation (2.13) as follows:

$$WQIFIR = \sum_i^m Wq_i \times W_i \tag{2.13}$$

Where: **WQIFIR**: proportion values for the selected parameters with a range of (0 -100); **Wq<sub>i</sub>**: stands for each parameter's quality, which ranges from 0 to 100; and **W<sub>i</sub>**: stands for each parameter's normalized weight.

EC, Na<sup>+</sup>, Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, and SAR are the most important variables that influence the water quality for agricultural use. The values of Wqi are determined for each parameter by the following equation (Meireles et al., 2010):

$$Wq_i = q_{imax} - \left( \frac{(X_{ij} - X_{inf}) \times q_{iamp}}{X_{amp}} \right) \tag{2.14}$$

Where **q<sub>imax</sub>** is the maximum class value of **q<sub>i</sub>**, **X<sub>ij</sub>** is the parameter's observed value, **X<sub>inf</sub>** is the value that corresponds to the class lower limit to which the parameter belongs, **q<sub>iamp</sub>** is the class amplitude, and **X<sub>amp</sub>** is the class amplitude to which the parameter belongs. **Table (2.6)** shows the limited values for each parameter.

**Table (2.6):** The limited values of computing water quality (Wqi) for each parameter (Meireles et al., 2010).

HCO <sub>3</sub> (meq/L)	Cl (meq/L)	Na (meq/L)	SAR (mmol/L) <sup>1/2</sup>	EC(µscm <sup>-1</sup> )	Wqi
(1.0 – 1.5)	(1.0 – 4.0)	(2.0 – 3.0)	(2.0 – 3.0)	(200 – 750)	<b>85 – 100</b>
(1.5 – 4.5)	(4.0 – 7.0)	(3.0 – 6.0)	(3.0 – 6.0)	(750 – 1500)	<b>60 – 85</b>
(4.5 – 8.5)	(7.0 – 10.0)	(6.0 – 9.0)	(6.0 – 12.0)	(1500 – 3000)	<b>35 – 60</b>
1 > HCO <sub>3</sub> = 8.5	1 > Cl = 10	2 > Na = 9	2 > SAR = 12	200 > EC = 3000	<b>0 – 35</b>

The relative weights for each parameter were assigned and their importance for irrigation water quality by the determinants of the Committee of Consultants at the University of California (**Table 2.7**) (Abdullah et al., 2016).

**Table (2.7):** Weights of parameters used in the irrigation using (WQIFIR) method (Meireles et al., 2010).

Parameters	Wi
EC (Electrical conductivity)	0.211
Na (Sodium)	0.204
HCO <sub>3</sub> (Bicarbonate)	0.202
Cl (Chloride)	0.194
SAR (Sodium Adsorption Ratio)	0.189

The advantage of this method is a confident way that contributes to decreasing the time and effort. Less number of parameters is required in comparison to all water quality parameters for a particular use. The index value relates to irrigation water use only, which makes it more accurate for this purpose. The lack of integrating this approach with more indicators or information of biological is one of its drawbacks. It is not allowed to add other parameters to the indicator even if they are important (Paun et al., 2016). **Table (2.8)** illustrates water use restrictions and recommendations for utilizing water for soil and plants depending on the readings of the WQIFIR.

**Table (2.8):** Restrictions and recommendations of WQIFIR for plants and soil (Meireles et al., 2010).

<b>IWQFIR</b>	<b>Restrictions</b>	<b>SOIL</b>	<b>PLANT</b>
<b>(85 – 100)</b>	<b>No Restriction (NR)</b>	It is indicated to be leached during irrigation processes and can be used on most soils with a low risk of causing salinity and sodicity issues unless the soil exhibits exceptionally poor permeability.	For the majority of plants, there is no toxicity concern.
<b>(70 – 85)</b>	<b>Low Restriction (LR)</b>	Salt leaching is advised for usage in irrigated soils with a light texture or moderate permeability. It is advised to avoid using heavy-textured soils in soils with a high clay content due to the possibility of soil sodicity.	Avoid plants that are susceptible to salt
<b>(55 – 70)</b>	<b>Moderate Restriction (MR)</b>	Suitable for usage in soils with values ranging from moderate to high permeability, with a suggested moderate salt leaching.	Plants that can tolerate salts just somewhat can be grown.
<b>(40 – 55)</b>	<b>High Restriction (HR)</b>	It is applied to soils that have high penetration and loose underlying layers. A high-frequency irrigation program needs to be put in place for water with $EC > 2000 \text{ dS m}^{-1}$ and $SAR > 7.0$ .	Except for waters that have low levels of Sodium, Chloride, and Bicarbonates, which shouldn't be used to water plants with specific salinity management strategies and moderate to high salt tolerance.
<b>(0 – 40)</b>	<b>Severe Restriction (SR)</b>	Should refrain from using it for irrigation when things are normal. occasionally used in exceptional circumstances. For water with a high SAR and little salt content, gypsum application is required. In water that has a high content of salt, soils must be very permeable, and additional water needs should be met to prevent salt buildup.	Except for waters with exceptionally low Na, Cl, and $\text{HCO}_3$ levels, just plants that have high salt tolerance.

**2.5.2 Other Irrigation Water Quality Indices**

In addition to the previous WQI methods, some other indices classify the acceptable water for use in irrigation depending on some main components (such as Na, Ca, Mg, etc.) in the water. The popular indices for water use in irrigation will be mentioned as follows:

### 2.5.2.1 Sodium Adsorption Ratio (SAR)

The SAR refers to sodium content (alkali risk), which has a significant indication in figuring out whether irrigation water is suitable for usage (Srinivasamoorthy et al., 2014). The qualities of the soil are negatively impacted by too much sodium in the water, which also reduces soil permeability (Sundaray et al., 2009). Higher salinity prevents water from reaching plant leaves because it interferes with osmotic processes, which reduces water and nutrient absorption from the soil (Arumugam and Elangovan 2009). SAR measures sodium hazard and it can be estimated using equation 2.15 (Wilcox, 1955; Shil et al., 2019):

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Mg}^{2+} + \text{Ca}^{2+}}{2}}} \quad (2.15)$$

Ionic concentrations are measured in meq/L. **Table (2.9)** shows the categories of using water in irrigation according to the SAR readings.

**Table (2.9):** Irrigation water classes according to the SAR (Shil et al., 2019).

SAR value	Suitability of water for Irrigation	Sodium hazard class
SAR less than 10	Excellent	I
10 < SAR < 18	Good	II
18 < SAR < 26	Fair poor	III
SAR more than 26	Unsuitable	IV

### 2.5.2.2 Kelly's Index (KI).

Kelly's index is also used to verify the WQ is appropriate for use in irrigation. Index of Kelly refers to the water that contains too much sodium. Equation 2.16 is used to determine the KI value (Kelly 1940; Shil et al., 2019):

$$\text{KI} = \frac{\text{Na}^+}{\text{Mg}^{2+} + \text{Ca}^{2+}} \quad (2.16)$$

Where: Na, Mg, and Ca are computed in meq/L. **Table (2.10)** shows the categories of using water in irrigation according to the KI values.

**Table (2.10):** Irrigation water classes according to the KI values (Kelly 1940; Shil et al., 2019).

KI value	Suitability of water for Irrigation	KI value refers to
KI < 1	Good	Acceptable for irrigation
KI > 1	Not good	Excess sodium in water

**2.5.2.3 Sodium Percentage (Na%) or (SSP)**

Because irrigation water with a higher sodium level has less permeability, the soluble sodium content is another index used to classify irrigation water (Todd 1980). Na percentage (Na%) is frequently used to assess water appropriateness for agricultural usage. This expression is also known as the soluble sodium percentage (SSP). It is calculated by the following equation (Wilcox 1955; Ewaid et al., 2019):

$$\text{Na\% or SSP} = \frac{(\text{Na}^+ + \text{K}^+) * 100}{\text{Mg}^{2+} + \text{Ca}^{2+} + \text{Na}^+ + \text{K}^+} \tag{2.17}$$

Each parameter is converted to unit of (meq/L). **Table (2.11)** shows the categories of using water in irrigation according to the SSP values.

**Table (2.11):** Irrigation water classes according to the SSP values (Belkhiri et al., 2010).

SSP value	Suitability of water for Irrigation
SSP < 20	Excellent
20 < SSP < 40	Good
40 < SSP < 60	Permissible
60 < SSP < 80	Doubtful
SSP > 80	Unsuitable

**2.5.2.4 Permeability Index (PI)**

The PI is another approach for determining whether irrigation water is suitable. Exposed irrigation water with significant ion concentrations affects the topsoil permeability (Ca, Mn, and CO<sub>3</sub>) (Ravikumar et al. 2011). Equation (2.18) shows the formula for calculating PI according to Doneen (1964) and Ewaid et al. (2019):

$$\text{PI} = \frac{(\text{Na}^+ + \sqrt{\text{HCO}_3^-}) * 100}{\text{Mg}^{2+} + \text{Ca}^{2+} + \text{Na}^+} \tag{2.18}$$

Each parameter is converted to unit of (meq/L). **Table (2.12)** shows the categories of using water in irrigation according to the PI values.

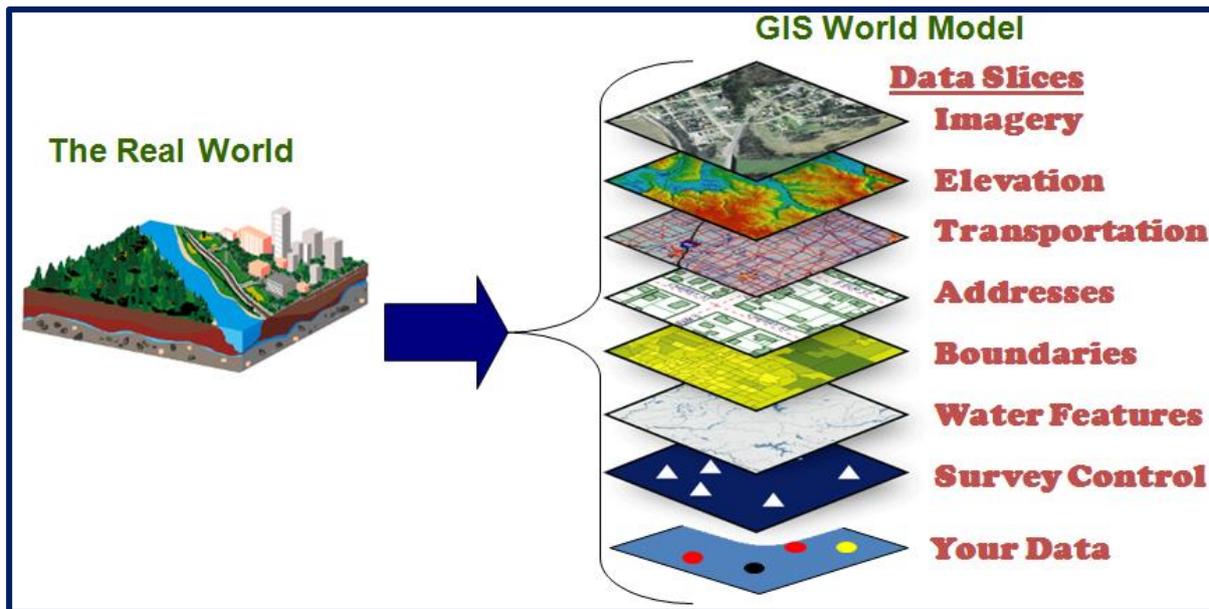
**Table (2.12):** Classification of irrigation water according to the PI values (Sundaray et al. 2009; Shil et al., 2019).

PI value	Suitability of water for Irrigation	Class
PI > 75%	Suitable for irrigation	I
25% < PI < 75%	Moderately suitable for irrigation	II
PI < 25%	Unsuitable for irrigation	III

## 2.6 Geographic Information Systems (GIS)

The GIS is a comprehensive software created for generating, collecting, storing, processing, controlling, and displaying any kind of geographical information. Such systems are regarded as crucial resources for the geoinformatics scientific field. GIS employs basic concepts from geography, cartography, and geodesy to enable users to create queries, present data in maps, analyze spatial data, and display the outcomes of every part of the selected features on raster maps (Kolios et al., 2017).

The data overlay is a structural feature of GIS. In a more analytical sense, every type of data has a unique data layer. GIS enables the analysis and fusion of numerous data layers to produce final data and deliverables. The ability to create final thematic digital maps that respond to user needs is provided by the integration of several data layers (**Figure 2.2**).



**Figure (2.2):** Overlay various data layers in GIS (State of Indiana, 2017).

### 2.6.1 ArcGIS Software

The high ability and features of ArcGIS dealing with geospatial information, enable this software to analyze big storage data easily and display the results quickly. According to Kolios et al. (2017), the following are considered to be fundamental ArcGIS components:

- ❖ Tools and menus for managing and importing geospatial information.
- ❖ A database management system for organizing and storing geographic data.
- ❖ Tools for spatial analysis, visualization, and geographic inquiries.
- ❖ A graphical user interface that allows users to access tools with ease.

### 2.6.2 Spatial Interpolation in ArcGIS

Spatial interpolation is a method for estimating unidentified data at specific points utilizing identified points data (Kolios et al., 2017).

From several points of data, interpolation makes predictions about the values of cells in the raster. It can be used to forecast unknown values for any point based on known points, including chemical concentrations, physical concentrations, precipitation, elevation, etc. There are many techniques of interpolation such as Inverse Distance Weighted (IDW), Kriging, Natural

Neighbor, Spline, Spline with Barriers, Topo to Raster, and Trend. The most common techniques used to generate interpolation maps in rivers are IDW, and Kriging as follows:

### 2.6.2.1 The Inverse Distance Weighting (IDW) Method

IDW employs a regional predictable interpolation approach like its foundation (Watson and Philip 1985). Unidentified data at one selected point can be estimated using IDW. Greater influence on the projected values will come from points nearer the forecast site than those from points more distant (Panhalkar and Jarag 2015).

The IDW method has irreplaceable advantages for modeling the water quality of rivers because the IDW has high accuracy compared with other methods. This method is also commonly applied by many researchers (e.g., Madhloom and Alansari, 2018; Chabuk et al., 2020). The IDW has adopted the following equation (Panhalkar and Jarag, 2015):

$$P_o = \frac{\sum_{i=1}^m P_i \frac{1}{D_i^S}}{\sum_{i=1}^m \frac{1}{D_i^S}} \quad (2.19)$$

Where;  $P_o$  is the required projected value,  $P_i$  is the defined value entered to calculate  $P_o$ ,  $D_i$  is the distance between  $p_i$  and  $p_o$ ,  $m$  is the number of defined values employed in estimation, and  $S$  is the given power (more than 1).

### 2.6.2.2 The Kriging Method

One of the most used geostatistical techniques is kriging (Krige, 1951). The sampled data are interpreted as the outcome of a random process, as is the case in many geostatistical models. Different techniques for calculating the weights and various forms of Kriging can be used (for example, ordinary Kriging, simple Kriging, Universal Kriging, etc.). Kriging uses variograms to quantify the spatial structure in the data and the actual values of the measured

sample points surrounding the place to estimate an unknown value at that position (Kolios et al., 2017).

In general, points closer to the location of interest are given greater weight than points further away when calculating the kriging weights. As a result, the predictions are less biased. Based on the spatial structure of the data, the weights are derived from the variogram and applied using the following formula to the sampled locations (Ali et al., 2006):

$$Z_o = \sum_{i=1}^n \lambda_i Z_i \quad (2.20)$$

Where;  $Z_o$  is the estimated value of an unknown point,  $Z_i$  is the  $Z$  value of known point  $i$ ,  $\lambda_i$  is the weight for point  $i$ , and  $n$  is the number of known points used in estimation.

### 2.6.3 ArcGIS Applications in the Environmental Monitoring

Due to its powerful computer mapping and analysis tools, which can integrate vast amounts of geographical analysis and combine geographic and non-geographic variables, geographic information systems (GIS) are essential for the control of environmental factors, analysis, as well as assessment.

Other mathematical models can be connected with GIS to provide significant outputs relevant to many scientific and environmental domains. With its spatial analysis Arc toolbox, the GIS can handle exceptionally huge amounts of information. For instance, the excellent, good, or bad status of the water can be determined using the WQI and GIS (Kolios et al., 2017).

IDW (spatial interpolation technique in GIS) is commonly used for producing interpolation maps for polylines and thus, particularly for rivers, because of their superior level of precision in WQ modeling (Madhloom & Alansari, 2018).

## 2.7 Previous Related Studies

Since the appearance of the first water quality index in 1965 by Horton et al. and the subsequent development of the WQI, many researchers have studied surface WQ for drinking and irrigation purposes by applying the WQI methods in addition to GIS software. Several main recent studies have considered the issue of this study earlier in the world and Iraq over the last few years.

**The previous studies conducted on rivers in different regions around the world to calculate the WQI for drinking uses are reviewed as follows:**

**Ji et al. (2016)** evaluated water quality deterioration in 2010 based on seven hydrochemical variables being measured every two weeks at seventeen sites on the River of Wen-Rui Tang, China. The WQ of the river has been evaluated using seven different techniques. These techniques consisted of Principal Component Analysis (PCA), Fuzzy Comprehensive Evaluation (FCE), Comprehensive Water Quality Identification Index (CWQII), Comprehensive Pollution Index (CPI), Water Quality Grading (WQG), Single-Factor Assessment (S-FA), and Nemerow Pollution Index (NPI). The CWQII technique was determined accurately in highly polluted waters with numerous impairments, therefore it was applied to evaluate the WQ in the Wen-Rui Tang River. Based on its approaches, qualities, and effectiveness, it was recommended to adopt it. The findings showed that total nitrogen, primarily composed of ammonium, was the predominant pollutant affecting the quality of the water. Because of dilution, temporal change in WQ was closely tied to precipitation. Water flow direction and anthropogenic effects (urban, industrial, and agricultural activities) were linked to the regional variance of water quality.

**Haritash et al. (2016)** investigated the Ganges River in India. In December 2008, water samples were taken from River Ganga to evaluate its suitability for drinking. In Rishikesh, water in the upper part can be used for drinking but after being disinfected (Class A); in the middle part, it can be used

for outdoor bathing (Class B); then, in the lower part, it can be utilized as a drinking water source (Class C). Except for *Escherichia coli* (*E. coli*) bacteria, all the criteria for drinking water quality were within the limit's ranges.

**Godwin and Oborakpororo (2019)** used the WA-WQI to study the quality of the surface water of the river around the Nigerian city of Warri. Numerous physicochemical elements were used to calculate the WQI. These elements are pH, temperature, dissolved oxygen, electrical conductivity, total dissolved solids, total suspended particles, sulphates, nitrates, phosphates, chlorides, turbidity, and biochemical oxygen demand. The obtained values for the water quality index ranged widely from 110.12 to 821.5. The high value of WQI is related to the high levels of total suspended solids (124 mg/l) and turbidity (119 mg/l).

**Marselina et al. (2022)** tested the quality of water in the Citarum River, West Java Province, Indonesia. They selected four sites along the river for nine years. Marselina et al. (2022) adopted three methods to calculate the WQI. These methods are NSF-WQI, CCME-WQI, and OWQI. The results for the nine years were evaluated by using the relationship between wet and dry years as well as between wet and dry months. The NSF-WQI method rated the water quality of Citarum River as Fair and Bad based on the WQI readings with a range of (42.9 - 65.6) during dry years, (39 - 58.8) during wet years, (49 - 62.3) during wet months, and (38.2 - 60.9) during dry months. According to the CCME-WQI method, the water quality of the river was classified into three categories (Fair, Marginal, and Bad). This classification was built based on the WQI results that ranged between (12.6 - 31.5) during dry years, (12.1 - 28.7) during wet years, (12.6 - 31.5) during dry months, and (21.2 - 33.1) during wet months. The Citarum River was rated as a Very Bad water quality when applying the method of O-WQI. The calculated values of the WQI ranged between (11.5 - 18.8) and (13.8 - 24.5) during dry and wet months, respectively. In addition, between (11.5 - 25.7) and (11.5 - 15.9) during dry and wet years,

respectively. These findings found that the assessment of the NSF-WQI method was the most effective in determining the water quality in the Citarum River.

**The previous studies conducted on Iraqi rivers to calculate the WQI for drinking uses are evaluated as follows:**

**Abbas & Hassan (2018)** used the water quality index (WQI) to examine the Diwanyiah River's water quality from September 2015 to June 2016. Along the river, four locations were chosen. The WQ of Diwanyiah River was subjected to applying the method of the CCME-WQI. For evaluating the WQ in Diwanyiah River, nine elements were chosen (T °C, pH, DO, TDS, alkalinity, turbidity, NO<sub>2</sub>, NO<sub>3</sub>, and PO<sub>4</sub>). The WQI readings indicated that the WQ of the river ranged between (poor – marginal).

To compare the findings with the CCME-WQI and NSF-WQI, **Ahmed et al. (2020)** studied the 16 physical and chemical in addition to biological variables in the Lower Zab River in Kirkuk City at two sites for the years from 2013 to 2019. The results showed that except for turbidity, DO, nitrate, and calcium which were readings greater than the standard limits, the analysis of all parameter levels was within the ranges recommended for drinking water (World Health Organization standards, and Iraqi standards). The high pollution in the Lower Zab River caused the water quality at the second site to be lower than it was at the first site, according to the calculated values of the WQI. Generally, drinking directly from the Lower Zab River is not permitted and requires pretreatment before the usage of drinking.

**Al-Ridah et al. (2020)** used the WA-WQI and the CCME-WQI to study WQ for drinking in the Shatt Al-Hillah River. Moreover, there are four water treatment plants (WTP) that take water from the river, which are Al-Tayarah, New Al-Hillah, Al-Hesain, and Al-Hashimyah. Water samples were taken monthly from January to December 2018 from the river and WTP. Nine variables measured are turbidity, pH, TH, Alk., EC, Mg, Ca, Cl, and TDS. The WA-WQI method for all stations found that water quality after treatment ranged

between (good, and severely contaminated) and the raw water quality ranged from severely polluted to unfit for human consumption. The river water was rated as Fair, and the treated water was rated as Good for drinking by the CCME-WQI method. The results of comparing the two models revealed that the CCME-WQI provided a better value for WQ than the value from the other method. In other words, the CCME-WQI is more flexible in application compared with WA-WQI.

Using the CCME-WQI, **Hommadi et al. (2020)** examined the water quality in the Euphrates River upstream of the Alhindya Barrage. Using the available data, a comparison of the water quality between the years 2008 and 2009 was made. Measured flow rates underwent statistical analysis, and the results showed that there was a statistically significant difference between the measured flow rates for those years. Compared to the CCME-WQI of 79 for 2009, the data showed that the CCME-WQI for 2008 was 94. This resulted from the mean water quantity falling from 370 m<sup>3</sup>/s in 2008 to 213 m<sup>3</sup>/s in 2009. The main cause of dry seasons, low rainfall intensity, and poor water quality are the phenomena of global warming.

**The earlier studies conducted on the evaluation of the water quality of rivers using WQI and GIS are as follows:**

**Chabuk et al. (2020)** used the WA-WQI and GIS software to assess the WQ along the River of Tigris. Twelve variables were gathered at 14 sites along the river (11 for calculating the WQI, and 3 for checking), including Ca, Mg, Na, K, Cl, SO<sub>4</sub>, HCO<sub>3</sub>, TH, TDS, BOD<sub>5</sub>, NO<sub>3</sub>, and EC. The water quality index was calculated using the weighted arithmetic method (WQI). The findings found the readings of all measured variables in wet and dry seasons raised from site 1 to site.11, while HCO<sub>3</sub> concentration was decreased for the selected sites (11). Along the river, the readings of BOD<sub>5</sub>, Na, Cl, Mg, SO<sub>4</sub>, Ca, TH, and NO<sub>3</sub> were higher in the dry season than they were in the wet season, while other readings levels of HCO<sub>3</sub>, EC, TDS, and K were higher in the wet season than they were

in the dry season. The results found that the readings of QWI for sites (1-7) classified the WQ for drinking uses as poor, and classified the WQ at sites (8-11) as good. During both seasons (2016), the Inverse Distance Weighted (IDW) technique, as a tool in the GIS, has been used to create the distributing maps of WQI for the total length of the river.

**El Behairy et al. (2021)** studied the Shatt Al-Arab River, in southern Iraq. They generated a WQI map using GIS and the Water Quality Index to characterize the river's level of pollution. Numerous water quality parameters, including pH, temperature, DO, BOD<sub>5</sub>, COD, nitrate, phosphate, TDS, TSS, turbidity, and EC, which were sampled at 37 sites along the river, were used to create the WQI. At the river branches, close to the governorate's administrative headquarters in Basra, poor water quality was seen. Additionally, it was found that unlawful discharges of industrial effluent and sewage, as well as high levels of sewage water discharged into river branches, were the main causes of river contamination.

In the Oued River (north of Morocco), the WQ was investigated by **(Azhari et al., 2022)**. Twenty-six physicochemical and biological variables were assessed in 13 surface water samples. The contamination sources of surface water were determined using cutting-edge methods such as multivariate statistical methods, water quality for irrigation, and GIS. Except for HCO<sub>3</sub> and BOD<sub>5</sub>, the results showed that practically all other variables had concentrations that were below WHO standards. This river was subjected to two kinds of pollution, (1): it can be linked to agricultural activities, and (2): is a result of the interaction between water and sediment. According to combining the WQI methods and IDW method in the GIS, the proportions of 7.7% and 38.5% of water for drinking are classified as excellent and good, respectively. 92.2% of the WQI values of the water for irrigation are considered suitable.

**Krishan et al. (2022)** conducted a study on one of India's most polluted rivers, the Gomti River. They employed the synthetic pollution index (SPI) and

the water quality index (WQI). Additionally, the data integration with the geographic information system (GIS) has been carried out for the seven sampling stations (L1 to L7) throughout 2013–2017 along with 12 water quality parameters. In five years, the study area's WQI varied from 78.98 to 249.4, and its SPI was from 0.9 to 2.1. The WQI is classified as badly contaminated and unfit for human consumption, according to the map interpolated using GIS, while SPI is classified as moderately polluted and severely polluted. It was discovered that the WQI and SPI scores were considerably influenced by the BOD and COD.

**The previous studies implemented on the assessment of the rivers' water quality for irrigation uses are as follows:**

**Meireles, et al. (2010)** conducted a study on the quality of the surface water used for irrigation in the Ceará state in Brazil's Acara Basin. The area's irrigation project's water supply from the Acara River was assessed for its qualitative dynamics. To create a water quality index (WQI) that accounts for soil salinity and sodicity threats, as well as water toxicity for plants, the WQI was utilized for evaluating the WQ. Ten sampling sites around the basin were used to collect water samples between April 2003 and September 2005, and the physical and chemical factors that affect the WQI were assessed at these sites. The findings demonstrated that, if the soil-water-plant is not adequately monitored, the use of water for irrigation in the Acara basin is possibly prone to create toxicity (crop cycle) problems in the long term.

**Al-Musawi (2018)** examined the WQI of the Diyala River, where three stations were picked along the river. These stations are D12 in Jalawla City, upstream of the Diyala River, station (D15) in Baaquba City, in the middle section of the river, and the final station (D17) near Baghdad City, which is located before the confluence point of the Rivers of Diyala and Tigris. The WQI was assessed using the Bhargava method for both irrigation purposes. The findings of the WQI values classified the Diyala River as excellent for irrigation

in the first section it but poor for irrigation in the middle section of the river. In the third section of the Diyala River, the WQ was suitable for irrigation.

**Yldz and Karakus (2020)** conducted a study on the quality of surface water used for irrigation in the Sivas district, Turkey. To calculate the SAR, KI, PI, as well as IWQI for the assessment of surface water quality, they used the data from 32 irrigation stations. The obtained Na%, KI, SAR, and values ranged from 3.3 to 57.9%, 0.05 to 1.4 meq/l, and, 0.1 to 9.4 respectively. According to the computed PI values, 93.8 percent fall into the (Suitable) class, while 6.2 percent fall into the class of (non-suitable). The computed values of the IWQI were classified as Very poor (68.9%), Bad (15.5%), Excellent (12.5%), and Unsuitable (3.1%).

**Elsayed et al. (2020)** used six methods of the WQI to assess the WQ of the Nile Delta for irrigation. In this study, 110 surface water samples were collected in the summer season from a network of water channels in 2018 and 2019. Twenty-one physical and chemical variables were measured. 82% of the WQI values for irrigation were within the high class, while the remaining values (18%) were within the medium class. The Na (%) values were calculated. 96 percent of the Na (%) values were within the healthful category, and the remains were within the category of irrigation permissible. The whole samples of the Northern Nile Delta have been rated as suitable for irrigation. According to the results, the other methods for evaluating the surface water for irrigation uses showed that valid for irrigation. These methods are SAR, KI, PI, and RSC.

**Ewaid et al. (2020)** created an irrigation water quality guide and Visual Basic software based on United Nations Food and Agricultural Organization criteria and the irrigation water quality index. This guide was evaluated using a three-year (2013–2015) monthly dataset for Al-Gharraf Canal in southern Iraq that included 612 tests for 17 different variables. Assuming good management of permeability and salinity, the guide classified the canal water as (Moderate Restriction) with a degree score of (65.6), indicating its suitability for use in the

irrigation of the majority of local crops. The outcomes also demonstrated the software's strong performance as a tool for evaluation, interpretation, guidance, and problem-solving related to irrigation water quality.

## 2.8 Summary

From reviewing all the previous research, the following can be concluded:

- 1) The most common methods used to evaluate the water quality index are WA-WQI and CCME-WQI.
- 2) Other methods of the WQI are based on a limited number of parameters and on charts to calculate the WQI values.
- 3) Most of the research focused on evaluating the WQ of rivers for either drinking uses or utilizing general indices to assess WQ for both drinking and irrigation uses.
- 4) Few researchers in Iraq used the irrigation water quality index (WQIFIR), which was developed by (Meireles et al., 2010).
- 5) The software commonly used for mapping the spatial distribution of river water quality is ArcGIS.
- 6) Al-Abbasiyah River has a very limited number of studies dealing with evaluating the quality of its water for irrigation and drinking purposes, despite the existing dense population and agricultural lands distributed on both river banks of the river.

Therefore, the current study focused on assessing the water quality of the Al-Abbasiyah River for drinking and irrigation uses as follows:

- a) Using the Weighted Arithmetic Water Quality Index (WA-WQI) and CCME-WQI to assess the water quality of the Al-Abbasiyah River to employ in household uses.
- b) The Water Quality Index for Irrigation uses (WQIFIR) will apply to assess the WQ of the river to irrigate the agricultural lands.
- c) Mapping the spatial distribution of river water quality for drinking and irrigation uses separately using ArcGIS 10.8 software.

- d) Developing computer applications to calculate WQIs for drinking and irrigation uses by using Visual Basic software.
- e) Creating linear regression models to estimate the values of the WQIs for the drinking and irrigation uses along the Al-Abbasiyah River using the SPSS software.

### 3.1 Introduction

This chapter includes the experimental work and methodology used in this study. The experimental work includes describing the study area, collecting samples, and selecting variables to conduct laboratory tests necessary to calculate water quality indices.

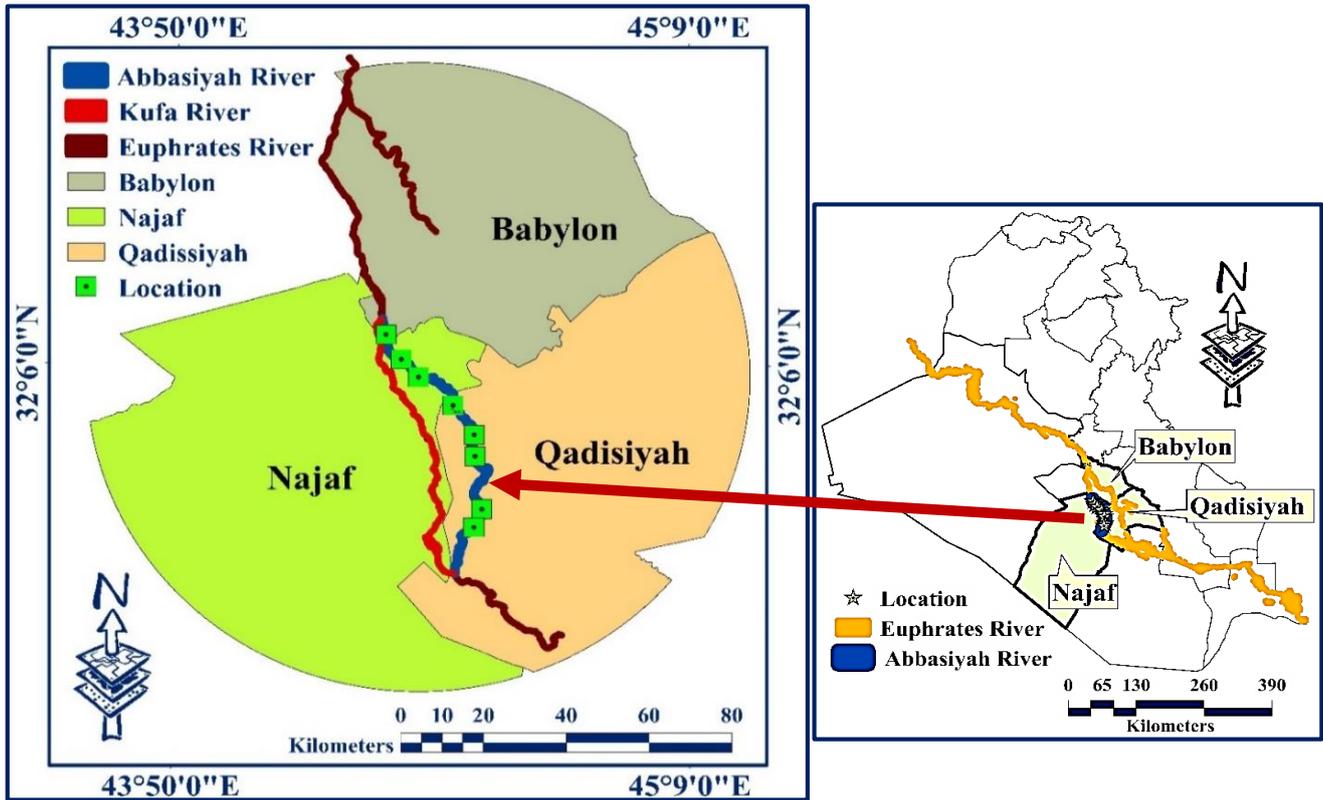
This chapter also includes the calculation of water quality indices for drinking and irrigation purposes in the Al-Abbasiyah River and the development of a program in Visual Basic language that can calculate the water quality indices used in this study after feeding it with the desired variables. In addition to create spatial distribution maps using GIS techniques as described in the following sections.

### 3.2 Study Area

Al-Abbasiyah River is one of the branches of the Euphrates River in Iraq, where the Euphrates River branches off at the south of Babylon Governorate to be divided into Al-Abbasiyah River and Al-Kufa River, about (2km) from Al-Kifil City and enters Al-Abbasiyah City after 8 km from the branching point. Al-Abbasiyah River length is about 80km and passes through Najaf Governorate (28 km inside Najaf Governorate), where it is called Al-Abbasiyah River, and then through Al-Qadisiyah Governorate (The remaining length of the river), where it is called Al-Shamiyah River and meets at the end of Al-Kufa River again to form together the main Euphrates River at a distance of about (8km) north of Al-Shanafiya city in Al-Qadisiyah Governorate. In this study, the river will be named along its length as Al-Abbasiyah River (**Figure 3.1**) (Iraqi Ministry of Water Resources, 2022a).

The river passes through several cities (Al-Abbasiyah, Al-Mhannawiyah, Al-Salahiyah, Al-Shamiyah, and Ghammas), as these cities depend entirely on Al-Abbasiyah River and its branches to get their requirements of drinking water, in addition to irrigating its surrounding agricultural lands. The large agricultural

lands on both sides of the river are always characterized by the cultivation of several important crops. Otherwise, on the riverbanks, much sewage is drained by a sewer into the river as shown in **Figure (3.2)**. So, draining wastewater into a river directly affects the contamination of the river environment (Iraqi Ministry of Water Resources, 2022a).



**Figure (3.1):** The mainstream of Al-Abbasiyah River.



**Figure (3.2):** Drainage wastewater and waste into the river.

Al-Abbasiyah River receives about 40% of the water from the Euphrates River and the rest (60%) goes to the Al-Kufa River. The annual average capacity discharge for the Al-Abbasiyah River is  $140.3\text{m}^3/\text{s}$ . The highest value of discharge is in summer, usually in the months of Rice cultivation, in June, July, August, and September with an average monthly range of ( $150$  to  $200\text{m}^3/\text{s}$ ). For the rest of the months of the year, the discharge values of the river are few to medium with an average monthly range of ( $25$  to  $95\text{m}^3/\text{s}$ ). In the study period, the average monthly discharge of the Al-Abbasiyah River was recorded as (about  $30\text{m}^3/\text{s}$ ) due to the water scarcity crisis in Iraq during recent years (Iraqi Ministry of Water Resources, 2022b).

Al-Abbasiyah Barrage controls the discharges of the Al-Abbasiyah River (**Figure 3.3**), where the barrage is located 8 km south of the branching area of the river. The Abbasiyah barrage was built in 1986 by a Chinese company, with a maximum design discharge of ( $1100\text{m}^3/\text{s}$ ) with seven radial gates powered by electricity. In the barrage upstream, the floor level is ( $19.7\text{m}$ ) above sea level with a length of ( $5$  m), while in the barrage downstream, the floor level is ( $19.2\text{m}$ ) above sea level with a length of ( $4\text{m}$ ). In addition to Al-Abbasiyah Barrage, Al-Shamiyah Barrage was built on the river, where Al-Shamiyah Barrage is located 3 km north of Al-Shamiyah City.



**Figure (3.3):** Al-Abbasiyah Barrage, Najaf Governorate.

Al-Abbasiyah River has (128) branches. The most important branches are the Al-Mhannawiyah stream with a length of ( $21\text{km}$ ) and its discharge

reaches (12 m<sup>3</sup>/s). Al-Haidari stream has a total length of 18km and employs to irrigate approximately 12,000 acres of agricultural areas situated on both sides. The Al-Wahhabi stream irrigates agricultural lands of about 17,000 dunams (Iraqi Ministry of Water Resources, 2022b).

### 3.3 Methodology of The Current Study

Figure (3.4) shows the steps of implementing the research plan from the beginning, through the collection and analysis of samples, the application of the necessary programs and equations, and the important results that were reached.

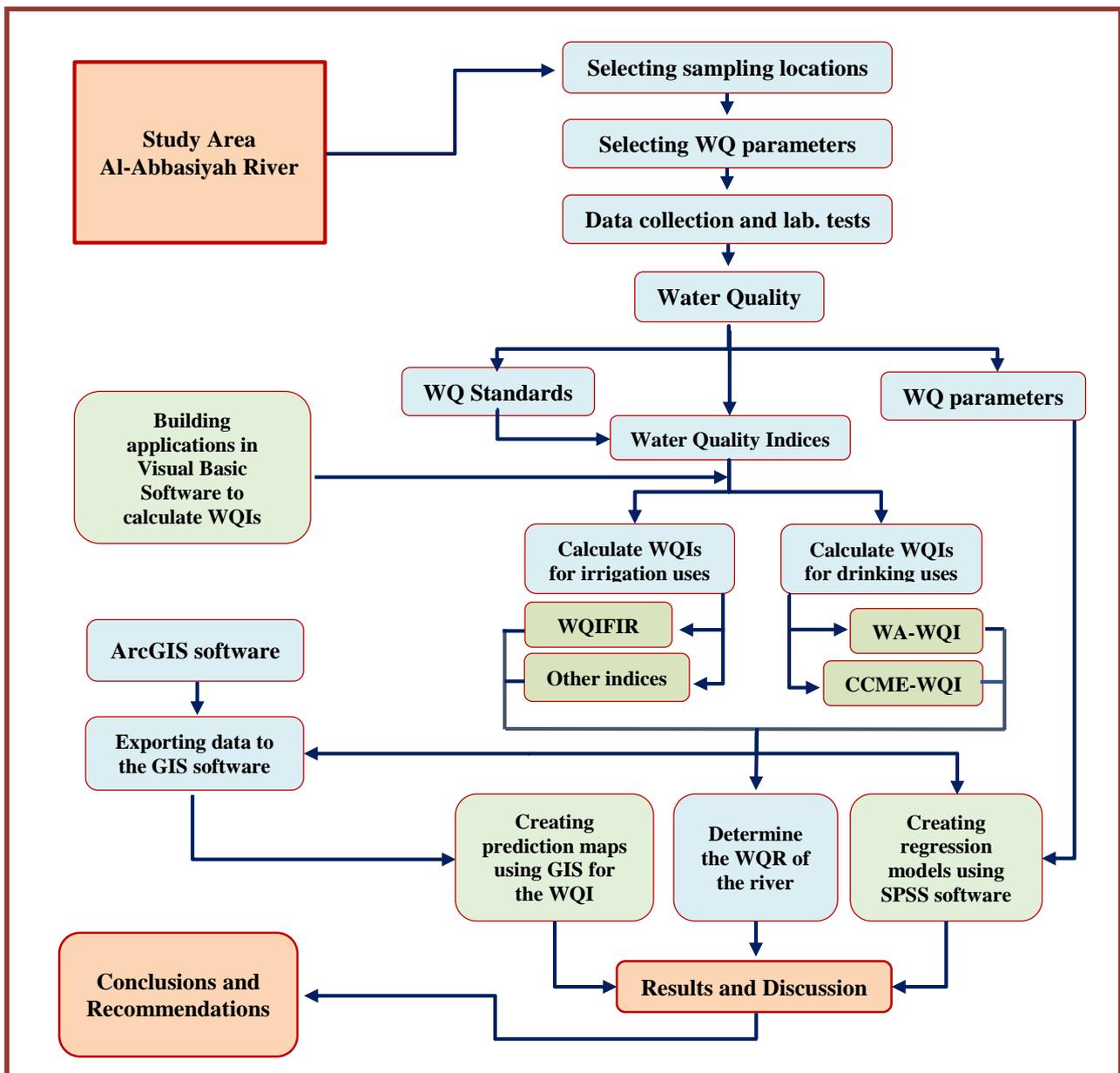


Figure (3.4): Methodology of The Study.

### 3.4 Selecting Sampling Locations

The choice of sampling locations is considered one of the main objectives of this study. Therefore, eight locations were set for sampling along the river (about 80 km) considering the nature of the area in each location and the different factors and activities that affect the water quality of the river. The locations were set at the beginning and end of each residential city or a large agricultural area along the river as follows:

**Location 1 (L-1):** It is located 4 km upstream of Al-Abbasiyah Barrage, and about 6km south of Al-Kifil City, within the borders of the Babylon Governorate. The cross-section of the river is 217m.

**Location 2 (L-2):** The cross-section of Location 2 is 110m. It is situated 4km before Al-Abbasiyah City and 4km downstream of Al-Abbasiyah Barrage, inside Al-Najaf Governorate's borders. It is far away 8 km from the previous location (L-1)

**Location-3 (L-3):** It is placed directly after Al-Abbasiyah City inside the boundaries of Al-Najaf Governorate and its cross-section is 115m. Location-3 is far away 7km from Location-2.

**Location-4 (L-4):** This location is located 4km upstream of the Al-Shamiyah barrage and directly after the Al-Salahiyah City, within the borders of the Al-Qadisiyah Governorate. Location-4 is far away from the previous location 15km, and its cross-section is 92 m.

**Location-5 (L-5):** It is situated downstream of the Al-Shamiyah barrage (6km) with a cross-section of 85m. It is located directly after Al-Shamiyah City (11km) inside Al-Qadisiyah Governorate's borders.

**Location-6 (L-6):** Location-6 is selected at 6km from Location-5. It is located within a largely agricultural area with a cross-section of 72m. This location administratively is situated inside Al-Qadisiyah Governorate's borders.

**Location-7 (L-7):** It is located at the end of a large agricultural area before Al-Ghammas City about 3km, in Al-Qadisiyah Governorate. This location is chosen at a distance of 18km from (L-6) with a cross-section of 51m.

**Location-8 (L-8):** The last selected location in this study is located directly after Al-Ghammas City (6km from Location-7) inside the boundaries of Al-Qadisiyah Governorate, and its cross-section is 54m.

### **3.5 Selecting the Water Quality Parameters**

Water is a complex substance that can be described by various parameters. These parameters provide information about the physical, chemical, and biological properties of water. The parameters that were tested for all samples taken from the river throughout the study period are as follows:

#### **3.5.1 Temperature (Temp)**

Water temperature can have a significant impact on aquatic life and water quality. Temperature can affect dissolved oxygen levels, chemical reactions, and the growth and reproduction of aquatic organisms. For example, warm water can decrease the amount of dissolved oxygen in the water and cause stress on aquatic life (US EPA, 2021a).

#### **3.5.2 Hydrogen Ions (pH)**

The pH of water is a measure of its acidity or alkalinity. It is a logarithmic scale ranging from 0 to 14, where 7 is considered neutral. pH can affect the chemical reactions and biological processes that occur in water. For example, acidic water can cause corrosion in pipes and harm aquatic life, while alkaline water can cause scaling on surfaces and affect water quality (APHA, AWWA, WEF, 2017).

#### **3.5.3 Electrical Conductivity (EC)**

Conductivity is the measure of the solution's ability to conduct electricity. Both the amount of TDS and the ion concentration of the water can be displayed. Extreme conductivity concentrations can indicate the presence of

dissolved minerals and salts, and it is measured in micro-Siemens per centimeter ( $\mu\text{S}/\text{cm}$ ) (APHA, AWWA, WEF, 2017).

#### **3.5.4 Total Dissolved Solids (TDS)**

Total dissolved solids (TDS) refer to the total amount of inorganic and organic substances dissolved in water. High TDS levels can affect water taste, clarity, and quality. TDS levels can be influenced by the presence of dissolved minerals, salts, and organic compounds (WHO, 2011).

#### **3.5.5 Total Suspended Solid (TSS)**

TSS refers to the total amount of suspended particles, such as sediment, organic matter, and other solids in water. By limiting the type of light that reaches the water, increased concentrations of TSS can impact the ecosystem as well as the overall quality and clarity of the water itself (US EPA, 2021b).

#### **3.5.6 Turbidity (Turb)**

Turbidity is the measure of the cloudiness or haziness of water due to the presence of suspended particles. High turbidity levels can affect water quality and clarity. Turbidity can be influenced by the presence of sediment, organic matter, and other suspended particles and it is measured by nephelometric turbidity units (NTU) (US EPA, 2021a).

#### **3.5.7 Dissolved Oxygen (DO)**

Dissolved oxygen (DO) is the amount of oxygen present in water that is available for aquatic life. DO is important for respiration and other metabolic processes in aquatic organisms. DO levels can be influenced by temperature, water flow, and the presence of organic matter. Low DO levels can lead to hypoxia and the death of aquatic organisms (US EPA, 2020).

#### **3.5.8 Biochemical Oxygen Demand (BOD)**

BOD is the amount of oxygen consumed by microorganisms while decomposing organic matter in water. It is a measure of the number of organic pollutants in water. High BOD levels can lead to hypoxia and the death of aquatic organisms (APHA, AWWA, WEF, 2017).

### 3.5.9 Bicarbonate ( $\text{HCO}_3^-$ )

Bicarbonate is an important component of alkalinity in water. It can affect the pH of the water and the solubility of metals. Bicarbonate can also serve as a source of carbon for aquatic organisms (USGS, 2019).

### 3.5.10 Total Alkalinity (Alk)

Total alkalinity is the measure of a solution's ability to neutralize the acid. bicarbonate, carbonate, and hydroxide ions are considered the major parameters that affect the alkalinity of water bodies. Alkalinity can affect the pH of the water and the solubility of metals (APHA, AWWA, WEF, 2017).

### 3.5.11 Total Hardness (TH)

Total hardness is the measure of the concentration of calcium and magnesium ions in water. Hard water can cause scaling on surfaces and affect the quality of water for industrial and domestic use (WHO, 2011).

### 3.5.12 Calcium ( $\text{Ca}^{+2}$ )

Calcium (Ca) is a divalent cation commonly found in water. It is important for human health and plays a critical role in maintaining strong bones and teeth. Calcium also helps with nerve function and muscle contraction, and it may be protective against cardiovascular disease. However, high levels of calcium in water can contribute to water hardness, which can cause scaling and reduce soap effectiveness (WHO, 2011).

### 3.5.13 Magnesium ( $\text{Mg}^{+2}$ )

Magnesium is a common ion found in water, and it plays an important role in the health and growth of plants and animals. It is also involved in several biochemical processes within the body, such as muscle and nerve function. However, high levels of magnesium in drinking water can cause water hardness, which can lead to scaling and reduce soap effectiveness (WHO, 2011).

### 3.5.14 Chloride ( $\text{Cl}^-$ )

Chloride is a common ion found in water, and it can have both positive and negative effects on water quality. Chloride is important for maintaining

electrolyte balance in the body, but high levels of chloride in water can be a sign of contamination from sewage or agricultural runoff (US EPA, 2021a).

### **3.5.15 Nitrate ( $\text{NO}_3^-$ )**

Nitrate is a common form of nitrogen found in water, and it is often a result of agricultural practices and wastewater discharge. The process of eutrophication which can result in blooms of algal species and destroy the aquatic ecosystem, can be caused by excessive levels of nitrates in the water column. Nitrate can also be converted into nitrite, which can be harmful to human health, particularly in infants (WHO, 2011).

### **3.5.16 Sulfate ( $\text{SO}_4^{2-}$ )**

Sulfate is a common ion found in water, and it can affect water's taste and odor as well as it can cause corrosion and rusting of pipelines and infrastructures. To the contrary, sulfate can also be an essential nutrient for aquatic life (US EPA, 2021a).

### **3.5.17 Sodium ( $\text{Na}^+$ )**

Sodium is a common ion found in water, and it can affect water's taste and health. High levels of sodium in water can be a concern for people with hypertension or cardiovascular disease, as it can increase blood pressure. However, sodium is also an important nutrient for the body, and it is necessary for several biological processes (WHO, 2011).

### **3.5.18 Potassium ( $\text{K}^+$ )**

Potassium is a less common ion found in water compared to sodium, but it is still important for the body's health. Potassium plays a role in several biological processes, such as muscle and nerve function, and it can also help regulate blood pressure (WHO, 2011).

## **3.6 Sample Collection**

Depending on the fluctuating weather and the pattern of drainage, the river flow varies dramatically over time. Due to the prevailing currents and turbulence, rivers typically achieve thorough and continuous vertical mixing.

Over long certain routes downstream of main confluences, lateral mixing occurs (Naveen et al., 2016).

After determining eight locations along the river, samples were taken from the raw river water at each location four times during the study period. The samples were taken in the summer and autumn seasons of 2022 and in the winter and spring seasons of 2023, as indicated in **Table (3.1)**. Sampling dates were set with the passage of the Landsat 9 satellite over the Al-Abbasiyah River to create a model for analyzing the river water parameters using remote sensing in future studies.

At each location, samples were taken at different depths from the center and sides of the river and then mixed to get one sample from the mixture to represent the actual form of the water quality in that site. Samples were placed in a well-sealed plastic bottle with a volume of (1.5 liters) for for physical and chemical tests and a glass bottle with a volume of (0.5 liters) for biological tests and refrigerated to preserve the sample until it was analyzed.

**Table (3.1):** Dates of collecting samples for the current study.

No.	Season	Date	Discharge of Al-Abbasiyah Barrage (m <sup>3</sup> /s)
1	Summer	04/08/2022	30
2	Autumn	15/10/2022	30
3	Winter	11/01/2023	30
4	Spring	08/03/2023	30

### 3.7 Laboratory Tests

The collected water samples from eight locations (along the Al-Abbasiyah River) during the four seasons were analyzed in the laboratory except for the temperature of the water body which was measured directly in the river. For the selected parameters, these tests were analyzed in a private laboratory in Al-Dewaniyah City, the laboratory of Babylon Water Directorate, and the laboratory of the Department of Environmental Engineering at the University of Babylon using standard chemical processes or modern electronic devices (**Figure 3.5**).

The standard methods for the examination of water and wastewater (APHA, 2017) were employed for all analyses and these tests are as follows :

➤ **Water Temperature (Temp)**

The water temperature (° C) was measured by using a mercury thermometer.

➤ **Hydrogen ions (pH)**

pH values have been measured using a pH meter device.

➤ **Electrical conductivity (EC)**

The EC values were measured in a laboratory using an EC meter device.

➤ **Total Suspend Solids (TSS) and Total Dissolved Solids (TDS)**

The values of TSS and TDS concentrations have been analyzed in the laboratory using a gravimetric procedure. In these tests, the solids of each water sample were filtered, dried, and weighed to determine the total nonfilterable residue (TNR) of the solids to obtain the TSS. The solids of water passed through the filter paper, were collected in a container, and dried in the oven. Then, the difference in the weight between the empty container and the container with dried solids to determine the TDS. They are expressed as (mg/l).

➤ **Turbidity (Turb)**

In the lab, the turbidity values for all samples were measured using a turbidity meter device with (NTU) unit.

➤ **Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD)**

The concentrations of DO and BOD were measured in the lab according to the Winkler method.

➤ **Nitrate (NO<sub>3</sub><sup>-</sup>)**

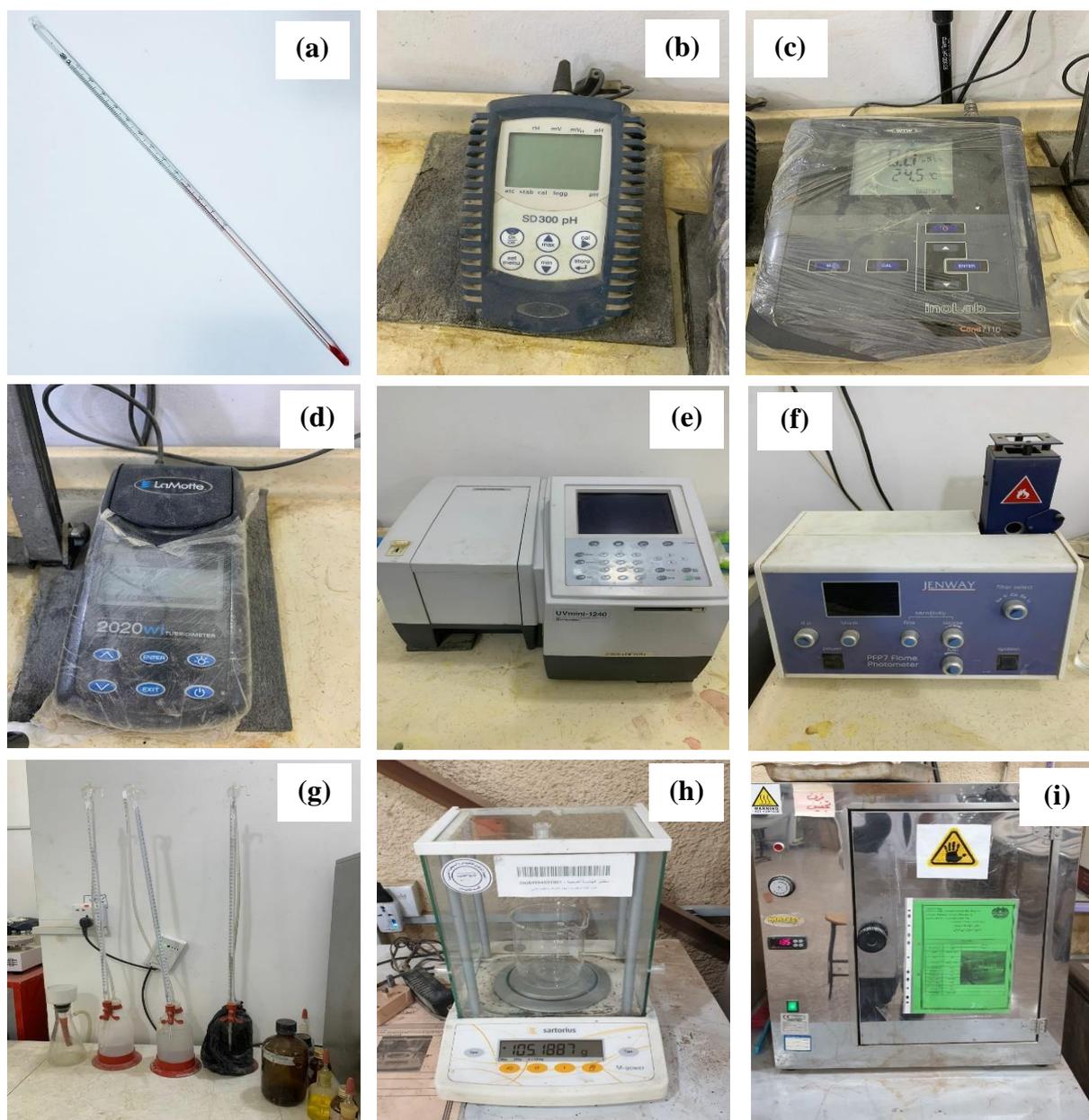
This test was carried out in the laboratory using a spectrophotometer.

➤ **Sodium (Na<sup>+</sup>) and Potassium (K<sup>+</sup>)**

These tests were carried out in the laboratory using a flame photometer.

➤ **Other tests**

Other tests were carried out using titration methods in the laboratory for the examination of the water and wastewater according to the standard methods of APHA (2017).



**Figure (3.5):** Equipment and tools used in laboratory tests (a): Mercury thermometer; (b): pH-Meter; (c): EC-Meter; (d): Turbidity-meter; (e): Spectrophotometer; (f): Flame photometer; (g): Burettes; (h): Electric balance; (i): Electric drying oven.

The values of collected samples during each season can be found in **Tables (3.2, 3.3, 3.4, and 3.5)**, while the average values for all collected parameters from locations of Al-Abbasiyah River during all seasons are shown in **Table (3.6)**.

**Table (3.2):** Results of laboratory tests for samples in the summer (2022).

No.	Parameter	L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	Mean	STD
1	Temp. (°C)	35	36	36	37	37	37	38	38	36.8	1.04
2	pH	7.19	7.32	7.40	7.54	7.6	7.66	7.72	7.73	7.52	0.19
3	EC (µS/cm)	1455	1500	1588	1682	1638	1673	1722	1798	1632	113.7
4	TDS (mg/l)	946	975	1032	1093	1065	1087	1119	1169	1061	73.9
5	Turb. (NTU)	6.13	11.70	4.89	4.76	5.14	9.49	14	9.29	8.18	3.49
6	DO (mg/l)	5.2	5.1	4.7	5.9	6.5	5.9	5.2	5.3	5.475	0.58
7	BOD <sub>5</sub> (mg/l)	0.6	1	0.5	0.7	1.1	0.4	1.9	0.5	0.84	0.50
8	HCO <sub>3</sub> (mg/l)	106	100	90	94	94	104	100	102	98.75	5.55
9	Alk. (mg/l)	114	112	110	102	102	104	108	118	108.8	5.85
10	TH (mg/l)	572	532	520	576	560	536	560	544	550	20.1
11	Ca (mg/l)	120.0	121.6	116.8	118.4	116.8	118.4	121.6	123.2	119.6	2.4
12	Mg (mg/l)	66.4	55.6	55.6	68.3	65.4	58.6	62.5	57.6	61.2	5.1
13	Cl (mg/l)	180.3	162.7	178.4	194.0	209.7	197.9	215.6	211.7	193.8	18.7
14	NO <sub>3</sub> (mg/l)	4.14	3.59	3.10	3.44	1.66	2.37	1.44	1.54	2.66	1.05
15	SO <sub>4</sub> (mg/l)	222.8	225.8	216.8	226.4	232.0	220.5	225.8	209.6	222.5	6.86
16	TSS (mg/l)	7.60	10.46	4.82	4.6	5.4	8.86	13.8	9.6	8.14	3.19
17	Na (mg/l)	130.3	133.9	148.2	154.2	164.9	166.1	187.5	187.9	159.1	21.8
18	K (mg/l)	12	12	13	14	13	14	16	15	13.6	1.41

STD: Standard Deviation.

**Table (3.3):** Results of laboratory tests for samples in the Autumn (2022).

No.	Parameter	L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	Mean	STD
1	Temp. (°C)	25	25	25	25.5	26	26.5	26.5	26.5	25.75	0.71
2	pH	7.35	7.26	7.28	7.31	7.34	7.33	7.60	7.50	7.37	0.12
3	EC (µS/cm)	1482	1515	1576	1581	1587	1599	1577	1586	1563	41.33
4	TDS (mg/l)	962	985	1024	1028	1032	1039	1025	1031	1016	27.23
5	Turb. (NTU)	12.30	16.20	7.79	4.23	6.98	7.3	14.7	11.9	10.17	4.20
6	DO (mg/l)	4.9	5.1	4.9	5	5.4	5.6	7.8	8.0	5.8	1.3
7	BOD <sub>5</sub> (mg/l)	2.9	3.3	2.1	2.6	2.8	2.3	2.8	2.9	2.71	0.38
8	HCO <sub>3</sub> (mg/l)	90	86	78	85	87	88	86	88	86	3.59
9	Alk. (mg/l)	94	98	90	96	92	100	94	96	95	3.21
10	TH (mg/l)	600	616	624	644	644	640	640	672	635	21.67
11	Ca (mg/l)	123.2	124.0	124.8	128.0	126.4	121.6	120.0	128.0	124.5	2.89
12	Mg (mg/l)	71.2	74.2	76.1	79.1	80.0	81.9	82.9	85.9	78.9	4.85
13	Cl (mg/l)	172.5	174.4	190.1	184.2	174.4	188.2	182.3	184.2	181.3	6.71
14	NO <sub>3</sub> (mg/l)	2.55	2.71	2.33	2.71	2.41	2.76	2.42	2.24	2.52	0.19
15	SO <sub>4</sub> (mg/l)	310.4	342.6	314.4	346.6	346.6	354.7	334.6	314.4	333	17.47
16	TSS (mg/l)	13.20	15.80	8.10	4.62	6.62	7.86	13.86	10.40	10.1	3.92
17	Na (mg/l)	131.2	136.4	164.8	168.9	171.5	173.6	173.1	173.4	161.6	17.46
18	K (mg/l)	9.3	9.2	9.4	10.1	9.5	9.6	9.7	9.5	9.54	0.28

STD: Standard Deviation.

**Table (3.4):** Results of laboratory tests for samples in the winter (2023).

No.	Parameter	L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	Mean	STD
1	Temp. (°C)	12	12	12	12	13	13	13	13	12.5	0.53
2	pH	7.82	7.81	7.9	7.91	7.82	8	7.78	7.77	7.85	0.08
3	EC (µS/cm)	1471	1468	1546	1476	1469	1486	1476	1482	1484	25.7
4	TDS (mg/l)	956	954	1004	959	955	966	959	963	965	16.7
5	Turb. (NTU)	4.27	8.63	3.74	3.13	2.63	2.82	3.74	7.62	4.57	2.27
6	DO (mg/l)	9.70	9.40	9.30	9.50	10.20	9.40	9.00	9.00	9.44	0.39
7	BOD <sub>5</sub> (mg/l)	1.8	1.7	1.9	2.1	1.7	1.1	2	1.6	1.74	0.31
8	HCO <sub>3</sub> (mg/l)	150	152	151	140	146	114	132	152	142.1	13.36
9	Alk. (mg/l)	150	152	151	140	146	150	152	152	149.1	4.19
10	TH (mg/l)	536	620	544	608	516	632	568	528	569	45.2
11	Ca (mg/l)	120	116.8	126.4	112	120	115.2	110.4	104	115.6	6.9
12	Mg (mg/l)	57.6	80.0	55.6	80.0	52.7	73.1	71.2	65.4	66.97	10.8
13	Cl (mg/l)	217.5	196.0	213.6	203.8	199.9	209.7	197.9	213.6	206.5	8.2
14	NO <sub>3</sub> (mg/l)	6.21	6.25	6.51	6.29	5.49	5.71	6.72	6.81	6.25	0.46
15	SO <sub>4</sub> (mg/l)	386.8	374.8	330.5	538.7	362.7	359	294.2	342.6	373.7	72.6
16	TSS (mg/l)	5.20	10.80	3.80	4.40	4.80	3.20	3.60	8.20	5.5	2.64
17	Na (mg/l)	114.2	113.8	119.8	115.2	112.3	114.5	113.8	112.1	114.5	2.4
18	K (mg/l)	7.5	7.6	7.9	7.7	6.4	6.2	6	5.9	6.9	0.85

STD: Standard Deviation.

**Table (3.5):** Results of laboratory tests for samples in the spring (2023).

No.	Parameter	L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	Mean	STD
1	Temp. (°C)	18	18	18	18	19	19	20	20	18.8	0.9
2	pH	8.11	8.15	8.03	8.12	8.2	8.24	8.23	8.27	8.17	0.08
3	EC (µS/cm)	1424	1426	1481	1516	1571	1575	1759	1810	1570	144.5
4	TDS (mg/l)	926	927	963	985	1021	1024	1143	1177	1021	93.9
5	Turb. (NTU)	3.12	5.65	3.52	2.63	2.75	2.98	4.64	4.99	3.78	1.15
6	DO (mg/l)	7.30	8.30	8.50	8.80	8.20	8.40	8.20	8.10	8.23	0.433
7	BOD <sub>5</sub> (mg/l)	1.1	1.3	2.2	3.5	2.2	1.9	2.8	1.7	2.08	0.78
8	HCO <sub>3</sub> (mg/l)	132	112	112	102	98	122	124	132	116.7	12.8
9	Alk. (mg/l)	132	128	124	122	112	134	132	136	127.5	7.9
10	TH (mg/l)	504	500	516	508	520	564	552	524	523.5	22.9
11	Ca (mg/l)	126.4	118.4	124.8	128	129.6	120	116.8	115.2	122.4	5.5
12	Mg (mg/l)	45.9	49.8	49.8	45.9	47.8	64.4	63.4	57.6	53.1	7.6
13	Cl (mg/l)	233.2	192.1	217.6	205.8	219.5	241.8	284.2	294.0	236.0	36.2
14	NO <sub>3</sub> (mg/l)	5.56	6.57	6.68	7.69	5.06	5.38	5.76	3.66	5.79	1.21
15	SO <sub>4</sub> (mg/l)	266.1	306.4	265.7	310.4	299.5	326.5	318.4	427.2	315.0	50.5
16	TSS (mg/l)	4.4	7.8	3.6	4.5	3.4	6.8	4.8	9.4	5.6	2.17
17	Na (mg/l)	155.4	153.9	167.4	170.5	174.8	183.5	200.9	209.7	177.0	20.08
18	K (mg/l)	7.8	7.0	7.4	7.2	7.0	7.4	7.6	7.8	7.4	0.32

STD: Standard Deviation.

**Table (3.6):** Results of laboratory tests for average sample values for all seasons.

No.	Parameter	L-1	L-2	L-3	L-4	L-5	L-6	L-7	L-8	Mean	STD
1	Temp. (°C)	22.5	22.8	22.8	23.1	23.8	23.9	24.4	24.4	23.4	0.75
2	pH	7.62	7.64	7.65	7.72	7.74	7.81	7.83	7.82	7.73	0.09
3	EC (µS/cm)	1458	1477	1548	1564	1566	1583	1634	1669	1562	70.9
4	TDS (mg/l)	947	960	1006	1016	1018	1029	1062	1085	1016	46.2
5	Turb. (NTU)	6.46	10.55	4.99	3.69	4.38	5.65	9.27	8.45	6.68	2.48
6	DO (mg/l)	6.78	6.98	6.85	7.30	7.58	7.33	7.55	7.60	7.24	0.34
7	BOD <sub>5</sub> (mg/l)	1.60	1.83	1.68	2.23	1.95	1.43	2.38	1.68	1.84	0.32
8	HCO <sub>3</sub> (mg/l)	120	113	108	105	106	107	111	119	111	5.52
9	Alk. (mg/l)	123	123	119	115	113	122	122	126	120	4.22
10	TH (mg/l)	553	567	551	584	560	593	580	567	569	15.1
11	Ca (mg/l)	122.4	120.2	123.2	121.6	123.2	118.8	117.2	117.6	120.5	2.44
12	Mg (mg/l)	60.3	64.9	59.3	68.3	61.5	69.5	70.0	66.6	65.1	4.3
13	Cl (mg/l)	200.9	181.3	199.9	197.0	200.9	209.4	220.0	225.9	204.4	13.9
14	NO <sub>3</sub> (mg/l)	4.62	4.78	4.66	5.03	3.66	4.06	4.08	3.56	4.31	0.54
15	SO <sub>4</sub> (mg/l)	296.5	312.4	281.9	355.5	310.2	315.2	293.3	323.4	311.1	22.5
16	TSS (mg/l)	7.6	11.2	5.1	4.5	5.1	6.7	9.0	9.4	7.32	2.41
17	Na (mg/l)	132.8	134.5	150.1	152.2	155.9	159.4	168.9	170.8	153.1	14.0
18	K (mg/l)	9.15	8.95	9.43	9.75	8.98	9.30	9.83	9.55	9.37	0.33

STD: Standard Deviation.

### 3.8 Water Quality Standards.

The calculation processes of WQ indices require using standard specifications for parameters. **Table (3.7)** presents the WQ standards for drinking uses for the selected parameters in this study according to the World Health Organization (2017), and Iraqi water standards for drinking (2009). In this study, the standards of WHO in 2017 are adopted.

**Table (3.7):** water quality limits of parameters for drinking uses according to Iraqi standards (2009) and WHO standards (2017).

No.	Parameter	Unit	Iraqi standards	WHO standards	No.	Parameter	Unit	Iraqi standards	WHO standards
1	Temp.	°C	....	25	10	TH	mg/l	500	500
2	pH	.....	6.5 - 8.5	6.5 - 8.5	11	Ca	mg/l	150	75
3	EC	µS/cm	2000	2000	12	Mg	mg/l	100	50
4	TDS	mg/l	1000	1000	13	Cl	mg/l	350	250
5	Turbidity	NTU	5	5	14	NO <sub>3</sub>	mg/l	50	50
6	DO	mg/l	5	5	15	SO <sub>4</sub>	mg/l	400	250
7	BOD <sub>5</sub>	mg/l	Nil	5	16	TSS	mg/l	...	20
8	HCO <sub>3</sub>	mg/l	....	125	17	Na	mg/l	200	200
9	Alkalinity	mg/l	200	120	18	K	mg/l	10	12

### 3.9 Calculation Process of WQI Method

The water quality indices aim to get a single value that represents the required value of the surface water quality at any location from which the sample was taken. As previously mentioned, there are different methods for calculating the WQI in the Al-Abbasiyah River for drinking and irrigation.

#### 3.9.1 Methods of Calculation WQI for Drinking Uses

To calculate the water quality for drinking uses in the Al-Abbasiyah River, two methods were adopted in this study **(1)**: Weighted Arithmetic-Water Quality Index (WA-WQI) and **(2)**: the Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI). In this study, to compare the results of them and to give a clear perception of the water quality of the river for drinking purposes, these methods were used.

##### 3.9.1.1 Weighted Arithmetic-Water Quality Index (WA-WQI)

This method was used to calculate the water quality index in eight locations (along the river) for all seasons (2022 – 2023). The values of measured parameters, that were analyzed in the laboratory and mentioned in **Tables (3.2, 3.3, 3.4, 3.5, and 3.6)**, were involved in the calculation of the water quality index. The World Health Organization standards (2017) for drinking purposes were used to find the weight of each parameter ( $w_i$ ) using **Equation (2.10)**. This method also included finding the sub-index for each parameter ( $q_i$ ) using **Equation (2.11)**. The final value of the water quality index was found in **Equation (2.12)**. The water quality rating is given for each WQI value according to **Table (3.8)**. The description of equations 2.10, 2.11, and 2.12 (for WA-WQI) were mentioned in Chapter 2.

**Table (3.8):** WQ rating according to WA-WQI (Brown et al., 1970).

WA-WQI Value	WQR	Symbol	WA-WQI Value	WQR	Symbol
0 - 25	Excellent	E-WQ	76 - 100	Very poor	VP-WQ
26 - 50	Good	G-WQ	> 100	Unsuitable uses for human	UUH-WQ
51 - 75	poor	P-WQ			

### 3.9.1.2 Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI)

Another method that was used to calculate the water quality index for drinking purposes in the Al-Abbasiyah River is CCME-WQI. The same measured water quality parameters that were used to calculate the WA-WQI were included in the CCME-WQI calculation. The allowable limits according to the WHO standards (2017) were also used corresponding to each parameter.

In this method, the final value of the water quality index was calculated according to **Equation (2.8)** after finding the value of the three factors (F1, F2, and F3) and the calculated value of (nse) using **Equations (2.2, 2.3, 2.4, and 2.7)**, respectively. **Equation (2.5)** was applied to estimate the excursion's value for all parameters except DO which was calculated using **Equation (2.6)**. After finding the CCME-WQI value for each site, the water quality index values were classified according to values in **Table (3.9)**. Note that **Table (3.9)** is an update to **Table (2.3)**, as this update was made to match the names of the water quality rating for the CCME-WQI with the WA-WQI to clearly compare the results from both indices during this study.

**Table (3.9):** WQR according to CCME-WQI (Modified after Paun et al., 2016).

CCME-WQI Value	WQR	Symbol
95 - 100	Excellent	E-WQ
80 - 94	Good	G-WQ
60 - 79	Poor	P-WQ
45 - 59	Very poor	VP-WQ
0 - 44	Unsuitable uses for human	UUH-WQ

### 3.9.2 Methods of Calculation WQI for Irrigation Use

Al-Abbasiyah River is considered the main source for irrigation of vast agricultural lands located on its banks. Therefore, evaluating the river water quality for irrigation uses is no less important than evaluating it for drinking uses. The index of water quality for irrigation was proposed by Meireles et al.

(2010). In addition, some other irrigation indices were used to evaluate the river water quality for irrigation uses as shown below:

### 3.9.2.1 Water Quality Index for Irrigation (WQIFIR)

The WQIFIR method was used to calculate the water quality of the Al-Abbasiyah River for irrigation purposes at eight selected sites along the river and for all seasons in which samples were taken. In this method, the water quality index was calculated based on the values of seven parameters only, where these parameters have a significant role in plants and soil. These parameters are  $\text{HCO}_3^-$ , EC, SAR, Ca, Mg,  $\text{Cl}^-$ , and  $\text{Na}^+$ . Each parameter has a specific weight ( $w_i$ ), which is shown in **Table (2.7)**. The value of the sub-index for each parameter ( $wq_i$ ) was calculated using Equation (2.14) according to the range values displayed in **Table (2.6)**. Then, Equation (2.13) was used to calculate the final value of WQIFIR. Finally, a water quality rating was given for each WQI value according to **Table (2.8)**.

### 3.9.2.2 Other Irrigation Water Quality Indices

In addition to the previous WQI methods, several other indices that describe the acceptability of water for irrigation purposes were used. These indices were applied to all eight sampling locations, along the Al-Abbasiyah River, during four seasons. These indices are Sodium adsorption ratio (SAR), Kelly's index (KI), soluble sodium percentage (SSP), and Permeability index (PI). **Equations (2.15, 2.16, 2.17, and 2.18)** were used to calculate the WQI values for irrigation in each location of the river based on the classification of each index listed in **Tables (2.9, 2.10, 2.11, and 2.12)**, respectively.

## 3.10 Application of Visual Basic Software for WQI Methods

Visual Basic10 (<https://visualstudio.microsoft.com/>) is one of the most important programming languages used by many researchers to create various computational programs, due to its ease of use compared to other programming

languages. Moreover, it gives a simple graphical interface to the user. Visual Basic is a tool that allows the creation of applications in the computer that perform certain functions based on the desire of the programmer and according to the codes written in the BASIC language (Kadhim, 2022).

In this study, three applications were built, using Visual Basic, to calculate the WQI methods. These methods are WA-WQI, CCME-WQI, and WQIFIR. The main objective of these applications is to facilitate the calculations and to provide a simple window that will be useful to give a fast indication of the WQI value for any surface water and also for any selected number of parameters at any time. They can also be used by anyone by simply entering the required parameters. The descriptions of these applications are as follows:

### **3.10.1 Visual Basic Application to Calculate WA-WQI Method**

This application was built to facilitate the calculation of WA-WQI for any water sample by simply entering the selected parameters of the WQ in the calculations for that sample. This application is characterized by its ease and the possibility of use by anyone interested in the field of water quality by downloading this application on a computer.

The application consists of two main windows. The first window (**Figure 3.6**) opens when opening the application, where it contains the title of the water quality index and its equations used to calculate it. The "Exit " button is used to end the application, and the "Start" button to open the second window.

In the second window (**Figure 3.7**), the number of water quality parameters included in the calculations is selected by users according to work requirements to calculate the final value of WQI and the possibility of use in various cases for waterbodies. This application is most suitable for the WA-WQI method because the main concept of this method states to use unspecified numbers of parameters to calculate the WQI.

The number of parameters is selected according to the user's desire (from 5 to 20) by using a "Drop List" at the top of the window. Then, the required data is entered, which includes the symbol of the parameters, their measured values ( $C_i$ ), the allowable standard limits ( $S_i$ ), and the ideal value ( $V_o$ ) for each parameter. The value of the WA-WQI and the water quality rating (WQR) for the selected samples (at any location) are calculated by simply pressing the "Calculate" button. This window also includes the "Exit" button to end the application and the "Return" button to return to the first window.

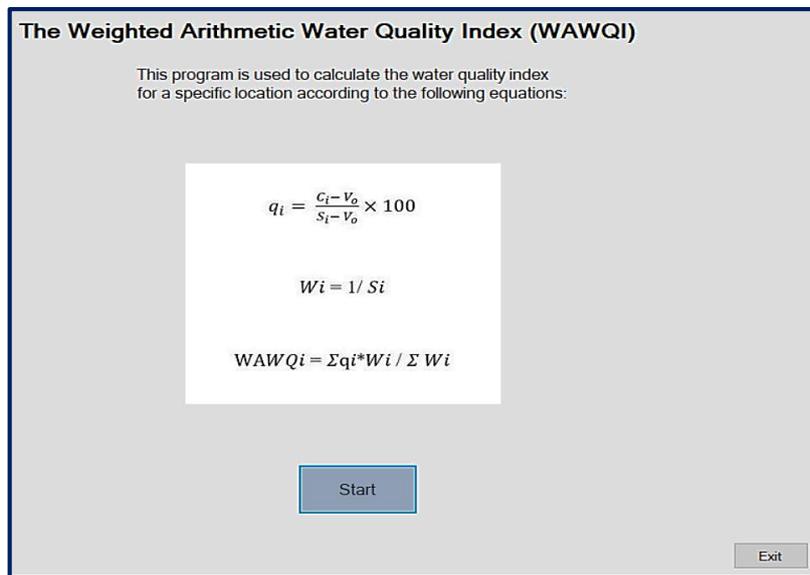


Figure (3.6): First window of Visual Basic application to calculate WA-WQI.

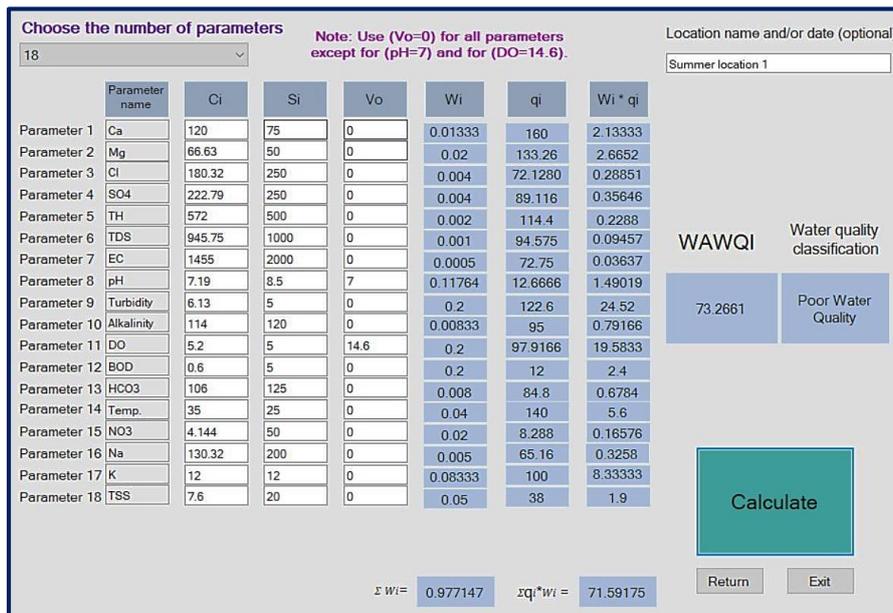


Figure (3.7): Second window of Visual Basic application to calculate WA-WQI.

### 3.10.2 Visual Basic Application to Calculate CCME-WQI Method

This application was built to facilitate the calculation of the CCME-WQI for any water sample by entering the required parameters in the calculations for that sample. The application consists of two main windows.

The first window (**Figure 3.8**) appears when the application is opened, containing the title of the CCME-WQI method and its equations that are used in the calculation process. Moreover, the button "Exit" is used to end the application, while the button "Start" to open the second window. In the second window (**Figure 3.9**), the choice "number of tests for each parameter" is selected based on the user's desire using a "drop-down list" at the top of the window. Then, the parameters to be included in the calculations are activated into the "Check box" corresponding to each parameter.

It is worth noting that, it is necessary to enter "DO" and "pH" within the first and second rows, respectively, if they are included in the calculations, due to these two parameters having different equations used for their calculating. If DO and pH parameters are not used in the calculations, it is possible to neglectable these two rows of them. This was done to make the application more generic and allow more freedom for the user to choose which parameters to include. In general, this application enables the user to choose whatever number of water quality parameters (up to 20 parameters).

Then, the required data is entered, which includes the symbol of the parameters, their measured values at any water body, and the standard allowable limits ( $S_i$ ) for each parameter. The CCME-WQI values and the WQR for measured parameters of samples at any location are calculated simply by pressing the button "Calculate". This window also includes an "Exit" button to end the application and also "Return" button to return to the first window.

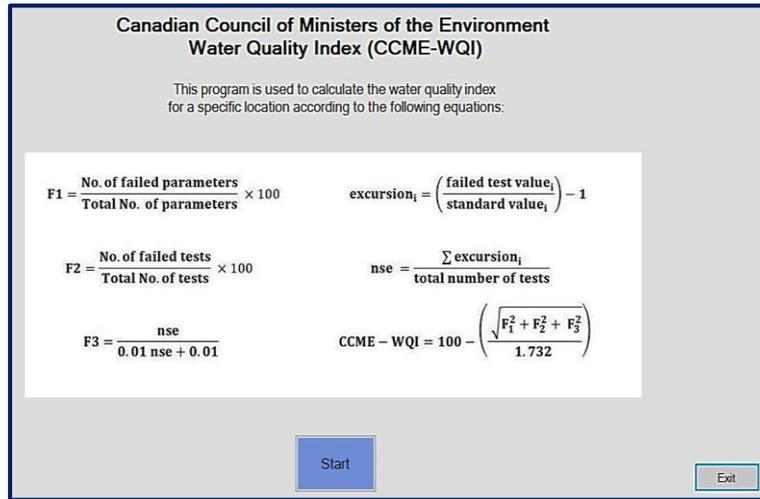


Figure (3.8): First window of the Visual Basic application to calculate CCME-WQI.

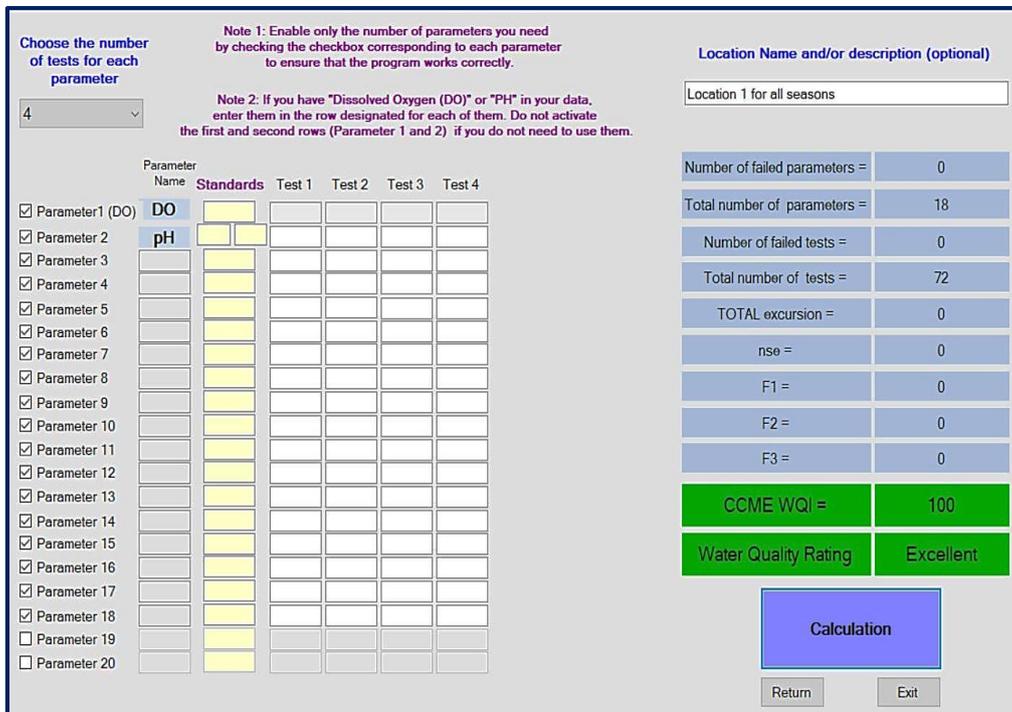


Figure (3.9): Second window of Visual Basic application to calculate CCME-WQI.

### 3.10.3 Visual Basic Application to Calculate WQI for Irrigation

This application was built to facilitate the calculation of irrigation water quality indices for any water sample. Similar to the previous two applications, this application is easy to use and can be applied to anyone interested in the field of water quality.

The application consists of two main windows. The first window (Figure 3.10) appears when the application is opened, containing the application title of the water quality index, a series of main equations, and tables that

involve standard limit values used in the calculations. In this window, the button “Exit” is used to end it, and the button “Start” to open the second window.

In the second window (Figure 3.11), the user can choose either to calculate the WQIFIR only or calculate the other irrigation indices that are used in this study. This is done based on the user's desire by using a "drop-down" list at the top of the window. After that, the values of the water quality parameters required for the calculations are entered by the user. The WQIFIR and other irrigation indices are calculated simply by pressing the “Calculate” button, where the application converts the units of parameters from (mg/l) to (meq/l) automatically to be used in the equations. This window includes two buttons (1): "Exit" to end the application and (2): "Return" to return to the first window.

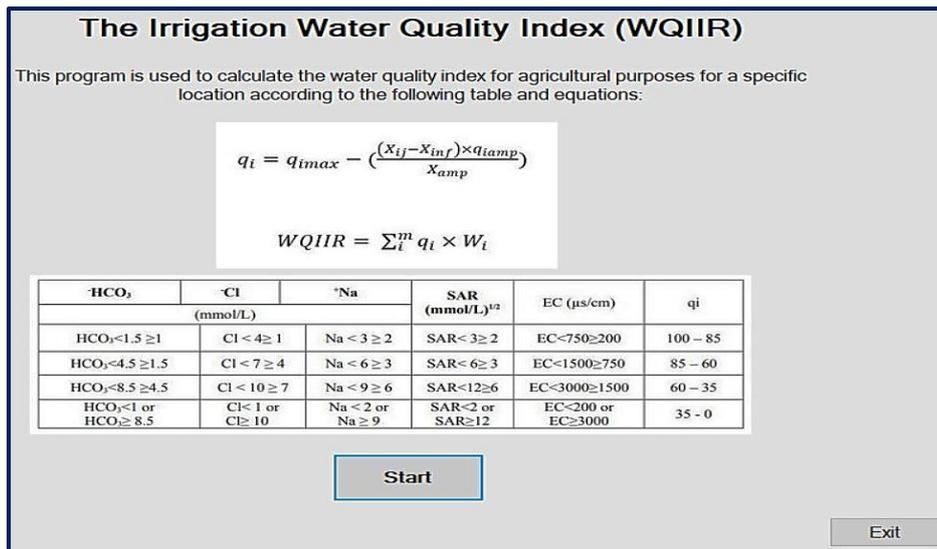


Figure (3.10): First window of Visual Basic application to calculate WQIFIR.

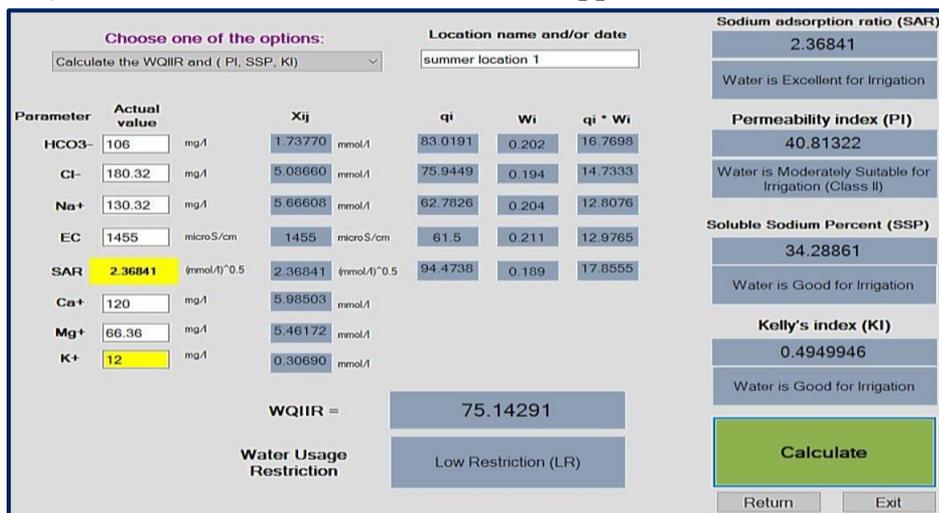


Figure (3.11): Second window of Visual Basic application to calculate WQIFIR.

### 3.11 Creating Prediction Maps Using IDW in GIS

Creating prediction maps of water quality index using IDW (Inverse Distance Weighting) in GIS (Geographic Information System) is a useful tool for visualizing spatial patterns and making predictions about water quality at locations where data is not available (Huang et al., 2019; Jena and Barik, 2020).

To generate spatial distribution maps of the water quality of the Al-Abbasiyah River for purposes of drinking and irrigation, the IDW method was applied in ArcGIS 10.8 software (<https://www.arcgis.com/index.html>). This method was used because it gives better results compared to other methods (Abbas, 2013, Chabuk et al., 2020).

In this study, spatial distribution maps were created, along the Al-Abbasiyah River, for the studied water quality parameters and the water quality indices for drinking and irrigation uses (WA-WQI, CCME-WQI, and WQIFIR) throughout the study period and each season.

Validation of the prediction map is essential by comparing it with independent data or through other means of verification. Also, it is important to keep in mind that the accuracy of the map depends on the quality and density of the input data, as well as the interpolation method used. IDW is just one method of spatial interpolation available in GIS software, and the appropriate method may depend on the specific data and research questions being addressed. Other interpolation methods include Kriging, Splining, and Trend Surface Analysis. Overall, creating prediction maps of water quality index using IDW in GIS can be a useful tool for visualizing spatial patterns and making predictions about water quality at locations where data is not available (Huang et al., 2019; Jena and Barik, 2020).

### 3.12 Statistical Analysis Using SPSS Software

Statistical analysis using SPSS (Statistical Package for the Social Sciences) software (IBM, 2020) has numerous applications in social sciences

research. Some of the most common applications include analyzing survey data, comparing means between groups, and testing the relationship between variables.

SPSS has important features represented by its capacity to implement a variety and vast statistical processes (simple and complicated). SPSS also provides a user-friendly interface that allows researchers to import and manipulate data, perform statistical tests, and visualize results with ease (Field, 2017; IBM, 2020).

SPSS is commonly used in various fields, including psychology, sociology, education, public health, and business. Researchers can use SPSS to analyze and interpret data from experimental and non-experimental designs, surveys, and observational studies. A further feature of SPSS is its capability to manage enormous amounts of data. This valuable software enables researchers to manage vast sets of data and resolve statistically complex problems. SPSS can also generate tables, graphs, and charts to visualize data and help researchers better understand their findings. However, it is important to note that while SPSS is a powerful tool, it is not a substitute for a strong understanding of statistical concepts and methods. Researchers should be familiar with the underlying principles of statistical analysis and interpretation to accurately analyze and report their findings (Field, 2017; IBM, 2020). Below is a brief explanation of the statistical methods that were applied in SPSS for this study.

### **3.12.1 Pearson's Correlation Analysis (PCA)**

It is a useful statistical method to illustrate the relationship's state to which one variable is dependent on the others (Belkhiri et al. 2011). The correlation coefficient ( $r$ ) is used to measure the strength and dependency of interactions between the variables. According to Mudgal et al. (2009), for the threshold of  $p < 0.05$ , a complete relationship between the variables occurs when the ( $r$ ) value = +1, while the value of (-1) shows a perfect relationship also but

inversely, and the zero value indicates no relationship between the variables. In general, PCA values with (r) more than 0.7 are thought to indicate a strong correlation, whereas r values of (0.5 to 0.7) are thought to indicate a moderate correlation (Shil et al., 2019). The dependence of variables on one another is vividly seen by Pearson's correlation matrix. Pearson's correlation coefficient (r) can be measured by the following equation (Emerson, 2015):

$$r = \frac{n(\sum(x * y) - (\sum x * \sum y))}{\sqrt{(n \sum x^2 - (\sum x)^2) * (n \sum y^2 - (\sum y)^2)}} \quad (3.1)$$

Where:  $x$  and  $y$  are the  $i^{\text{th}}$  observed and estimated values, respectively; and  $n$  is the number of observations.

### 3.12.2 Regression Models

Regression analysis, in general, focuses on the investigation of relationships between quantitative variables to determine, approximate, and confirm the relationship (Johnson & Bhattacharyya, 2019). The statistical method of regression is used to establish the relationship between two or more variables. It is one of the most statistical tools that has been used because it offers simple procedures for determining a functional relationship between variables (Chatterjee & Hadi, 2006). Simple, multiple, and nonlinear regression are different types of regression analysis.

#### 3.12.2.1 Simple Regression

It is used to check the relationship between two variables that appear in a data set. The formula below provides the true relationship between Y and X (Zare Abyaneh, 2014) as follows:

$$Y = \beta_0 + \beta_1 X \quad (3.2)$$

Where:  $\beta_1$  and  $\beta_0$  are regression coefficients; and X and Y are independent and dependent variables, respectively.

### 3.12.2.2 Multiple Regression

A linear regression model with more than independent variables and one dependent variable is known as multiple linear regression. Multiple linear regression assumes that there are multiple independent variables and that the response variable is a linear function of the model parameters. Multiple linear regression models have the following general form (Zare Abyaneh, 2014):

$$Y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \dots + \beta_n \cdot x_n \quad (3.3)$$

where:  $Y$  is a dependent variable;  $(\beta_0, \beta_1, \beta_2, \dots, \beta_n)$  are regression coefficients;  $(x_1, x_2, \dots, x_n)$  are independent variables in the model.

### 3.12.3 Coefficient of determination ( $R^2$ )

The coefficient of determination ( $R^2$ ) ranges from 0 to 1 and is used as a guide for determining the precision of a linear model. Also, the coefficient of determination assesses a model (the level of variability in the data set) and predicts future results (Johnson & Bhattacharyya, 2019).

### 3.12.4 P-Value

The P-value is a statistical measurement employed to check a hypothesis' validity against actual data. The significance of the results concerning the null hypothesis can be determined by a p-value when doing a statistical test. The null hypothesis states that there is no relationship between the two variables being investigated. It states that the results are unintentional and have no effect on the theory being studied. So, the null hypothesis assumes that the thing you are attempting to prove did not occur. According to the alternative hypothesis, the independent variable did affect the dependent variable, and the results are significant for the investigated theory (McLeod, 2019).

The p-value, which ranges from 0 to 1, is frequently used to indicate the statistical significance level. The evidence that you must reject the null hypothesis is stronger the smaller the p-value. A p-value of 0.05 or less indicates statistical significance. As a result, the alternative hypothesis is accepted, and

rejected the hypothesis of null is. A p-value greater than 0.05 denotes a strong index supporting the null hypothesis but statistically is not significant. This indicates according to McLeod (2019), that rejects the alternative hypothesis while adopting the null hypothesis.

### 3.12.5 Shapiro-Wilk Test

The Shapiro-Wilk test is a hypothesis test that is applied to a sample to check if data is normally distributed and the null hypothesis is that the sample has been generated from a normal distribution. Thus, the null hypothesis is disproved and there is proof that the tested data are not normally distributed if the p-value is smaller than the set alpha level (0.05). Yet if the p-value exceeds the set alpha level (0.05), the null hypothesis cannot be disproved and there is proof that the tested data are normally distributed.

In addition, the test provides a W value; low values suggest that the population is not normally distributed. The test has limitations, the most significant of which is that it is biased by sample size. A greater sample size increases the likelihood of obtaining a statistically significant result (Razali & Yap, 2011).

### 3.12.6 MSE and RMSE

After a regression model is built, it must be verified that it can accurately predict the value of the response variable using the values of the predictor variables. To determine the model's fit to a data set, two measures are frequently used: the mean squared error (MSE) and the root mean squared error (RMSE), which are calculated as follows.

**MSE** is a statistic that shows the average squared difference between a dataset's actual values and predicted values. The smaller the MSE, the more accurately a model matches a dataset (Chai et al., 2009).

$$MSE = \frac{1}{n} \sum_{i=1}^n (P_i - O_i)^2 \quad (3.4)$$

where:  $P_i$  and  $O_i$  are the predicted and observed values for the  $i^{\text{th}}$  observation, respectively;  $n$  is the number of observations.

**RMSE** is a statistic that represents the square root of the mean squared difference between the predicted and actual values in a dataset. The smaller the RMSE, the more accurately a model fits a data set. RMSE is the most easily interpreted statistic, as it has the same units as the quantity plotted on the vertical axis or Y-axis. It is calculated as (Chai et al., 2009):

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (P_i - O_i)^2} \quad (3.5)$$

where:  $P_i$  and  $O_i$  are the predicted and observed values for the  $i^{\text{th}}$  observation, respectively;  $n$  is the number of observations.

## 4.1 Introduction

This chapter includes studying the results obtained throughout the study period and discussing these results to find out the reasons for the fluctuation in parameter values and, consequently, the water quality of the water body.

The results contain displaying and analyzing the values of the collected water quality parameters. In addition, studying the values of the water quality indices, that were calculated for each selected location in the river, and creating spatial distribution maps using the IDW technique in the GIS. Linear regression models were also created by using SPSS software to ensure a clear judgment on the quality of the river water for drinking and irrigation purposes during the study period, as shown in the following sections.

## 4.2 Water Quality Parameters (WQP)

In this study, eighteen parameters were tested, and their results were as follows:

### 4.2.1 Water Temperature (Temp)

The lowest temperature value was 12 °C in winter and the highest value was 38 °C in summer. The annual average water temperature along the river during the study period was 23.4 °C. According to the standard limit of the WHO (2017) of 25 °C, this value is considered acceptable. By observing **Figure (4.1a)**, it appears that there is almost no difference in water temperature between different locations along the river for the same season, but it changes from one season to another.

### 4.2.2 Hydrogen Ions (pH)

pH has an impact on aquatic species since numerous of their biological functions are dependent on it. The pH values of the river water ranged between 7.19 in (L-1) in summer and 8.27 in spring in (L-8) (**Figure (4.1b)**). The yearly mean of the pH for all sites along the river during the study period was 7.73, which was within the standard range of the WHO, 2017 (6.5 and 8.5),

### 4.2.3 Electrical Conductivity (EC)

The minimum and maximum values of EC (in spring) were 1424  $\mu\text{S}/\text{cm}$  in (L-1) and 1810  $\mu\text{S}/\text{cm}$  in (L-8), respectively. The annual average value of EC (1562) during the study period was within the standards limit of WHO, 2017 (2000  $\mu\text{S}/\text{cm}$ ). **Figure (4.1c)** illustrates the change in EC values at all locations during the study period (August 2022 – March 2023). It is noted that EC increases gradually with the length of the river as a result of the gradual decrease in water discharge into the river and the increase in agricultural and other human activities on both sides of the river.

### 4.2.4 Total Dissolved Solids (TDS)

The annual average of TDS along the river was 1015.5 mg/l, which is very slightly above the standard limit of WHO, 2017 (1000 mg/l). The lowest value of TDS was 925.6 mg/l in (L-1) (spring) while the highest value of 1176.5 mg/l was recorded in the same season in (L-8) (**Figure (4.1d)**). According to Ewaid et al. (2020), erosion of soil, runoff from agriculture, residential garbage contamination, and other actions by humans may be the main reasons for gradually increasing TDS with the river length.

### 4.2.5 Total Suspended Solids (TSS)

In the summer and autumn seasons, the TSS readings were slightly higher than their readings in winter and spring. The lowest reading of TSS was 3.2 mg/l at (L-6) during winter whereas the highest reading was 15.8 mg/l at (L-2) during autumn (**Figure (4.1e)**). According to the standards limit of WHO (2017) (20 mg/l), the average value of TSS (7.3 mg/l) along the river during all seasons was accepted. The decrease in the TSS values was due to the reduction in the discharge of the Al-Abbasiyah barrage throughout the study period, which led to a decrease in the river velocity and an increase in sedimentation rates.

### 4.2.6 Turbidity (Turb)

The lowest value of turbidity was 2.63 NTU at (L-4) and (L-5) in spring and winter, respectively, while during autumn the maximum reading of turbidity

(16.2 NTU) was in (L-2) (**Figure (4.1f)**). The mean annual reading of turbidity along the river was 6.68 NTU. This value was over the allowable limit of WHO in 2017 (5 NTU). The highest turbidity values were recorded in the autumn and summer seasons, during which the large agricultural lands on both sides of the river are cultivated with rice and other crops. This leads to the existence of pollution from organic materials in addition to surface runoff that contains large particles at the suspension level.

#### 4.2.7 Dissolved Oxygen (DO)

Location (L-5) had the highest DO reading of 10.2 mg/l during winter, while location (L-3) had a minimum reading of 4.7 mg/l during summer (**Figure (4.2a)**). The average annual reading of DO was 7.2 mg/l, which was within the recommended values of DO (> 5 mg/l) by WHO 2017. The DO readings during both spring and winter seasons were greater than those that were observed during summer and autumn. This is because the soluble content of oxygen within water reduces at high temperatures. The greater level of organic matter in water bodies, whereby degradation accelerates the loss of oxygen as well as stream stagnation, was the cause of the fall in oxygen in the water levels during the summer months (Izonfuo and Bariweni, 2001).

#### 4.2.8 Biochemical Oxygen Demand (BOD<sub>5</sub>)

The BOD<sub>5</sub> values of the river water ranged between 0.4 mg/l at location (L-6) in summer and 3.5 mg/l during spring in location (L-4) (**Figure (4.2b)**). 1.8 mg/l represented the average reading of the BOD<sub>5</sub> for all locations along the river during all seasons. All readings of BOD<sub>5</sub> were lower than the allowable upper limit by WHO, 2017 (5 mg/l).

#### 4.2.9 Bicarbonate (HCO<sub>3</sub>)

Compared to the recorded readings from the winter and spring seasons, the HCO<sub>3</sub> readings throughout both seasons summer and autumn, were lower. HCO<sub>3</sub> values ranged from 78 mg/l during autumn at (L-3) to 152 mg/l at (L-2) and (L-8) during winter. The average value of HCO<sub>3</sub> along the Al-Abbasiyah

River during all seasons was 110.9 mg/l (within the standard limit of WHO, 2017). **Figure (4.2c)** demonstrates the values of  $\text{HCO}_3$  at the selected locations during the study period.

#### 4.2.10 Total Alkalinity (Alk)

Alkalinity measurements throughout summer and autumn were found less than those during both spring and winter. **Figure (4.2d)** shows the change in alkalinity values at all locations during the study period. Alkalinity values ranged from 90 mg/l at (L-3) during autumn to 152 mg/l at (L-2, L-7, and L-8) in winter, where this value was upper than the allowable standard limit of WHO (2017) (120 mg/l). The average reading of alkalinity during the four seasons in the river was 120 mg/l.

#### 4.2.11 Calcium (Ca)

For calcium ions, there was no significant change between the values within the different seasons and locations of the river. However, all Ca values were higher than the WHO standard limit (2017) of Ca (75 mg/l). As a result of the geological formation of the river's bed, which consists of a large percentage of limestone. The Ca values ranged between 104 mg/l at location (L-8) in winter and 129.6 (mg/l) at (L-5) in spring (**Figure (4.2e)**). Throughout the seasons, the mean concentration of calcium equaled 120.5 (mg/l) at all locations along the Al-Abbasiyah River.

#### 4.2.12 Magnesium (Mg)

The Mg values of the river water ranged between 45.87 mg/l at locations (L-1), and (L-4) in spring to 85.88 mg/l during autumn at (L-8). The mean concentration of magnesium for all locations along the river during all seasons was 65 mg/l, which was above the standard limit OF WHO (2017) of Mg (50 mg/l) (**Figure (4.2f)**).

#### 4.2.13 Total Hardness (TH)

The TH values of the river water ranged between 500 mg/l (in spring) at location (L-2) and 672 mg/l (in autumn) at location (L-8). The average TH

concentration for all locations of the river throughout four seasons was 569 mg/l. All readings were over the WHO standard limit (2017) of the TH (500 mg/l) due to high values of calcium and magnesium ions in the river water as a result of the river passing through an area consisting of a large proportion of limestone. The total hardness values at all locations during the four seasons are shown in **Figure (4.2g)**.

#### 4.2.14 Chloride (Cl)

The river water's chloride levels varied from 294 mg/l (L-2) during spring to 162.68 mg/l (L-8) in summer. The average value of the Cl for the selected locations along the river during all seasons was 204.4 mg/l, which was within the acceptable limit (250 mg/l) of WHO (2017) (**Figure (4.2h)**).

#### 4.2.15 Nitrate (NO<sub>3</sub>)

In comparison to the winter and spring seasons, the NO<sub>3</sub> levels during summer and autumn were lower. The lowest and highest readings of NO<sub>3</sub> (mg/l) were 1.438 at (L-7) during summer and 7.686 during spring at (L-4), respectively (**Figure (4.3a)**). The average reading of NO<sub>3</sub> during the study period along the river was 4.305 mg/l, and this reading was within the permissible standard limit of WHO (2017).

#### 4.2.16 Sulfate (SO<sub>4</sub>)

The seasonal average value of the SO<sub>4</sub> for all locations along the river was 311 mg/l, which was above the upper WHO limit (2017) (250 mg/l) (**Figure (4.3b)**). The river's SO<sub>4</sub> levels varied from 209.6 (mg/l) during summer to 538.71 (mg/l) during winter at (L-8).

#### 4.2.17 Sodium (Na)

The Na values of the river water varied from 112.1 mg/l in winter to 209.68 mg/l in spring at location (L-8) (**Figure (4.3c)**). The seasonal average value of Na for the eight locations along the river was 153 mg/l, and this value was within the standard limit of WHO (2017) of 200 mg/l.

4.2.18 Potassium (K)

The K values in summer were higher than their values in autumn, winter, and spring seasons (Figure (4.3d)). The concentrations of potassium ranged from 5.9 mg/l during winter at (L-8) to 16 (mg/l) during summer at (L-7). According to the standard limit of WHO (2017) (12 mg/l), The average value of K (9.4 mg/l) of the river during all seasons was accepted.

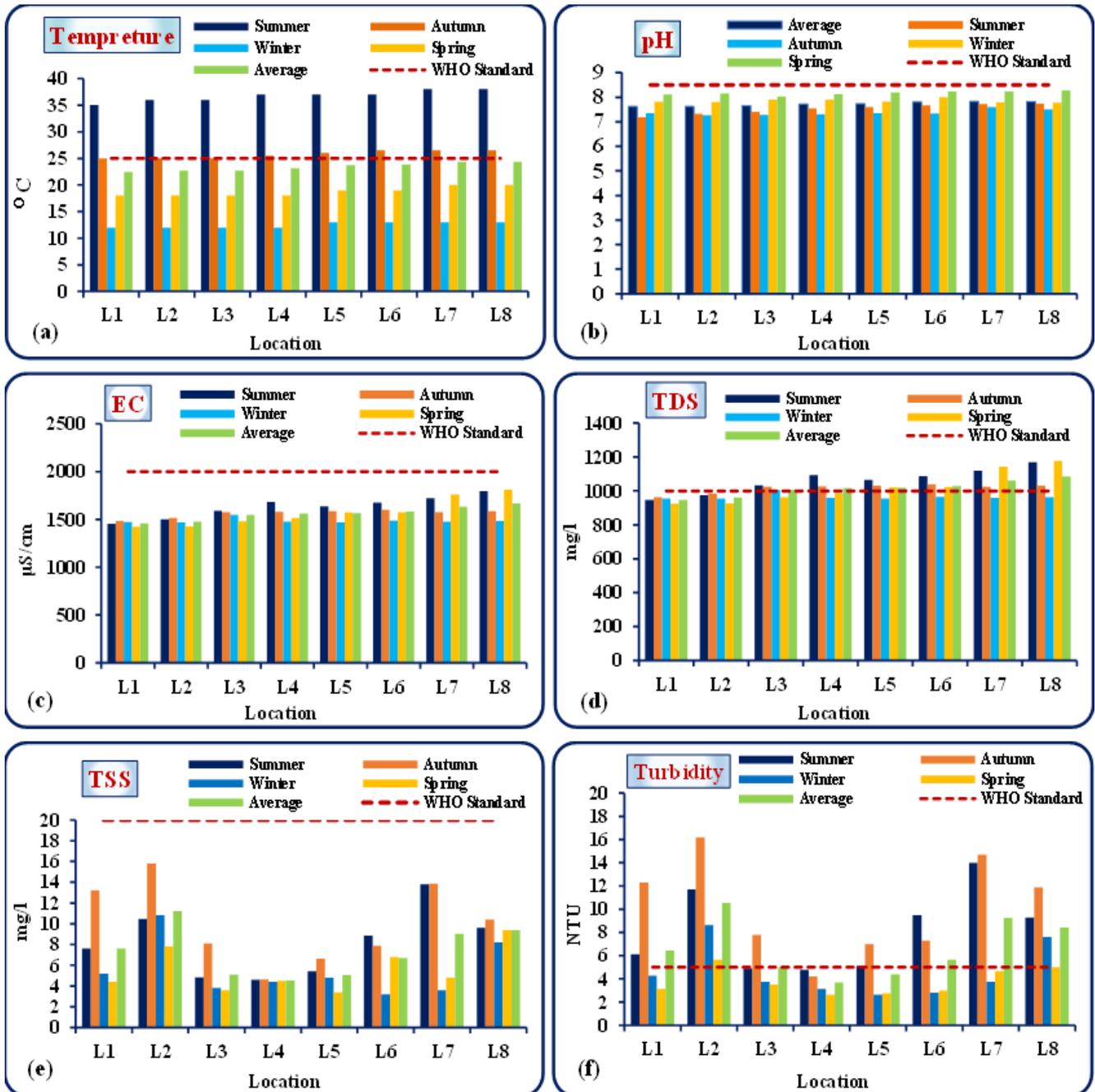
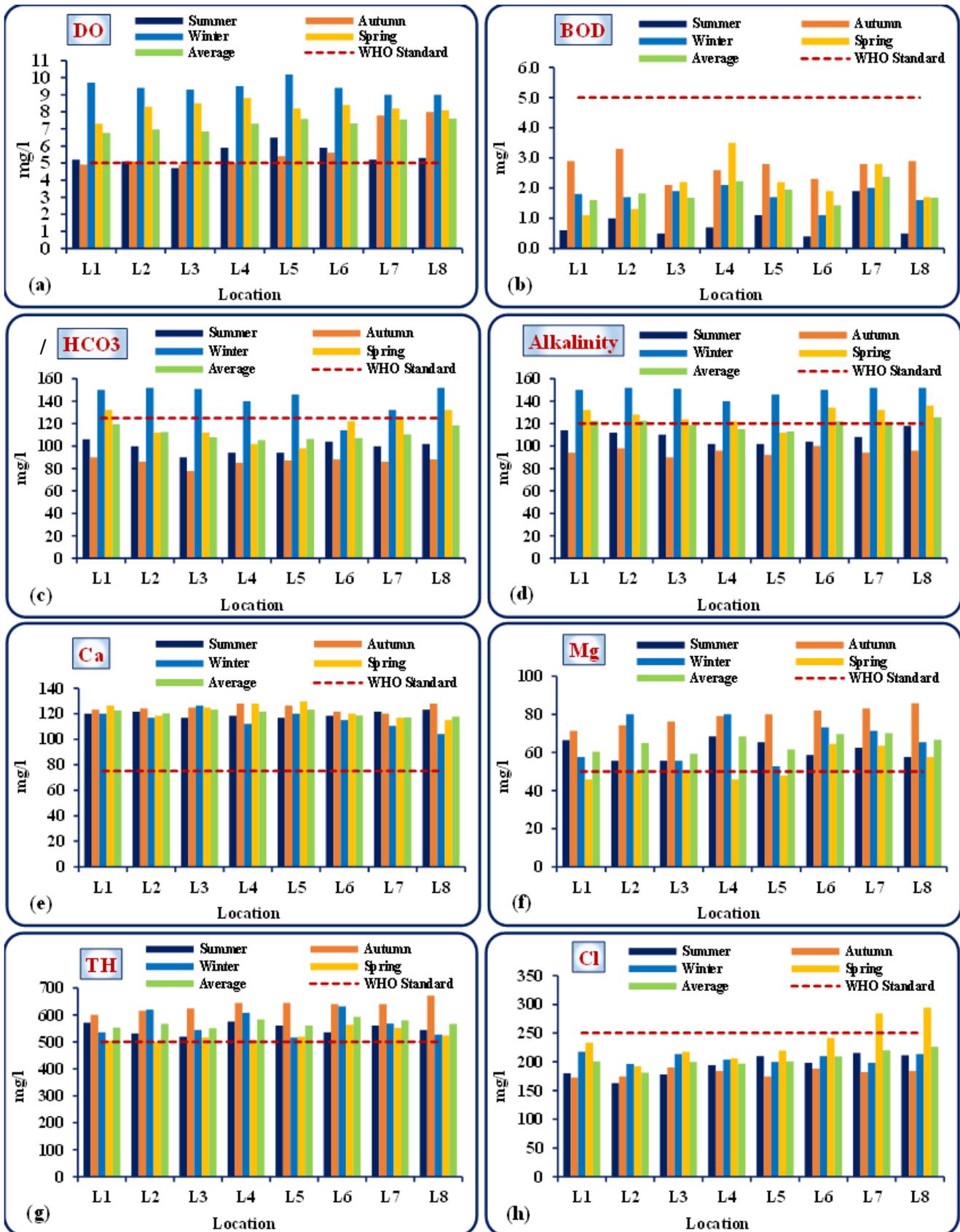
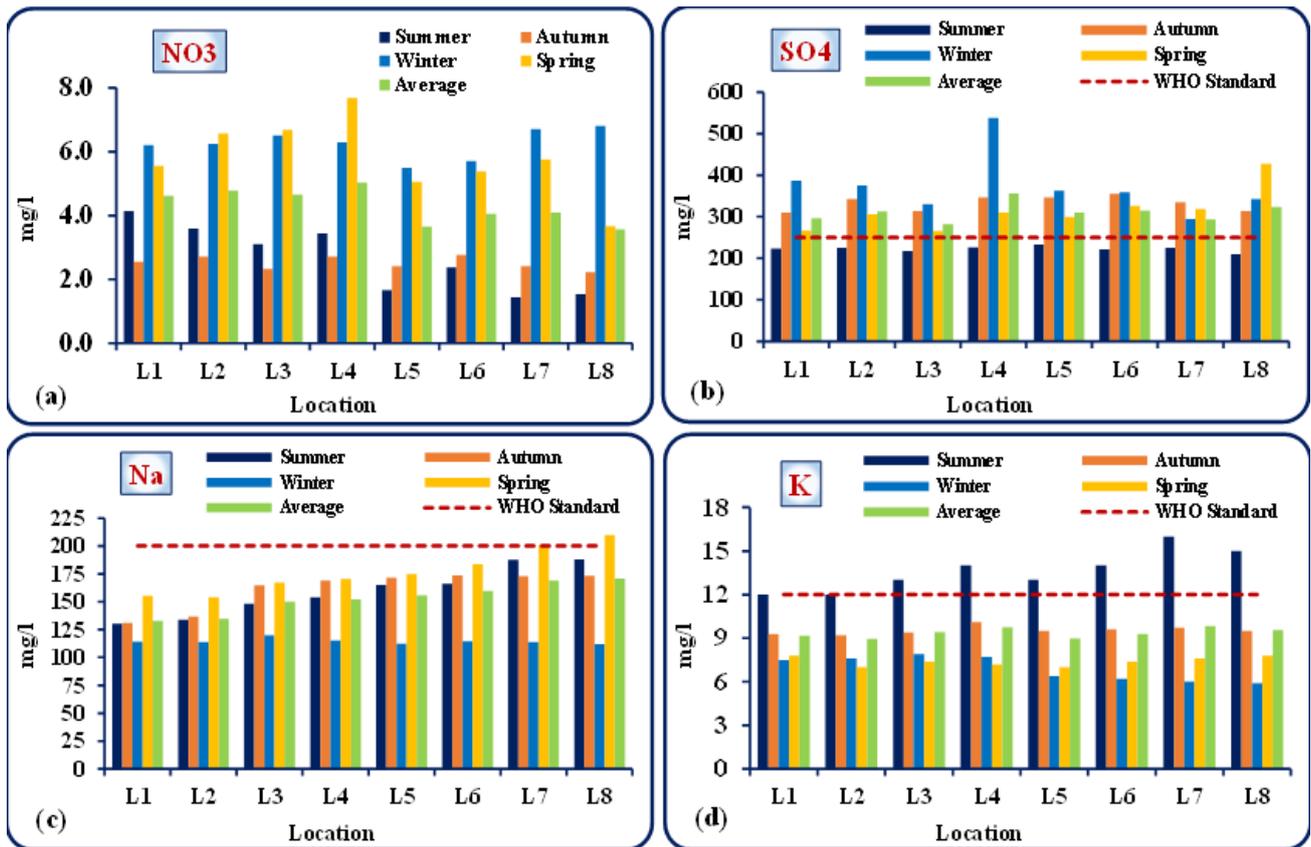


Figure (4.1): Concentration values of selected parameters measured at locations along Al-Abbasiyah River for (a): Temp.; (b): pH; (c): EC; (d): TDS; (e): TSS; (f): Turbidity.



**Figure (4.2):** Concentration values of selected parameters measured at locations along Al-Abbasiyah River for (a): DO; (b): BOD; (c): HCO<sub>3</sub>; (d): Alkalinity; (e): Ca; (f): Mg; (g): TH; (h): Cl.



**Figure (4.3):** Concentration values of selected parameters measured at locations along Al-Abbasiyah River for (a): NO<sub>3</sub>; (b): SO<sub>4</sub>; (c): Na; (d): K.

The main reason for changes in values of water quality parameters in the Al-Abbasiyah River is due to many factors, including differences in temperatures between summer and winter, night and day, and sewage discharge directly into the river in some cities where the river passes through them. In addition, disposed of fertilizers and animal waste from the farms existing on both banks of the river into the river stream, which led to rising concentrations for some parameters in the river.

### 4.3 Water Quality Indices

Water quality monitoring can help researchers predict and understand the different natural processes in the environment of the river and determine human impacts on an ecosystem. In this study, the applications that were previously built by the Visual Basic software were used to calculate the WQI methods for

purposes of drinking and irrigation in the Al-Abbasiyah River. The results were presented and discussed as shown in the following sections.

### 4.3.1 Al-Abbasiyah River Water Quality for Drinking Uses

The Al-Abbasiyah River is regarded as the main supply of water to drink for numerous towns and cities that are situated across it (on both sides), as was previously noted. As a result, it was required to assess the river's water quality for drinking, as demonstrated in the following sections:

#### 4.3.1.1 WA-WQI Method

To determine the WA-WQI for each season, 18 variables were measured at eight locations along the Al-Abbasiyah River throughout four seasons. Additionally, the WA-WQI yearly average values for every variable and each location along the river were determined.

**Table (4.1)** and **Figure (4.4)** show the WA-WQI values for the Al-Abbasiyah River. They ranged in summer between 70.3 in location (L-4) and 119.9 in location (L-7), while in autumn they ranged between 72 in location (L-4) and 125 in location (L-2). The WA-WQI values in winter ranged between 49.7 in location (L-5) and 79.4 in location (L-2) and in spring between 59.1 and 72.5 in locations (L-1) and (L-7), respectively.

By observing the values of the WQI for all seasons during the study period, it was clear that the quality of the river water during winter and spring was slightly better than in both seasons summer and autumn. One of the main causes of the decline in river water quality in summer and autumn is because of the reduction in river water discharge and the increase in evaporation rates brought on by the high temperatures in the dry season (Al-Mansouri, 2017).

The average of WA-WQI throughout whole locations along the river was 77 and varied from 65.8 in location (L-4) to 93.1 in location (L-2). The WA-WQI had average values of 74.8 (L-1), 93.1 (L-2), 68.7 (L-3), 65.8 (L-4), 66.4 (L-5), 71.6 (L-6), 91.1 (L-7) and 84.5 (L-8). The average values of the WA-

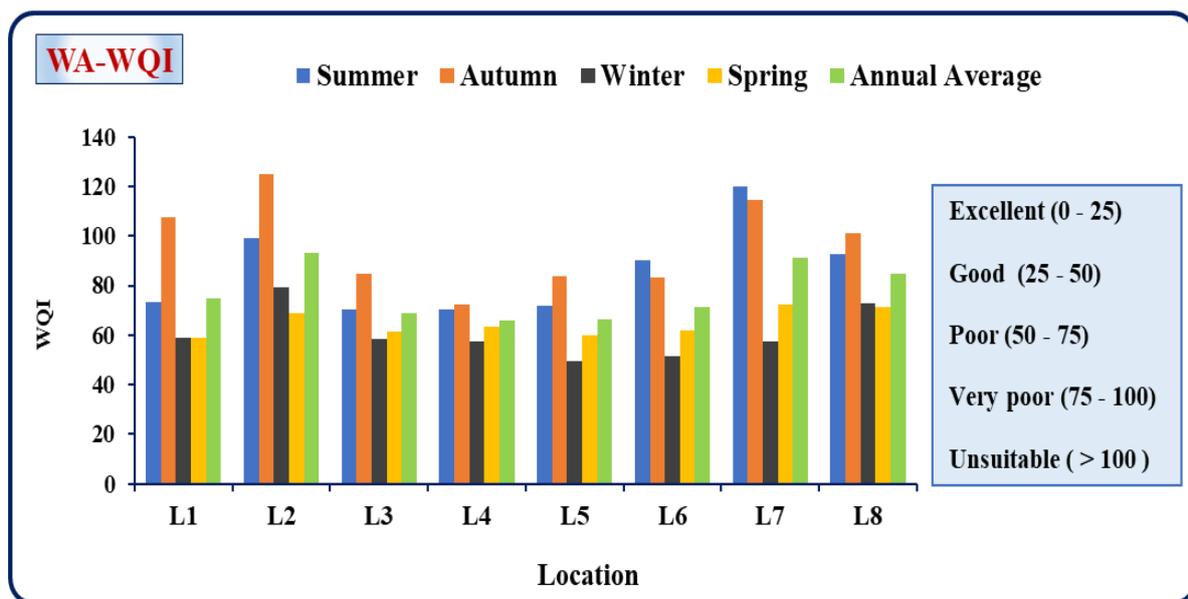
WQI in summer, autumn, winter, and spring, respectively, were 86.0, 96.5, 60.7, and 64.8 and were classified as "Very Poor" for summer and autumn, and "Poor" for winter, and spring.

It can be concluded from these values that the water of the Al-Abbasiyah River was polluted during the study period as a result of many of the measured parameters exceeding their permissible values, so this water is not suitable for direct use for drinking in all seasons and must undergo treatment before use.

**Table (4.1):** The results of WA-WQI by using all parameters (with turbidity).

Location	Summer		Autumn		Winter		Spring		Average	
	WQI	WQA	WQI	WQA	WQI	WQA	WQI	WQA	WQI	WQA
L-1	73.3	P-WQ	107.8	UUH-WQ	58.9	P-WQ	59.1	P-WQ	74.8	P-WQ
L-2	99.3	VP-WQ	125.1	UUH-WQ	79.4	VP-WQ	68.7	P-WQ	93.1	VP-WQ
L-3	70.4	P-WQ	84.5	Very poor	58.6	P-WQ	61.6	P-WQ	68.7	P-WQ
L-4	70.3	P-WQ	72.1	P-WQ	57.5	P-WQ	63.4	P-WQ	65.8	P-WQ
L-5	72.0	P-WQ	83.7	VP-WQ	49.7	G-WQ	60.1	P-WQ	66.4	P-WQ
L-6	90.2	VP-WQ	83.0	VP-WQ	51.3	P-WQ	61.8	P-WQ	71.6	P-WQ
L-7	119.9	UUH-WQ	114.3	UUH-WQ	57.6	P-WQ	72.5	P-WQ	91.1	VP-WQ
L-8	92.8	VP-WQ	101.3	UUH-WQ	72.8	P-WQ	71.2	P-WQ	84.5	VP-WQ
<b>Ave.</b>	<b>86.0</b>	<b>VP-WQ</b>	<b>96.5</b>	<b>VP-WQ</b>	<b>60.7</b>	<b>P-WQ</b>	<b>64.8</b>	<b>P-WQ</b>	<b>77.0</b>	<b>VP-WQ</b>

Note: G-WQ: Good water quality; P-WQ: Poor water quality; VP-WQ: Very poor water quality; UUH-WQ: Unsuitable use for human water quality.



**Figure (4.4):** The values of WA-WQI using all parameters (with turbidity).

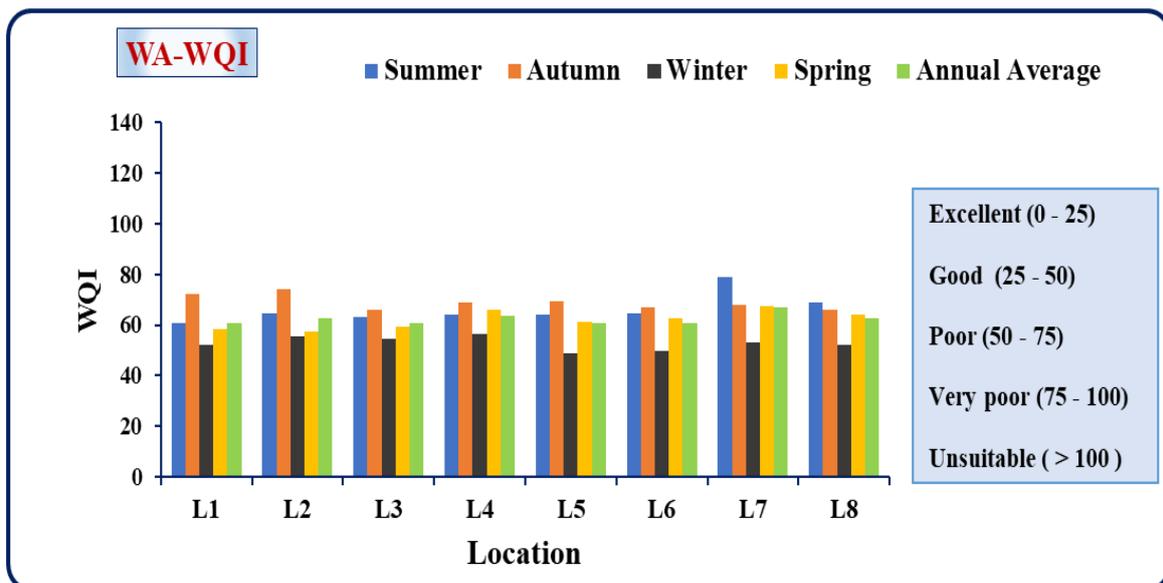
According to Judran & Kumar (2020), turbidity has a significant impact on the WA-WQI values, and high turbidity values, especially those that exceed the permissible standard limits, can lead to a significant increase in the WA-WQI value, and thus lead to a change in the WQ classification at that location.

So, in this study, the WA-WQI values for all locations were recalculated for all seasons using all measured parameters except turbidity, to compare the WA-WQI values obtained in the two cases. The WA-WQI values calculated without including turbidity are shown in **Table (4.2)** and **Figure (4.5)**.

**Table (4.2):** The values of WA-WQI using all parameters (without turbidity).

Location	Summer		Autumn		Winter		Spring		Average	
	WA-WQI	WQR	WA-WQI	WQR	WA-WQI	WQR	WA-WQI	WQR	WA-WQI	WQR
L-1	60.6	P-WQ	72.3	P-WQ	52.2	P-WQ	58.3	P-WQ	60.8	P-WQ
L-2	64.7	P-WQ	73.9	P-WQ	55.4	P-WQ	57.3	P-WQ	62.8	P-WQ
L-3	62.9	P-WQ	66.2	P-WQ	54.5	P-WQ	59.3	P-WQ	60.7	P-WQ
L-4	63.9	P-WQ	68.9	P-WQ	56.2	P-WQ	66.1	P-WQ	63.8	P-WQ
L-5	64.1	P-WQ	69.3	P-WQ	48.9	G-WQ	61.4	P-WQ	60.9	P-WQ
L-6	64.5	P-WQ	66.8	P-WQ	49.9	G-WQ	62.4	P-WQ	60.9	P-WQ
L-7	78.7	VP-WQ	68.1	P-WQ	53.2	P-WQ	67.2	P-WQ	66.8	P-WQ
L-8	68.9	P-WQ	66.1	P-WQ	52.6	P-WQ	63.8	P-WQ	62.8	P-WQ
Ave.	63.2	P-WQ	63.0	P-WQ	62.3	P-WQ	61.9	P-WQ	62.4	P-WQ

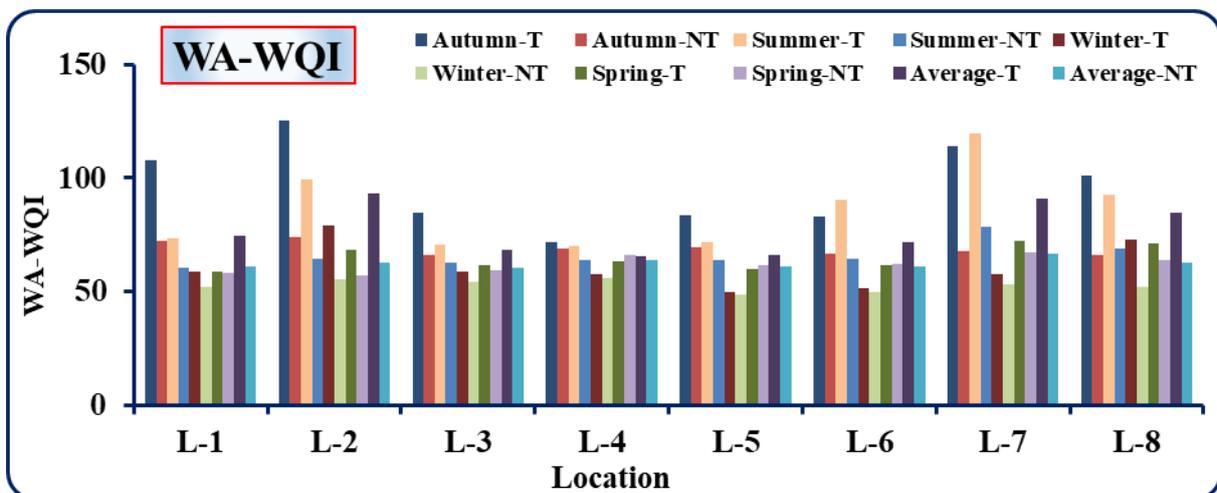
Note: G-WQ: Good water quality; P-WQ: Poor water quality; VP-WQ: Very poor water quality; UUH-WQ: Unsuitable use for human water quality.



**Figure (4.5):** The values of WA-WQI using all parameters (without turbidity).

The results showed that the lowest value of WA-WQI (without turbidity) was 49.96 in location (L-5) in winter, and the highest value was 78.66 in location (L-7) in summer. Most river water quality values in all seasons and locations were rated as "Poor" except for only three readings at location (L-7) in summer was rated "Very Poor", and locations (L-5) and (L-6) in winter were rated "Good". Moreover, the annual average values ranged between 60.7 in location (L-3) and 66.8 in location (L-7).

When comparing the results of WA-WQI calculated in both cases (with and without turbidity), it showed a clear difference in the calculated value, especially for locations that had turbidity values greater than the WHO standard (5 NTU) (**Figure 4.6**). It is noted that no significant change in the locations that had low turbidity values, in contrast to the locations with high turbidity values. These results correspond to the results obtained by Judran & Kumar (2020) in their study on Al- the Gharraf River.



**Figure (4.6):** The values of WA-WQI during all seasons (with and without turbidity).

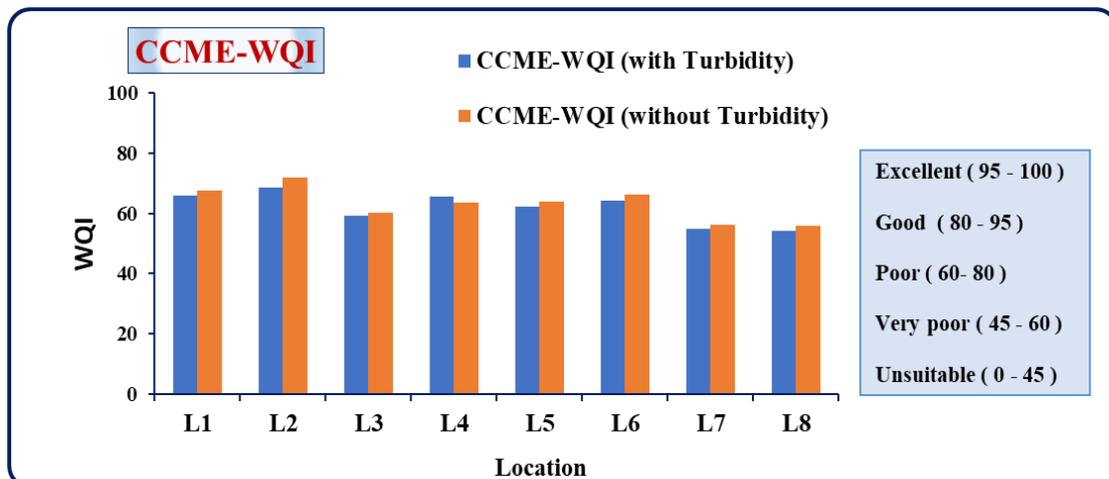
The reason for this significant effect of turbidity on the values of WA-WQI is due to the mathematical style that the model built on it. It was calculated based on giving a weight to each parameter, and this weight is inverse of the standard value for the parameter according to equation (2.10). So, since the WHO standard for turbidity in water for drinking is 5 NTU, turbidity has a significant impact on the calculated WA-WQI values. As for the parameters

whose standard specification values are low (such as DO, BOD, etc.), they did not have a significant effect, like turbidity, because most of the measured values of these parameters did not exceed the permissible limits of the WHO standards.

#### 4.3.1.2 CCME-WQI Method

CCME-WQI was also used to assess the water quality of the Al-Abbasiyah River for drinking uses and to compare its results with the results of WA-WQI. All the measured water quality parameters during all seasons were used to compute the CCME-WQI values as an annual average. **Table (4.3)** and **Figure (4.7)** showed that the lowest CCME-WQI value was 54.03 with a rating of "Very Poor" at location (L-8), and the highest value for CCME-WQI was 68.42 with a rating of "Poor" at location (L-2). Therefore, the water quality rating along the Al-Abbasiyah River was "Poor" except for locations (L-3, L-7, and L-8) which were rated as "Very Poor".

Similar to what was applied to WA-WQI, CCME-WQI was recalculated using the same parameters except for the turbidity to compare the changes in CCME-WQI values in both cases. In contrast to what occurred in the case of WA-WQI due to the change in the calculation method in CCME-WQI, the results indicated that there was not much difference in the results of both cases (with and without turbidity).



**Figure (4.7):** The average values of CCME-WQI using all parameters, (with and without turbidity).

**Table (4.3):** The values of CCME-WQI and their rating for all seasons using all parameters (with and without turbidity).

Location	CCME-WQI with turbidity	WQR	CCME-WQI without turbidity	WQR
L-1	65.740	Poor	67.646	Poor
L-2	68.416	Poor	71.769	Poor
L-3	59.169	Very poor	60.155	Poor
L-4	65.724	Poor	63.713	Poor
L-5	62.282	Poor	63.859	Poor
L-6	64.341	Poor	66.106	Poor
L-7	54.808	Very Poor	56.269	Very Poor
L-8	54.034	Very Poor	55.788	Very Poor
<b>Ave.</b>	<b>61.8</b>	<b>Poor</b>	<b>63.2</b>	<b>Poor</b>

The estimated yearly mean values for the CCME-WQI and WA-WQI techniques using the parameters (with and without turbidity) are presented in **Table (4.4)** for all seasons and locations.

**Table (4.4):** The values of CCME-WQI and WA-WQI with their rating for all seasons using all parameters (with and without turbidity).

Location	CCME-WQI-Tur	WQR	WA-WQI-Tur	WQR	CCME-WQI-No-Tur	WQR	WA-WQI-No-Tur	WQR
L-1	65.740	P-WQ	74.8	P-WQ	67.646	P-WQ	60.8	P-WQ
L-2	<b>68.416</b>	<b>P-WQ</b>	<b>93.1</b>	<b>VP-WQ</b>	71.769	P-WQ	62.8	P-WQ
L-3	<b>59.169</b>	<b>VP-WQ</b>	<b>68.7</b>	<b>P-WQ</b>	60.155	P-WQ	60.7	P-WQ
L-4	65.724	P-WQ	65.8	P-WQ	63.713	P-WQ	63.8	P-WQ
L-5	62.282	P-WQ	66.4	P-WQ	63.859	P-WQ	60.9	P-WQ
L-6	64.341	P-WQ	71.6	P-WQ	66.106	P-WQ	60.9	P-WQ
L-7	54.808	VP-WQ	91.1	VP-WQ	<b>56.269</b>	<b>VP-WQ</b>	<b>66.8</b>	<b>P-WQ</b>
L-8	54.034	VP-WQ	84.5	VP-WQ	<b>55.788</b>	<b>VP-WQ</b>	<b>62.8</b>	<b>P-WQ</b>
<b>Ave.</b>	<b>61.8</b>	<b>P-WQ</b>	<b>77.0</b>	<b>VP-WQ</b>	<b>63.2</b>	<b>P-WQ</b>	<b>62.4</b>	<b>P-WQ</b>

**Note:** P-WQ: Poor water quality; VP-WQ: Very poor water quality.

When comparing the annual average results for both indices, the findings using **Table (4.4)** revealed that there was little variation between the WQR obtained from WA-WQI and CCME-WQI. According to the annual average values (with turbidity) of the WA-WQI, Al-Abbasiyah River water was rated as "Poor" at locations (L-1, L-3, L-4, L-5, L-6) and as "Very Poor" at locations (L-2, L-7, L-8), while according to CCME-WQI, the river water was rated as

"Poor" at locations (L-1, L-2, L-4, L-5, L-6) and as "Very Poor" at locations (3, 7, 8). For the annual average values (without turbidity) of the WA-WQI and CCME-WQI (respectively), the river water was rated as "Poor" at locations (L-8) and as "Poor" at locations (L-6) and as "Very Poor" at locations (L-7), and (L-8).

The decline in river water quality can be attributed to improper waste disposal, a large amount of agricultural and urban runoff, sewage, excessive use of inorganic fertilizers, and improper operation and maintenance of the sewage system (Rabee et al., 2011). In general, it can be concluded that the water of the Al-Abbasiyah River was polluted in the study area, and therefore this water is not suitable for direct drinking use in all seasons.

### **4.3.2 Al-Abbasiyah River Water Quality for Irrigation Use**

Water quality assessment can help researchers predict and realize natural processes in the environment and determine human impacts on the ecosystem and the quality of crops grown. Assessment of the water quality of the Al-Abbasiyah River for irrigation uses is shown in the following sections:

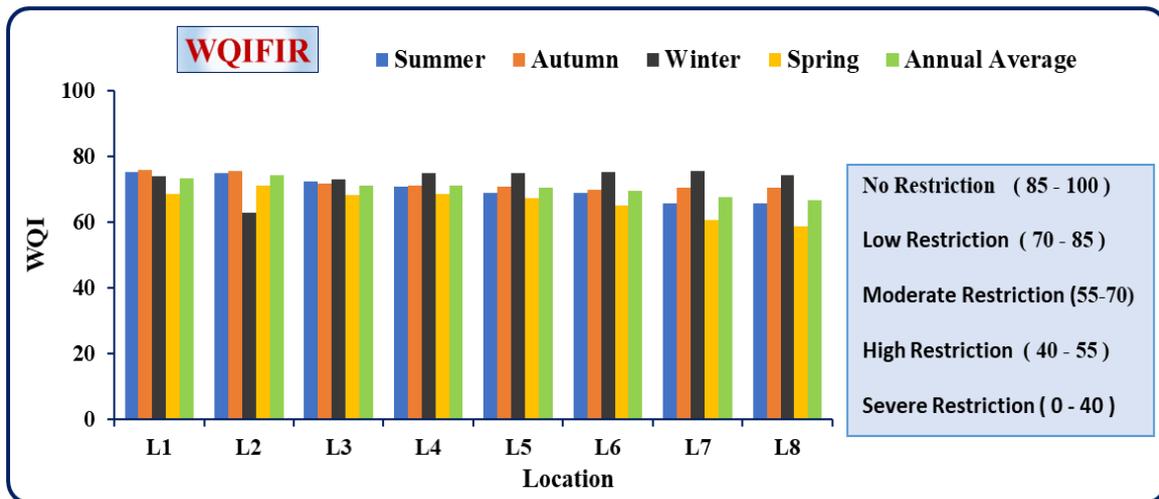
#### **4.3.2.1 WQIFIR Method**

The Al-Abbasiyah River's WQIFIR values for all seasons were computed using an application that was previously created using Visual Basic software. This application was provided with the values of the five parameters needed to calculate the WQIFIR ( $\text{HCO}_3$ , Cl, Na, EC, and SAR). The WQIFIR annual average was also calculated using the mean value for each parameter and each location along the river. The values of the WQIFIR for all seasons along the river are shown in **Table (4.5)** and **Figure (4.8)**.

**Table (4.5):** The values of WQIFIR for Al-Abbasiyah River.

Location	Summer		Autumn		Winter		Spring		Average	
	WQIFIR	WQR	WQIFIR	WQR	WQIFIR	WQR	WQIFIR	WQR	WQIFIR	WQR
L-1	75.1	LR	75.9	LR	73.9	LR	68.6	MR	73.4	LR
L-2	75.1	LR	75.5	LR	63.0	MR	71.1	LR	74.2	LR
L-3	72.5	LR	71.9	LR	73.1	LR	68.2	MR	71.1	LR
L-4	70.9	LR	71.1	LR	75.1	LR	68.5	MR	71.2	LR
L-5	68.9	MR	70.9	LR	74.9	LR	67.4	MR	70.4	LR
L-6	68.8	MR	69.9	MR	75.4	LR	65.0	MR	69.4	MR
L-7	65.9	MR	70.5	LR	75.5	LR	60.5	MR	67.7	MR
L-8	65.6	MR	70.4	LR	74.2	LR	58.8	MR	66.8	MR

Note: LR: Low restriction; MR: Moderate restriction.



**Figure (4.8):** The values of WQIFIR for Al-Abbasiyah River during all seasons.

The WQIFIR values for Al-Abbasiyah River ranged in summer between 65.6 in location (L-8) and 75.1 in location (L-1), while in autumn it ranged between 69.9 in location (L-6) and 75.9 at location (L-1). The WQIFIR values ranged between 63.1 in location (L-2) and 75.5 in location (L-7) in winter, and between 58.8 and 71.13 in location (L-8) and (L-2) in spring, respectively.

There was a small variation in the WQ of the river for use as irrigation during all seasons based on the WQIFIR values observed for each season. The WQIFIR's annual average value varied from 66.8 in location (L-8) to 74.2 in location (L-2). Therefore, the river water quality rating for irrigation ranged between low restriction (LR) in locations (L-1) to (L-5) and moderate restriction (MR) in locations (L-6), (L-7), and (L-8) according to WQR for irrigation found in **Table (2.8)** in Chapter 2.

The conclusions from the results mentioned above, the Al-Abbasiyah River's water was suitable for irrigating plants throughout the study period, but there were some limitations due to the high salinity in some areas caused by regional natural features, techniques for managing land, agriculture-related irrigation actions, and drainage systems throughout the Al-Abbasiyah River (Ewaid et al., 2020).

#### 4.3.2.2 Other Irrigation Water Quality Indices

Other irrigation water quality indices are used to classify water as acceptable for irrigation use depending on some major constituents (such as Na, Ca, Mg, etc.) in the water. The results of these indices are shown as follows:

##### A. Sodium Adsorption Ratio (SAR)

SAR values in the river water varied from 1.99 during winter at (L-2) to 3.98 during spring at (L-8). The values of the annual average SAR ranged between 2.46 in location (L-1) and 3.12 in location (L-8). Therefore, the SAR values of the river water for all locations and seasons throughout the study period were classified as “Excellent” as they did not exceed 10, due to the relatively low sodium ion values in Al-Abbasiyah River water. Thus, the water is excellent for irrigation purposes for almost all soils. **Table (4.6)** and **Figure (4.9a)** illustrate the change in SAR values at all locations over the study period.

Based on the previous results, it is clear that the water of the Al-Abbasiyah River has a low sodium risk. Excess sodium is absorbed into the soil particles and leads to a significant decrease in the permeability of agricultural soils that receive this irrigation water (Haritash et al., 2016). Thus, the water of the Al-Abbasiyah River can be considered suitable for irrigation throughout all seasons of the year.

##### B. Kelly's Index (KI).

Between 0.39 during winter at (L-2) and 0.87 during spring at (L-8), the KI values of the river water varied. The results indicated that the values of KI in

the spring were slightly higher than in the other seasons due to the high values of sodium ions in spring. The values of the annual average of KI ranged between 0.52 in location (L-2) and 0.65 in location (L-8). Therefore, the KI values of the river water for all locations and seasons throughout the study period were classified as “Good” because these values did not exceed 1, due to the relatively low sodium ion values in Al-Abbasiyah River water. Thus, the water is acceptable for irrigation purposes for almost all soils. **Table (4.7)** and **Figure (4.9b)** show the variation in KI values at all locations during all seasons.

### **C. Soluble Sodium Percentage (Na%) or (SSP)**

The SSP values of the river water varied from 29.29% at (location 2) during winter to 47.05% at (location 8) during spring. The annual average values of SSP ranged between 34.90 % at location (L-2) and 40.33 % at location (L-8). Therefore, the SSP values of the river water for all locations based on the annual average values of the SSP were classified as "Good" since they were within the range of  $40 < \text{SSP} < 20$ , except the value for location (L-8), which was classified as “Permissible” for irrigation. **Table (4.8)** and **Figure (4.9c)** show the change in SSP values at all locations over the study period.

### **D. Permeability index (PI)**

The PI values of the river water varied from 37.594% at (location 2) during winter to 54.02% at (location 8) during spring. The readings of the annual average of PI ranged between 41.94 % at location (L-2) and 46.98 % at location (L-8). Thus, the PI values of the river water for all locations and seasons during the study period were classified as "Moderately suitable for irrigation" within the category of  $25\% < \text{PI} < 75\%$ . **Table (4.9)** and **Figure (4.9d)** demonstrate the change in PI values at all locations over the study period.

**Table (4.6):** The values of SAR for Al-Abbasiyah River during all seasons.

Location	Summer		Autumn		Winter		Spring		Average	
	SAR	SAR class	SAR	SAR class						
L-1	2.37	Excellent	2.33	Excellent	2.15	Excellent	3.01	Excellent	2.46	Excellent
L-2	2.52	Excellent	2.39	Excellent	1.99	Excellent	2.99	Excellent	2.46	Excellent
L-3	2.83	Excellent	2.87	Excellent	2.23	Excellent	3.20	Excellent	2.78	Excellent
L-4	2.79	Excellent	2.89	Excellent	2.03	Excellent	3.29	Excellent	2.74	Excellent
L-5	3.03	Excellent	2.94	Excellent	2.15	Excellent	3.33	Excellent	2.86	Excellent
L-6	3.12	Excellent	2.98	Excellent	2.05	Excellent	3.36	Excellent	2.87	Excellent
L-7	3.45	Excellent	2.97	Excellent	2.08	Excellent	3.72	Excellent	3.05	Excellent
L-8	3.50	Excellent	2.91	Excellent	2.12	Excellent	3.98	Excellent	3.12	Excellent

**Table (4.7):** The values of KI for Al-Abbasiyah River during all seasons.

Location	Summer		Autumn		Winter		Spring		Average	
	KI	KI class	KI	KI class						
L-1	0.49	Good	0.48	Good	0.46	Good	0.67	Good	0.52	Good
L-2	0.55	Good	0.48	Good	0.39	Good	0.67	Good	0.51	Good
L-3	0.62	Good	0.57	Good	0.48	Good	0.71	Good	0.59	Good
L-4	0.58	Good	0.57	Good	0.41	Good	0.73	Good	0.57	Good
L-5	0.64	Good	0.58	Good	0.47	Good	0.73	Good	0.61	Good
L-6	0.67	Good	0.59	Good	0.42	Good	0.71	Good	0.59	Good
L-7	0.73	Good	0.59	Good	0.44	Good	0.79	Good	0.63	Good
L-8	0.75	Good	0.56	Good	0.46	Good	0.87	Good	0.65	Good

**Table (4.8):** The values of SSP for Al-Abbasiyah River during all seasons.

Location	Summer		Autumn		Winter		Spring		Average	
	SSP	SSP class	SSP	SSP class	SSP	SSP class	SSP	SSP class	SSP	SSP class
L-1	34.29	Good	33.10	Good	32.49	Good	40.84	Permissible	35.19	Good
L-2	36.54	Good	33.42	Good	29.29	Good	40.73	Permissible	34.90	Good
L-3	39.44	Good	37.22	Good	33.22	Good	41.97	Permissible	38.03	Good
L-4	37.98	Good	37.09	Good	29.96	Good	42.78	Permissible	37.01	Good
L-5	40.10	Permissible	37.39	Good	32.84	Good	42.79	Permissible	38.47	Good
L-6	41.41	Permissible	37.82	Good	30.39	Good	42.00	Permissible	38.10	Good
L-7	43.32	Permissible	37.76	Good	30.97	Good	44.71	Permissible	39.54	Good
L-8	44.01	Permissible	36.65	Good	32.22	Good	47.05	Permissible	40.33	Permissible

Table (4.9): The values of PI for the Al-Abbasiyah River during all seasons.

Location	Summer		Autumn		Winter		Spring		Average	
	PI	class PI	PI	class PI						
L-1	40.8	Moderate	39.1	Moderate	41.7	Moderate	48.9	Moderate	42.6	Moderate
L-2	43.1	Moderate	39.1	Moderate	37.6	Moderate	48.2	Moderate	41.9	Moderate
L-3	45.5	Moderate	42.2	Moderate	42.2	Moderate	49.0	Moderate	44.8	Moderate
L-4	43.6	Moderate	42.1	Moderate	38.0	Moderate	49.5	Moderate	43.3	Moderate
L-5	45.8	Moderate	42.5	Moderate	42.3	Moderate	49.3	Moderate	45.0	Moderate
L-6	47.5	Moderate	43.0	Moderate	37.9	Moderate	48.8	Moderate	44.4	Moderate
L-7	48.7	Moderate	42.8	Moderate	39.3	Moderate	51.4	Moderate	45.8	Moderate
L-8	49.7	Moderate	41.6	Moderate	41.8	Moderate	54.0	Moderate	47.0	Moderate

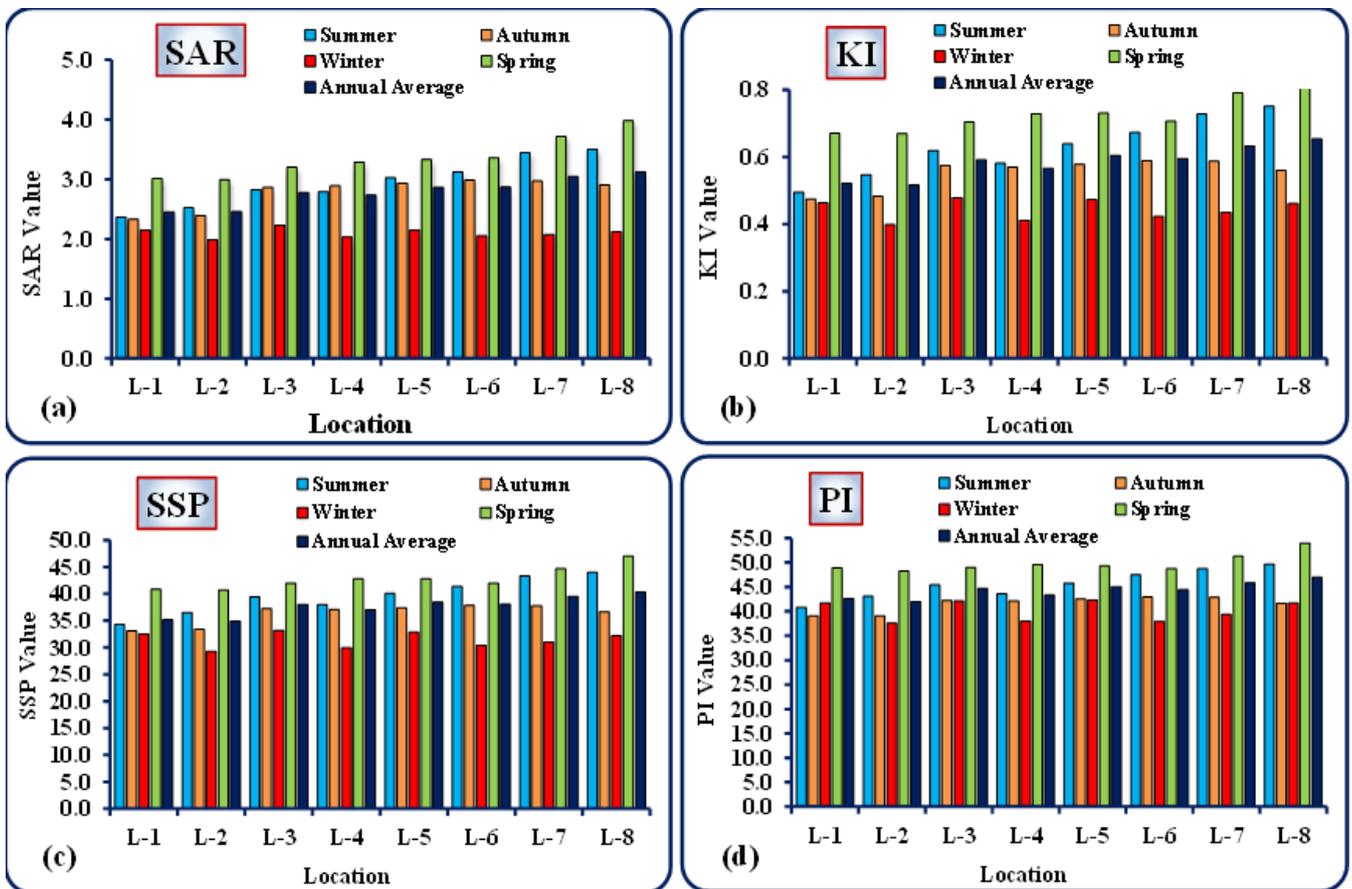


Figure (4.9): The values of water quality indices for Irrigation use for Al-Abbasiyah River (a): SAR; (b): KI; (c): SSP; (d): PI.

#### 4.4 Linear Regression Models (LRMs) for WQI Methods

SPSS software was used to analyze the type of statistical relationship that exists between the studied water quality parameters and WQI methods. Firstly, correlations were used to investigate the strength of the relationship

between the WQI methods and the studied parameters. Then, linear regression models (LRM) for water quality indices for drinking and irrigation purposes were created based on the eighteen studied water quality parameters.

#### 4.4.1 Linear Regression Models of Drinking Water Quality

Linear regression models were created to estimate the water quality of the Al-Abbasiyah River for drinking uses using WA-WQI values (with and without turbidity) and water quality parameters calculated for all locations and seasons during the study period. The CCME-WQI values were not relied upon to create linear regression models because they would give less accurate regression models due to the small number of readings given by the CCME-WQI method, as it gave values for water quality as an annual average only (eight readings only). And the inability to use it to calculate the water quality for each season, because its application requires repeated testing.

##### 4.4.1.1 LRMs for WA-WQI (with turbidity)

The creation of the linear regression model depends on the inclusion of independent parameters that have a high correlation and a significant relationship ( $P\text{-value} < 0.05$ ) with the dependent variable for which the model was to be built. **Table (4.10)** shows the correlation matrix between WA-WQI (with turbidity) and the measured water quality parameters for all seasons. Many parameters showed a high correlation with the WA-WQI.

Before creating a linear regression model, it was necessary to test the distribution of the WA-WQI (with turbidity) data using the Shapiro-Wilk normality test, as shown in **Table (4.11)**. It was found that the values of WA-WQI (with turbidity) are not subject to the normal distribution, so the logarithm of the data was taken to make the normal distribution of the data.

Linear regression models were created by SPSS software based on water quality parameters that have a high correlation and significant relationship with the WA-WQI (with turbidity). Several attempts were made by changing the

lowest correlation coefficient for the parameters involved in creating regression models to obtain the best models with the best possible coefficient of determination ( $R^2$ ).

**Table (4.12)** shows the obtained linear regression models for estimating WA-WQI (with turbidity). The first model has a p-value equal to  $2.45E-20$  and an  $R^2$  equal to 97%, and it was obtained using the parameters that have a correlation greater than 60% and a significant relationship ( $P$ -value  $< 0.05$ ) with WA-WQI (with turbidity). The second model has a p-value equal to  $3.10E-19$  and an  $R^2$  equal to 95%, and it was obtained using the parameters that have a correlation greater than 70% and a significant relationship ( $P$ -value  $< 0.05$ ) with WA-WQI (with turbidity). Thus, both models have a high  $R^2$  and can be used to estimate the water quality of the Al-Abbasiyah River for drinking uses with acceptable accuracy.

Table (4.10): Correlation matrix between the WA-WQI (with turbidity) and water quality parameters for all seasons.

Correlation	Log (WA-WQI)	WAWQI	Temp.	pH	EC	TDS	Turb.	DO	BOD	HCO <sub>3</sub>	ALK.	TH	Ca	Mg	Cl	NO <sub>3</sub>	SO <sub>4</sub>	TSS	Na	K	
Log (WA-WQI)	1																				
WA-WQI	0.99	1																			
Temp.	0.61	0.57	1																		
pH	-0.57	-0.55	-0.56	1																	
EC	0.33	0.29	0.53	0.05	1																
TDS	0.33	0.29	0.53	0.06	1.00	1															
Turb.	<b>0.96</b>	0.98	0.47	-0.55	0.17	0.17	1														
DO	<b>-0.66</b>	-0.62	-0.84	0.73	-0.34	-0.34	-0.50	1													
BOD	0.22	0.25	-0.37	0.01	-0.10	-0.10	0.20	0.14	1												
HCO <sub>3</sub>	-0.59	-0.57	-0.71	0.58	-0.29	-0.29	-0.44	0.78	-0.18	1											
ALK.	<b>-0.69</b>	-0.66	-0.74	0.65	-0.31	-0.31	-0.53	0.81	-0.20	0.94	1										
TH	0.40	0.40	0.07	-0.55	0.03	0.03	0.40	-0.24	0.41	-0.41	-0.42	1									
Ca	0.20	0.20	0.19	-0.15	0.03	0.03	0.10	-0.31	0.36	-0.49	-0.51	0.13	1								
Mg	0.40	0.39	0.05	-0.54	0.04	0.04	0.41	-0.19	0.34	-0.29	-0.33	0.95	-0.13	1							
Cl	-0.38	-0.38	-0.32	0.78	0.45	0.45	-0.43	0.44	-0.01	0.48	0.48	-0.41	-0.21	-0.36	1						
NO <sub>3</sub>	<b>-0.73</b>	-0.71	-0.82	0.65	-0.56	-0.56	-0.63	0.80	0.08	0.74	0.81	-0.44	-0.27	-0.40	0.32	1					
SO <sub>4</sub>	-0.28	-0.26	-0.72	0.26	-0.22	-0.22	-0.21	0.55	0.47	0.43	0.38	0.32	-0.22	0.37	0.22	0.37	1				
TSS	<b>0.91</b>	0.92	0.37	-0.41	0.17	0.17	0.94	-0.42	0.21	-0.32	-0.43	0.32	0.04	0.35	-0.28	-0.55	-0.08	1			
Na	0.32	0.28	0.44	0.19	0.76	0.76	0.11	-0.35	0.17	-0.49	-0.50	-0.01	0.37	-0.08	0.43	-0.45	-0.24	0.15	1		
K	0.57	0.54	0.94	-0.51	0.55	0.55	0.46	-0.75	-0.44	-0.54	-0.60	0.06	0.15	0.05	-0.28	-0.77	-0.65	0.36	0.34	1	

\* All values within the table represent the correlation coefficient (r).

**Table (4.11):** Results of Shapiro-Wilk Test for WA-WQI values with turbidity.

WQI	P-value	W value	W critical	Type of distribution
WA-WQI with Turb	0.011154	0.9099	0.9338	Not normal distribution
Log (WA-WQI) with Turb	0.177882	0.9532	0.9338	Normal distribution

**Table (4.12):** Linear regression model to estimate the WA-WQI (with turbidity).

No.	Model	R	R <sup>2</sup>	P-value
1	Log (WA-WQI) with Turb = $1.87 + 0.017 * \text{Turb} - 0.007 * \text{DO} - 0.001 * \text{Alk} + 0.006 * \text{TSS}$	0.985	0.97	2.45E-20
2	Log (WA-WQI) with Turb = $1.772 + 0.023 * \text{Turb} - 0.012 * \text{NO}_3$	0.973	0.95	3.10E-19

\* All parameters are in (mg/l) except Turb in (NTU).

#### 4.4.1.2 LRMs for WA-WQI (without turbidity)

**Table (4.13)** shows the correlation matrix between WA-WQI (without turbidity) and the measured water quality parameters for all seasons. Most parameters showed a moderate or high correlation with the WA-WQI. The WA-WQI (without turbidity) data was tested using the Shapiro-Wilk normality test and it was found to be subject to a normal distribution, as shown in **Table (4.14)**.

Linear regression models were created by SPSS software based on water quality parameters that have a significant correlation with the WA-WQI (without turbidity) in the same way that was used to create the WA-WQI (with turbidity) models.

**Table (4.15)** shows the obtained linear regression models to estimate WA-WQI (without turbidity). The first model has a p-value of 2.92E-11 and R<sup>2</sup> of 91%, obtained using parameters that correlate greater than 60% and a significant relationship (P-value < 0.05) with the WA-WQI (without turbidity). The second model has a p-value of 9.38E-10 and an R<sup>2</sup> of 79%, obtained using parameters that correlate greater than 65% and significant relationship with the WA-WQI (without turbidity). It seemed clear that the first model had a higher R<sup>2</sup>, and was more accurate than the second model, but its application needed to measure the values of seven variables, while the second model had a lower R<sup>2</sup>,

but it needed to measure the values of three variables only when applied. Thus, both models can be used to estimate Al-Abbasiyah River water quality for drinking uses based on the available data.

By comparing the models of WA-WQI (with turbidity) with the models of WA-WQI (without turbidity), it turned out that turbidity has the greatest effect compared to other water quality parameters. There, turbidity was not included in creating the models of WA-WQI (without turbidity) leading to a decrease in  $R^2$  values and an increase in the number of variables in the models compared to the models of WA-WQI (with turbidity). This was due to the very high correlation coefficient of turbidity (96%) with the WA-WQI (with turbidity). However, in the case of WA-WQI (without turbidity), the highest correlation coefficient was (81%) for Alkalinity.

Table (4.13): Correlation matrix between the WA-WQI (without turbidity) and water quality parameters for all seasons.

Correlation	WA-WQI	Temp.	pH	EC	TDS	DO	BOD	HCO <sub>3</sub>	ALK	TH	Ca	Mg	Cl	NO <sub>3</sub>	SO <sub>4</sub>	TSS	Na	K	
WA-WQI	1																		
Temp.	<b>0.68</b>	1																	
pH	-0.41	-0.56	1																
EC	0.55	0.53	0.05	1															
TDS	0.55	0.53	0.06	1.00	1														
DO	<b>-0.76</b>	-0.84	0.73	-0.34	-0.34	1													
BOD	0.34	-0.37	0.01	-0.10	-0.10	0.14	1												
HCO <sub>3</sub>	-0.76	-0.71	0.58	-0.29	-0.29	0.78	-0.18	1											
ALK.	<b>-0.81</b>	-0.74	0.65	-0.31	-0.31	0.81	-0.20	0.94	1										
TH	0.30	0.07	-0.55	0.03	0.03	-0.24	0.41	-0.41	-0.42	1									
Ca	0.45	0.19	-0.15	0.03	0.03	-0.31	0.36	-0.49	-0.51	0.13	1								
Mg	0.23	0.05	-0.54	0.04	0.04	-0.19	0.34	-0.29	-0.33	0.95	-0.13	1							
Cl	-0.15	-0.32	0.78	0.45	0.45	0.44	-0.01	0.48	0.48	-0.41	-0.21	-0.36	1						
NO <sub>3</sub>	<b>-0.74</b>	-0.82	0.65	-0.56	-0.56	0.80	0.08	0.74	0.81	-0.44	-0.27	-0.40	0.32	1					
SO <sub>4</sub>	-0.32	-0.72	0.26	-0.22	-0.22	0.55	0.47	0.43	0.38	0.32	-0.22	0.37	0.22	0.37	1				
TSS	<b>0.60</b>	0.37	-0.41	0.17	0.17	-0.42	0.21	-0.32	-0.43	0.32	0.04	0.35	-0.28	-0.55	-0.08	1			
Na	<b>0.66</b>	0.44	0.19	0.76	0.76	-0.35	0.17	-0.49	-0.50	-0.01	0.37	-0.08	0.43	-0.45	-0.24	0.15	1		
K	<b>0.61</b>	0.94	-0.51	0.55	0.55	-0.75	-0.44	-0.54	-0.60	0.06	0.15	0.05	-0.28	-0.77	-0.65	0.36	0.34	1	

\* All values within the table represent the correlation coefficient (r).

**Table (4.14):** The Shapiro-Wilk Test values for WA-WQI without turbidity.

WQI	P-value	W value	W critical	Type of distribution
WA-WQI <sub>without Turb</sub>	0.736211	0.977887	0.933792	Normal distribution

**Table (4.15):** Linear regression models to estimate the WA-WQI (without turbidity).

No.	Model	R	R <sup>2</sup>	P-value
1	WA-WQI <sub>without Turb</sub> = <b>64.575 - 0.554 * Temp - 1.682 * DO - 0.16 * Alk + 1.07 * NO<sub>3</sub> + 0.732 * TSS + 0.115 * Na + 1.567 * K</b>	0.956	0.91	2.92E-11
2	WA-WQI <sub>without Turb</sub> = <b>72.018 - 1.407 * DO - 0.113 * Alk + 0.093 * Na</b>	0.891	0.79	9.38E-10

\* All parameters are in (mg/l) except Temp. in (°C).

#### 4.4.2 Linear Regression Models for Irrigation Water Quality

Using the WQIFIR values and parameters computed for all locations and seasons during the study period employing SPSS software, linear regression models were developed to evaluate the river’s WQ for irrigation applications.

Initially, a correlation matrix was created between the WQIFIR values and the measured water quality parameters for all seasons, as shown in **Table (4.16)**. The correlation matrix showed that only some variables had a correlation coefficient greater than 50% such as (pH, TDS, EC, Na, and Cl), while the other parameters had a very weak correlation coefficient.

**Table (4.16):** Correlation matrix between the WQIFIR and water quality parameters for all seasons.

Correlation	(WQIIR) <sup>3</sup>	WQIIR	Temp	pH	EC	TDS	Turb	DO	BOD	HCO <sub>3</sub>	ALK	TH	Ca	Mg	Cl	NO <sub>3</sub>	SO <sub>4</sub>	TSS	Na	K	
(WQIIR) <sup>3</sup>	1																				
WQIIR	1.00	1																			
Temp	-0.10	-0.08	1																		
pH	-0.51	-0.52	-0.56	1																	
EC	<b>-0.65</b>	-0.66	0.53	0.05	1																
TDS	<b>-0.65</b>	-0.66	0.53	0.06	1.00	1															
Turbidity	0.08	0.08	0.47	-0.55	0.17	0.17	1														
DO	-0.05	-0.07	-0.84	0.73	-0.34	-0.34	-0.50	1													
BOD	-0.03	-0.03	-0.37	0.01	-0.10	-0.10	0.20	0.14	1												
HCO <sub>3</sub>	-0.03	-0.07	-0.71	0.58	-0.29	-0.29	-0.44	0.78	-0.18	1											
ALK	0.00	-0.03	-0.74	0.65	-0.31	-0.31	-0.53	0.81	-0.20	0.94	1										
TH	0.17	0.17	0.07	-0.55	0.03	0.03	0.40	-0.24	0.41	-0.41	-0.42	1									
Ca	-0.13	-0.09	0.19	-0.15	0.03	0.03	0.10	-0.31	0.36	-0.49	-0.51	0.13	1								
Mg	0.18	0.17	0.05	-0.54	0.04	0.04	0.41	-0.19	0.34	-0.29	-0.33	0.95	-0.13	1							
Cl	<b>-0.69</b>	-0.72	-0.32	0.78	0.45	0.45	-0.43	0.44	-0.01	0.48	0.48	-0.41	-0.21	-0.36	1						
NO <sub>3</sub>	0.08	0.07	-0.82	0.65	-0.56	-0.56	-0.63	0.80	0.08	0.74	0.81	-0.44	-0.27	-0.40	0.32	1					
SO <sub>4</sub>	0.07	0.04	-0.72	0.26	-0.22	-0.22	-0.21	0.55	0.47	0.43	0.38	0.32	-0.22	0.37	0.22	0.37	1				
TSS	-0.04	-0.05	0.37	-0.41	0.17	0.17	0.94	-0.42	0.21	-0.32	-0.43	0.32	0.04	0.35	-0.28	-0.55	-0.08	1			
Na	<b>-0.77</b>	-0.76	0.44	0.19	0.76	0.76	0.11	-0.35	0.17	-0.49	-0.50	-0.01	0.37	-0.08	0.43	-0.45	-0.24	0.15	1		
K	-0.12	-0.10	0.94	-0.51	0.55	0.55	0.46	-0.75	-0.44	-0.54	-0.60	0.06	0.15	0.05	-0.28	-0.77	-0.65	0.36	0.34	1	

\* All values within the table represent the correlation coefficient (r).

Before creating the linear regression models, the WQIFIR data distribution was tested using the Shapiro-Wilk normality test, as shown in **Table (4.17)**. Due to the WQIFIR values are not subject to the normal distribution, several statistical methods were tried to make them subject to a normal distribution. It was tried to take the logarithm, the exponential function, and square the data to obtain a normal distribution, but the normal distribution of the data was not achieved except when the WQIFIR values were cubed.

Linear regression models were created based on the water quality parameters that have a high correlation and significant relationship with the WQIFIR values. Several attempts occurred by changing the lowest correlation coefficient of the parameters involved in regression model creation to obtain the best models with the best possible coefficient of determination ( $R^2$ ).

**Table (4.18)** shows the best models obtained for estimating WQIFIR values. Two models have an  $R^2$  of 75%, obtained using parameters that have greater than 60% correlation and a significant relationship ( $P$ -value  $< 0.05$ ) with the WQIFIR values. The first model has a  $p$ -value equal to  $1.50E-08$  in terms of three parameters (EC, Na, and Cl), while the second model has a  $p$ -value equal to  $2.07E-09$  in terms of only two parameters (Na, and Cl). Thus, both models have the same  $R^2$  and can be used to estimate the water quality of the Al-Abbasiyah River for irrigation uses.

**Table (4.17):** The Shapiro-Wilk Test values for the WQIFIR.

WQI	P-value	W value	W critical	Type of distribution
WQIIR	0.023225	0.921769	0.933792	Not normal distribution
(WQIIR) <sup>3</sup>	0.076227	0.940276	0.933792	Normal distribution

**Table (4.18):** Linear regression models to estimate the WQIFIR.

No.	Model	R	R <sup>2</sup>	P-value
1	(WQIFIR) <sup>3</sup> = 772959.464 - 24.898 * EC - 946.51 * Cl - 1226.315 * Na	0.865	0.75	1.50E-08
2	(WQIFIR) <sup>3</sup> = 746474.43 - 960.381 * Cl - 1288.894 * Na	0.865	0.75	2.07E-09

\* All parameters are in (mg/l) except EC in ( $\mu$ S/cm).

#### 4.4.3 Validation of Linear Regression Models

Linear regression models are considered one of the statistical methods that enable researchers to create models for the studied case based on observed values. The accuracy of these models depends on the accuracy of measurements, the number of observations, and other factors.

To validate the linear regression models generated based on the WQIs values calculated at the eight sampling locations (L-1 to L-8) during the four seasons, five additional locations (from P-1 to P-5) were randomly selected along the river in the spring season. Water samples were taken from these additional new locations and measured the same 18 variables used for the current research throughout spring. Tables (4.19) and (4.20) show the coordinates and results of laboratory tests for the additional locations.

**Table (4.19):** Coordinates and locations of additional sampling (predicted) collected in the spring season.

Location	Latitude	Longitude	Description
P-1	32°05'18.3"N	44°26'44.6"E	It is located between L-2 and L-3
P-2	32°01'24.5"N	44°32'37.9"E	It is located between L-3 and L-4
P-3	31°57'59.0"N	44°35'29.8"E	It is located between L-4 and L-5
P-4	31°55'13.6"N	44°35'35.8"E	It is located between L-5 and L-6
P-5	31°48'23.5"N	44°35'58.8"E	It is located between L-6 and L-7

**Table (4.20):** Laboratory tests for the predicted locations collected in the spring.

No.	Parameter	P-1	P-2	P-3	P-4	P-5	Mean	STD
1	Temp. (°C)	18	18	18	19	19	18.40	0.55
2	pH	7.95	8.18	8.25	8.22	8.15	8.15	0.12
3	EC (µS/cm)	1462	1494	1534	1550	1705	1549	93.8
4	TDS (mg/l)	950	971	997	1007	1108	1006	60.9
5	Turb. (NTU)	3.43	2.85	2.56	2.77	3.90	3.10	0.55
6	DO (mg/l)	8.3	8.7	8.1	7.8	8.0	8.18	0.34
7	BOD <sub>5</sub> (mg/l)	3.1	1.3	2.1	1.3	1.4	1.84	0.78
8	HCO <sub>3</sub> (mg/l)	130	116	128	118	120	122.4	6.2
9	Alk. (mg/l)	138	128	136	130	128	132	4.7
10	TH (mg/l)	480	556	528	552	560	535.2	33.3
11	Ca (mg/l)	124.8	131.2	123.2	121.6	129.6	126.1	4.1
12	Mg (mg/l)	40.99	55.63	53.68	60.51	57.58	53.68	7.53
13	Cl (mg/l)	203.8	229.3	233.2	219.5	259.8	229.1	20.6
14	NO <sub>3</sub> (mg/l)	9.702	6.625	5.027	4.101	4.693	6.030	2.260
15	SO <sub>4</sub> (mg/l)	277.8	310.4	320.8	302.3	330.5	308.4	20.1
16	TSS (mg/l)	10.6	12.2	4.2	6.2	5.4	7.7	3.5
17	Na (mg/l)	166.6	171.4	178.2	188.4	205.8	182.1	15.6
18	K (mg/l)	6.8	7.2	7.0	7.4	7.8	7.2	0.4

Subsequently, WQIs for drinking and irrigation uses (WA-WQI with turbidity, WA-WQI without turbidity, and WQIFIR) were calculated in these additional locations using the eighteen laboratory-measured water quality parameters to obtain observed values for the WQIs as shown in **Table (4.21)**.

**Table (4.21):** The calculated values (observed values) of WQIs for the additional locations in spring.

Location	WA-WQI with Turb.	WQR	WA-WQI without Turb.	WQR	WQIFIR	WQR
P-1	66.0	P-WQ	65.3	P-WQ	68.4	MR
P-2	58.5	P-WQ	58.9	P-WQ	67.3	MR
P-3	60.1	P-WQ	62.4	P-WQ	65.8	MR
P-4	59.2	P-WQ	60.1	P-WQ	65.7	MR
P-5	63.5	P-WQ	59.8	P-WQ	61.5	MR

P-WQ: Poor water quality; MR: Moderate restriction.

Then, the values of water quality parameters measured for the five additional locations (P-1 to P-5) during spring were substituted into the final equations of the linear regression models obtained in all cases (WA-WQI with turbidity, WA-WQI without turbidity, and WQIFIR), to obtain the predicted values of WQIs and compare them with the observed values.

The observed values (calculated as shown in **Table (4.21)**) and predicted values (calculated using LRMs) of WQIs were compared using the mean square error (MSE) and root mean square error (RMSE), as shown in **Table (4.22)**:

**Table (4.22):** The (MSE) and (RMSE) between observed and predicted values (using LRMs) of WQIs for the additional locations in spring.

WQI	LRM Number	MSE	RMSE
WA-WQI (with Turb)	Model No. 1	12.658	3.558
	Model No. 2	28.929	5.379
WA-WQI (without Turb)	Model No. 1	20.309	4.507
	Model No. 2	15.549	3.943
WQIFIR	Model No. 1	0.689	0.83
	Model No. 2	0.434	0.659

By observing the MSE and RMSE values, it is clear that the RMSE values for the WA-WQI models (with turbidity) were 3.558 and 5.379, respectively.

While for the WA-WQI models (without turbidity), it was 4.507 and 3.943, respectively. The RMSE value for the WQIFIR models was 0.83 and 0.659, respectively. These results indicate that the error rate in the linear regression models that were created using the SPSS program in the current study was very small and did not exceed 5.379 in the worst cases. This means that these models give acceptable results that are close to the true value of the WQIs and can be used to predict the water quality of the Al-Abbasiyah River in the future and under the same conditions as the current study.

#### **4.5 Spatial Distribution Maps (SDM) of Water Quality for Al-Abbasiyah River.**

Water resource issues can be better solved by utilizing GIS technology to display and analyze water quality, determine water availability, and comprehend the natural environment on a local or regional scale. GIS can be utilized to map the spatial distribution of various contaminants, and the data gathered is invaluable for helping decision-makers execute corrective measures (Latha & Rao, 2010).

In this study, ArcGIS 10.8 software and the IDW method were used to create spatial distribution maps of the water quality for the Al-Abbasiyah River for drinking and irrigation uses based on WQI methods values calculated at each location of the Al-Abbasiyah River during all seasons as follows:

##### **4.5.1 Spatial Distribution Maps of Drinking Water Quality**

ArcGIS 10.8 software and the IDW method were used to create spatial distribution maps (SDM) of the water quality for the Al-Abbasiyah River for drinking uses based on WA-WQI values (with and without turbidity). These models were calculated using physical, chemical, and biological parameters taken from eight locations along the river during this study. While the CCME-WQI values were not relied upon to create the spatial distribution maps as a result of the unavailability of the CCME-WQI values for each season, the

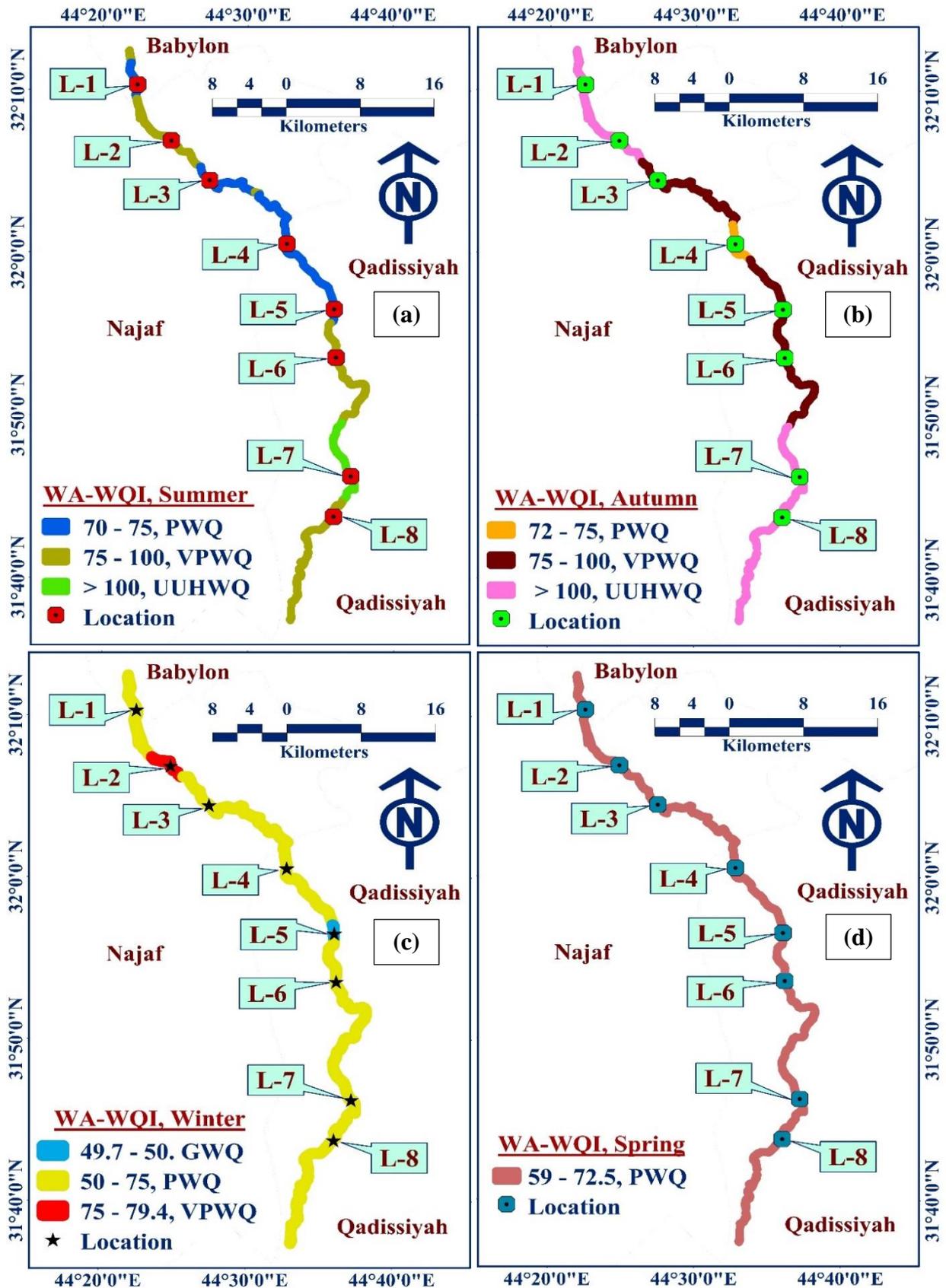
obtained values were limited to the water quality values as an annual average. Thus, it is not possible to notice the seasonal change in river water quality, in addition to that the results of CCME-WQI do not differ much from the results of WA-WQI.

**Figures (4.10) and (4.11)** show the SDM of the water quality of Al-Abbasiyah River for drinking uses based on the values of WQ-WQI with turbidity and WA-WQI without turbidity, respectively, during all seasons.

In these Figures, the classification of WA-WQI values (with turbidity) in summer besides autumn ranged between "PWQ" to "UUHWQ" along the river, while in winter, the classification was "PWQ" along the river except for some small areas that were its water quality rating is "GWQ" and "VPWQ". In spring, the drinking water quality along the river was classified as "PWQ".

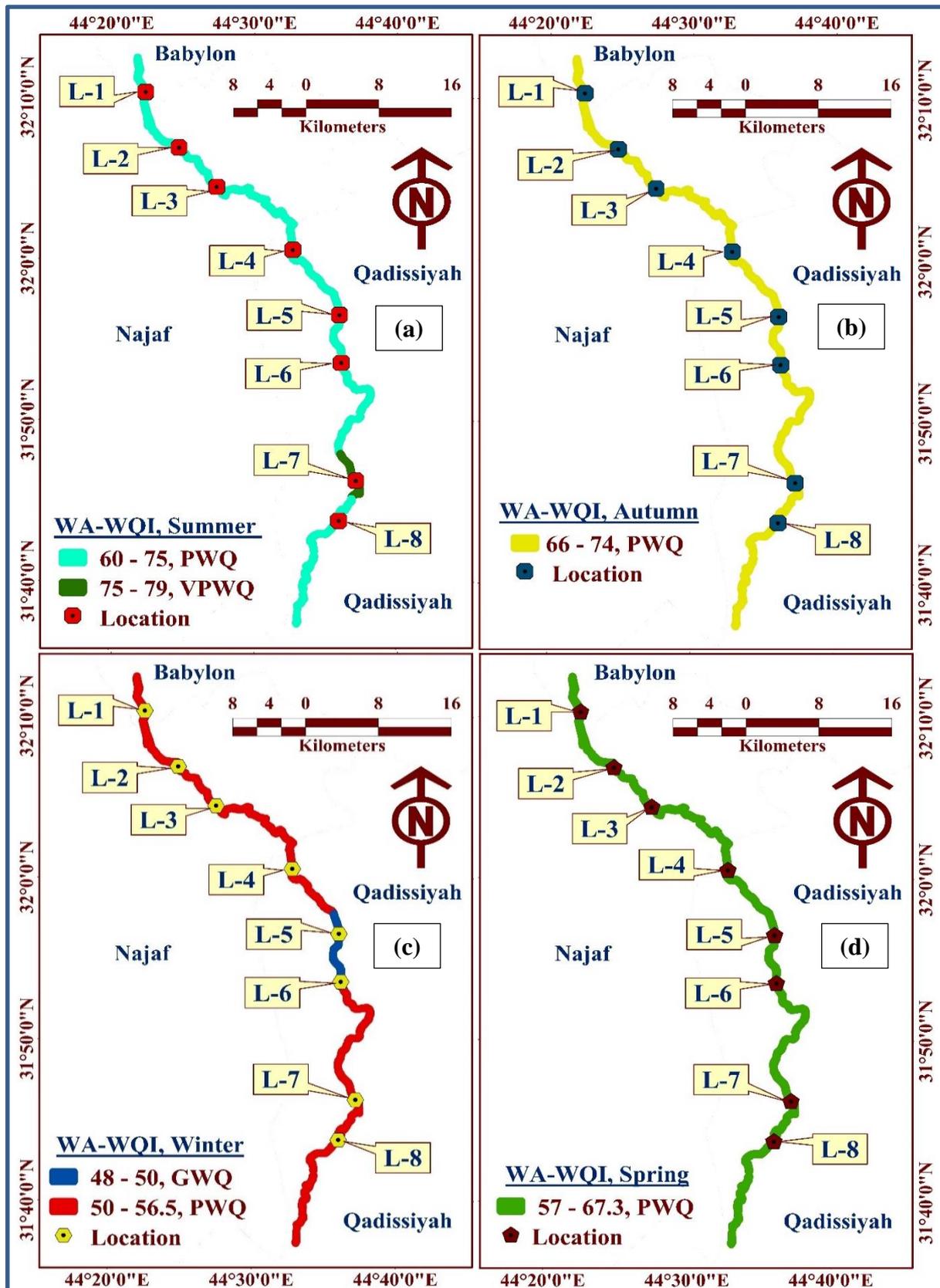
On the other hand, the classification of WA-WQI values (without turbidity) in summer and winter seasons was "PWQ" along the river except for some small areas which were classified as "VPWQ" and "GWQ" in summer and winter, respectively. While in autumn and spring, the river was classified as "PWQ".

The SDMs of the annual average values of WA-WQI (with and without turbidity) are presented in **Figure (4.12)**. The annual average of drinking water quality along the Al-Abbasiyah River based on the WA-WQI values (without turbidity) was within the category (60 - 67) with the "PWQ" classification. While, based on the WA-WQI values (with turbidity) the river was classified into two categories (65 - 75), and (93.2 - 75) with the classification of "PWQ" and "VPWQ" respectively.



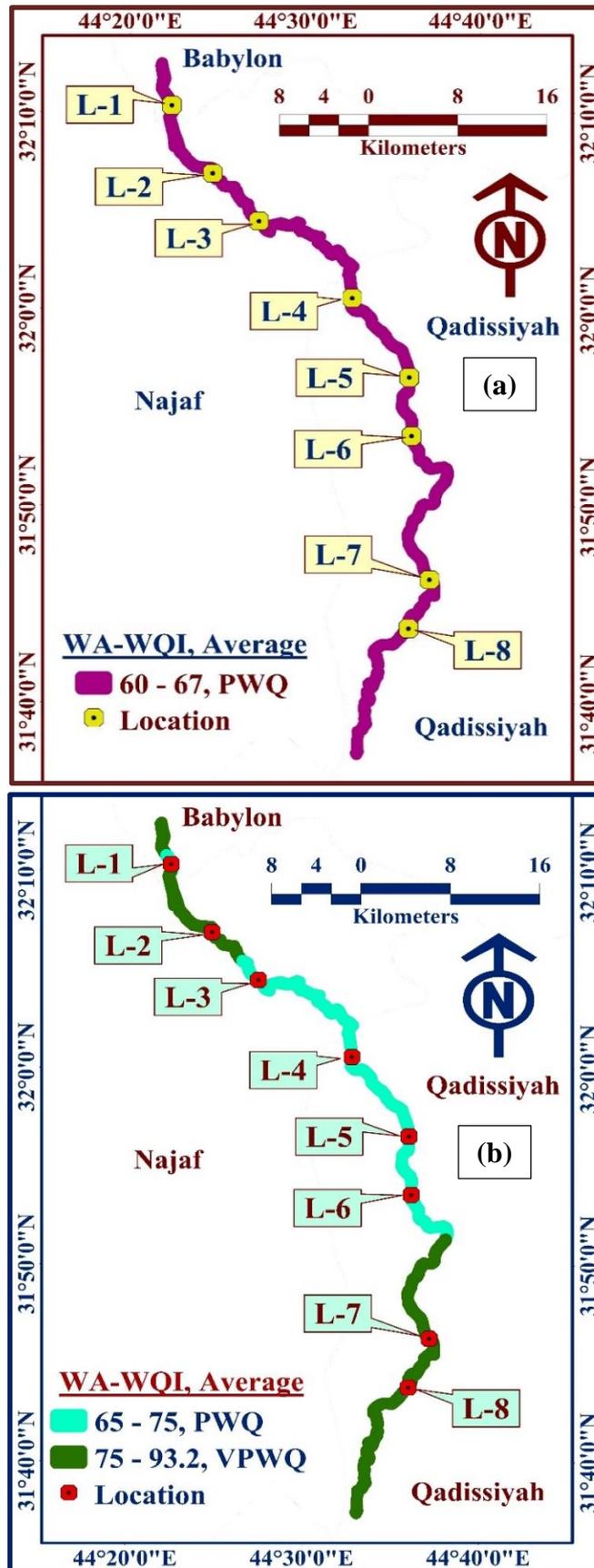
**Figure (4.10):** Maps of WA-WQI values (with turbidity) along the Al-Abbasiyah River that resulted using the interpolation method IDW for the seasons (a): **Summer**; (b): **Autumn**; (c): **Winter**; (d): **Spring**.

**Note:** G-WQ: Good water quality; P-WQ: Poor water quality; VP-WQ: Very poor water quality; UUH-WQ: Unsuitable use for human water quality.



**Figure (4.11):** Maps of WA-WQI values (NO turb.) along the Al-Abbasiyah River using the interpolation method IDW for the seasons (a): Summer; (b): Autumn; (c): Winter; (d): Spring.

**Note:** G-WQ: Good water quality; P-WQ: Poor water quality; VP-WQ: Very poor water quality.



**Figure (4.12):** Maps of WA-WQI for average readings during all seasons of the river using the interpolation method (IDW) (a): **without turbidity**; (b): **with turbidity**.

**Note:** P-WQ: Poor water quality; VP-WQ: Very poor water quality.

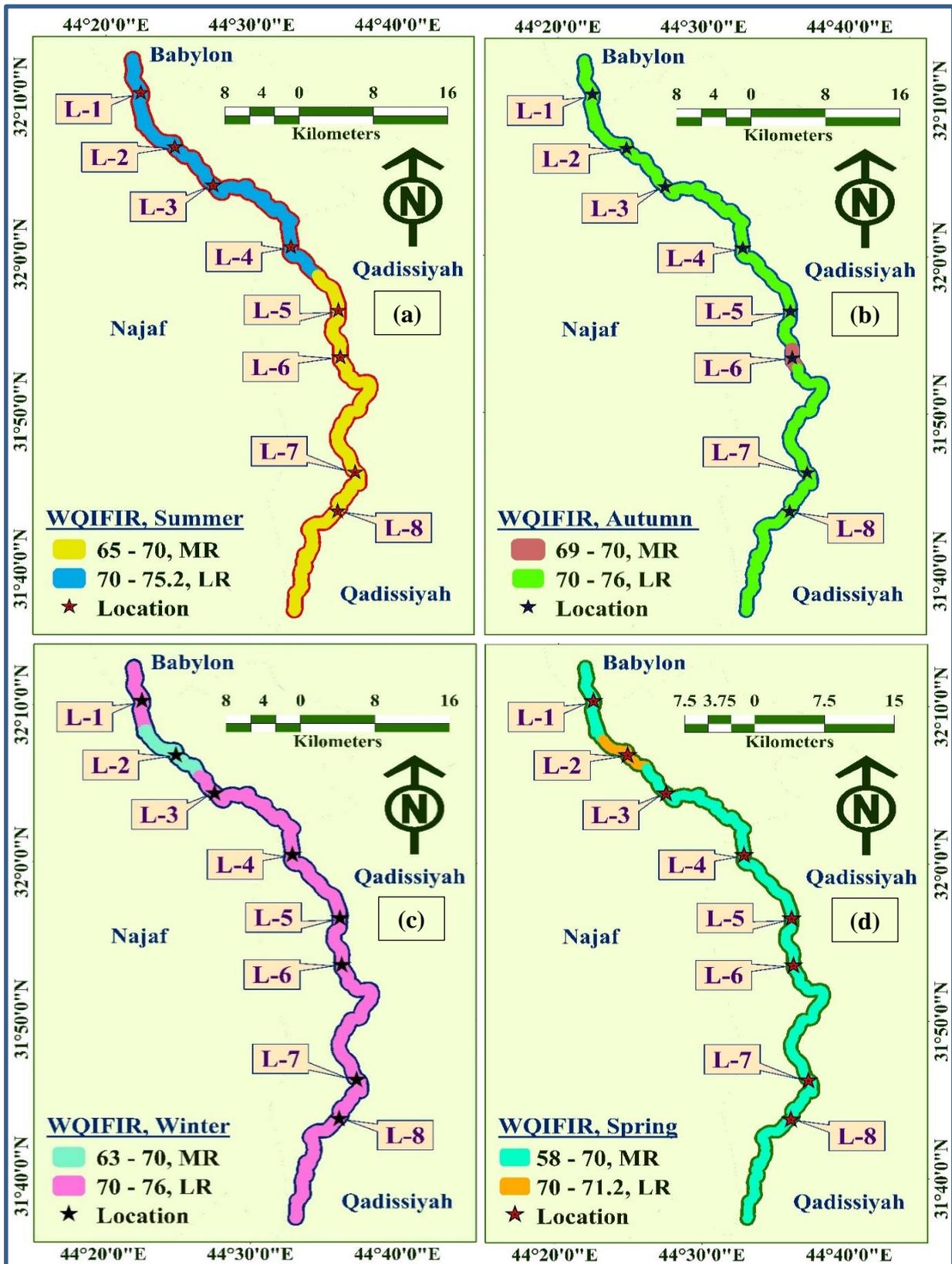
#### 4.5.2 Spatial Distribution Maps for Irrigation Water Quality

ArcGIS 10.8 software and the IDW method were used to create spatial distribution maps of the water quality of the Al-Abbasiyah River for irrigation uses based on WQIFIR values. These maps were created using the WQIFIR values resulting from the measured parameters taken from eight locations along the river during this study.

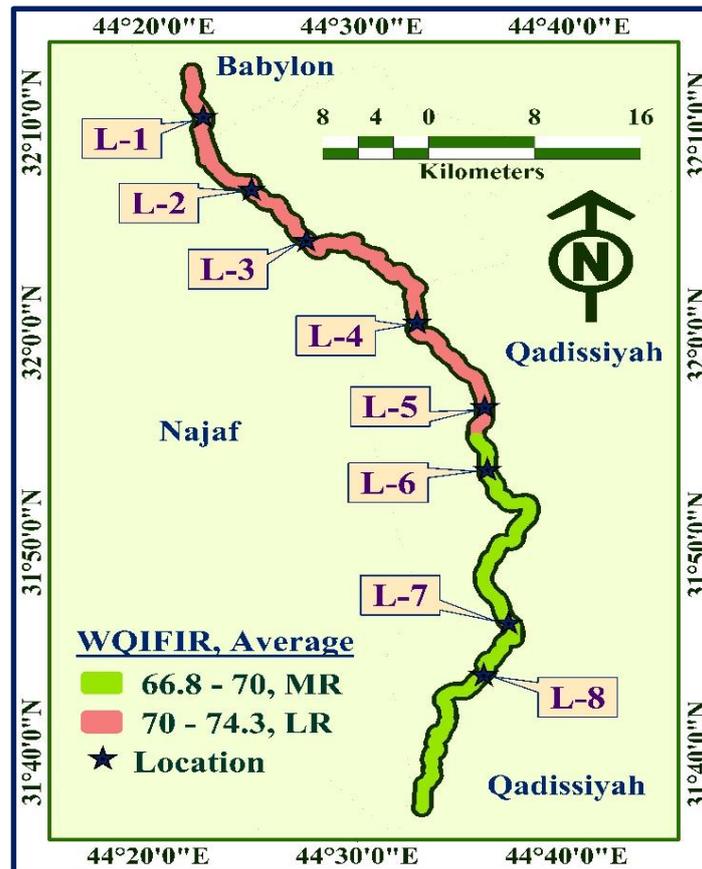
**Figure (4.13)** shows SDMs of the water quality of the Al-Abbasiyah River for irrigation uses based on WQIFIR values during four seasons in this study. The importance of these maps lies in the fact that they give a quick impression of the mechanism of changing the river water quality along the length of the river associated with each standard classification of water quality clearly to the researchers and decision-makers.

The classification of the WQ, based on WQIFIR values, in summer, ranged between “LR” at locations (L-1 to L-4) and “MR” at locations (L-5 to L-8), while in autumn and winter seasons, the rating was “LR” along the river except for locations (L-2) and (L-6) for winter and autumn respectively which were rated “MR”. In spring, the WQ was rated "MR" along the river except for location (L-2) which was rated "LR".

The SDM of the annual average of WQIFIR values is shown in **Figure (4.14)**. Depending on the WQIFIR values, the Al-Abbasiyah River's mean yearly quality of water for irrigation use, fell between two categories (66.8 - 70), (70 - 74.3), with a classification of "MR" and "LR," respectively.



**Figure (4.13):** Maps of WQIFIR values along the Al-Abbasiyah River resulted using the interpolation method IDW for the seasons (a): Summer; (b): Autumn; (c): Winter; (d): Spring. **Note:** LR: Low restriction; MR: Moderate restriction.



**Figure (4.14):** Maps of average WQIFIR values for all seasons along the Al-Abbasiyah River that resulted using the interpolation method IDW.

**Note:** LR: Low restriction; MR: Moderate restriction.

Monitoring the sources of the contaminants and attempting to minimize or reduce their effects are strategies that can be used to preserve the surface water in Iraq. Moreover, determining the appropriate technologies that can be used to treat polluted water depends on knowing the causes and sources of pollution. Thus, applying all the above-developed models to predict the Al-Abbasiyah River water quality is useful to monitor and assess the river status (Chabuk et al., 2020).

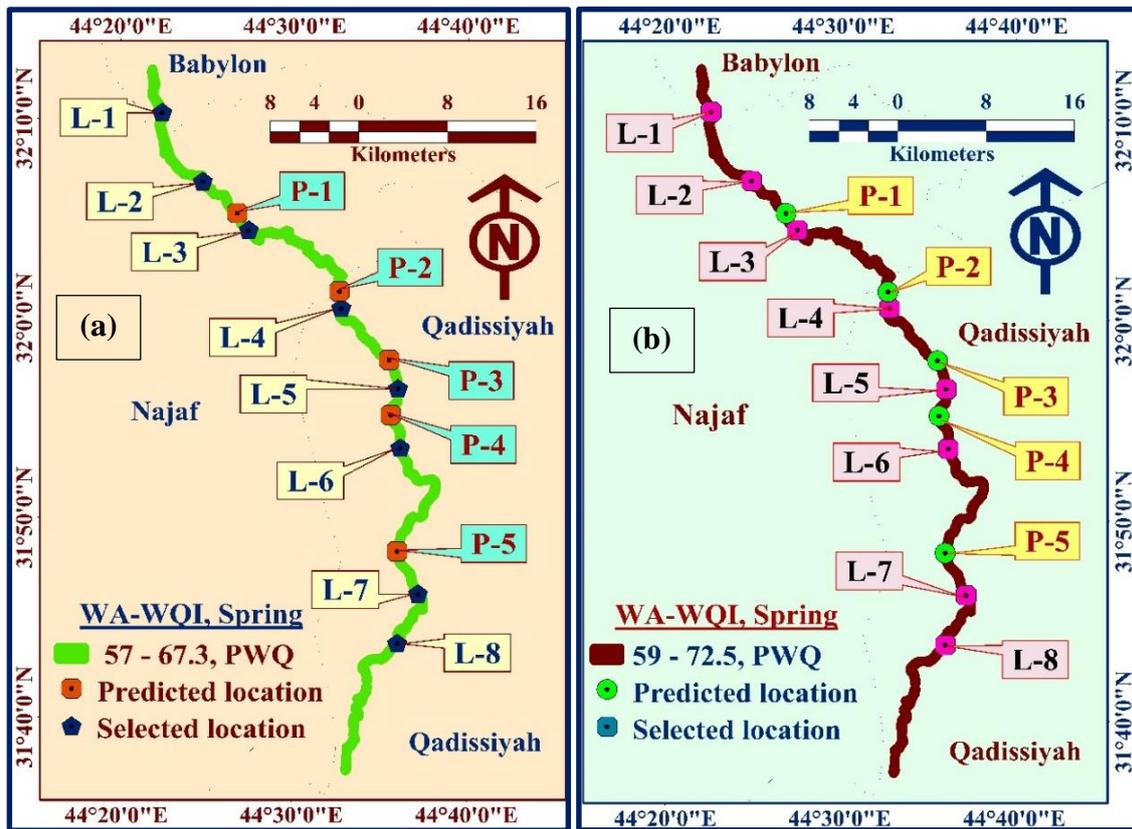
### 4.5.3 Validation of Spatial Distribution Maps

Creating spatial interpolation maps of WQIs using the IDW method in GIS can be a useful tool for visualizing spatial patterns and predicting water quality in locations where data are not available. However, the predicted values need to be validated at those locations along the river. The inaccuracy of the results can lead to low-quality maps in describing the river's WQ.

Based on the calculated WQI method values in the eight sampling locations (from L-1 to L-8), the IDW technique was utilized in the present study to predict the values of WQI methods at all locations along the river length. To validate the IDW model and the created SDMs, the same five additional locations (P-1 to P-5) that were used to validate the linear regression models were relied upon. The coordinates of these additional locations and the values of the water quality parameters that were measured in spring for it were previously mentioned in **Tables (4.19)** and **(4.20)**. Also, the WQIs values for drinking and irrigation uses (WA-WQI with turbidity, WA-WQI without turbidity, and WQIFIR) were calculated at these additional locations as previously described in **Table (4.21)**.

#### 4.5.3.1 Validation of SDMs for Drinking Uses

**Figure (4.15)** shows the spatial distribution maps of the WA-WQI values (with and without turbidity) for the five additional locations in the spring. These maps provide the WA-WQI values that were predicted using the IDW method in the additional locations (predicted values) to be compared with the calculated WA-WQI values (observed values) for these same locations that were mentioned in **Table (4.21)**.



**Figure (4.15):** Maps of WQI interpolation values that showed the selected and predicted locations along the river using IDW in Spring (a): without turbidity; (b): with turbidity.

**Note:** P-WQ: Poor water quality.

Table (4.23) shows the observed and predicted WA-WQI values for the five additional sites in the spring. It also shows the values of the mean square error (MSE) and the root mean square error (RMSE), which were used to determine the error rate in the results of the IDW method used in the current study.

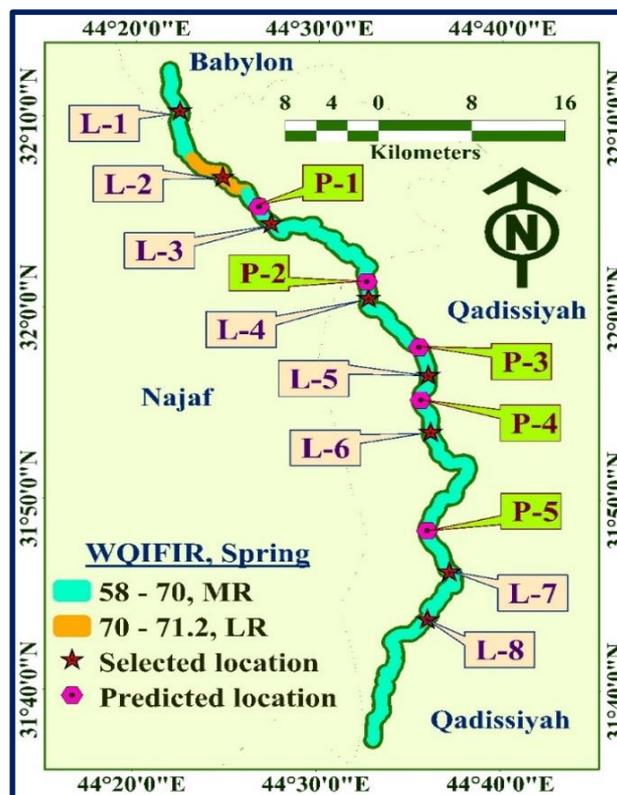
**Table (4.23):** Comparison of observed (measured) values and predicted (by the IDW method) values of the WA-WQI using MSE and RMSE.

Location	WA-WQI with turb.		WA-WQI without turb.	
	Observed	Predicted	Observed	Predicted
P-1	66	59.1	65.3	63.5
P-2	58.5	61.7	58.9	63.3
P-3	60.1	62.2	62.4	61
P-4	59.2	62	60.1	61.3
P-5	63.5	62.2	59.8	62.1
MSE	14.358		6.258	
RMSE	3.789		2.502	

By observing the MSE and RMSE values, it is clear that the MSE and RMSE values for the WA-WQI (with turbidity) were 14.358 and 3.789, respectively. While for the WA-WQI (without turbidity), it was 6.258 and 2.502, respectively. These results indicate that the error rate in the IDW model that was created in the current study was very small. This means that these models give acceptable results that are close to the true value of the WQIs and can be used to predict the water quality of the Al-Abbasiyah River for drinking uses in the future and under the same conditions as the current study.

#### 4.5.3.2 Validation of SDMs for Irrigation Uses

Figure (4.16) shows the spatial distribution map of the WQIFIR values for the five additional locations in the spring. This map provides the WQIFIR values that were predicted using the IDW method in the additional locations (predicted values) to be compared with the calculated WQIFIR values (observed values) for these same locations that were mentioned in Table (4.21).



**Figure (4.16):** Maps of WQIFIR interpolation values that showed the selected and predicated locations along the river using IDW in Spring.

**Note:** LR: Low restriction; MR: Moderate restriction.

**Table (4.24)** shows the observed and predicted WQIFIR values for the five additional sites in the spring. It also shows the values of the mean square error (MSE) and the root mean square error (RMSE), which were used to determine the error rate in the results of the IDW method used in the current study.

**Table (4.24):** Comparison of observed (measured) values and predicted (by the IDW method) values of WQIFIR using MSE and RMSE.

Location	WQIFIR	
	Observed	Predicted
<b>P-1</b>	68.4	68.7
<b>P-2</b>	67.3	68.4
<b>P-3</b>	65.8	67.3
<b>P-4</b>	65.7	66.4
<b>P-5</b>	61.5	61.6
<b>MSE</b>	0.81	
<b>RMSE</b>	<b>0.9</b>	

By observing the MSE and RMSE values, it is clear that the MSE and RMSE values for the WQIFIR were 0.81 and 0.9, respectively. These results indicate that the error rate in the IDW model that was created in the current study was very small. This means that this model gives acceptable results that are close to the true value of the WQI and can be used to predict the water quality of the Al-Abbasiyah River for irrigation uses in the future and under the same conditions as the current study.

## 5.1 Conclusions

The conclusions of this study can be summarized as follows:

1. By measuring eighteen water quality parameters for the water of Al-Abbasiyah River, it was found that some of these parameters were within the WHO standards for all locations and seasons such as (pH, EC, TSS, DO, NO<sub>3</sub>, BOD). The other measured parameters exceeded the WHO standard in some or all of the locations and seasons as a result of the discharge of sewage water or the disposal of fertilizers and animal waste directly into the river in some cities through which the river passes.
2. The applications created in the Visual Basic software are a very important tool that shortens the time required to calculate the WQIs accurately and easily.
3. The results of the WQIs show that:
  - a. The results of the annual average of the WA-WQI (with turbidity) and CCME-WQI (with and without turbidity) showed that the WQR of Al-Abbasiyah River for drinking uses ranged between “poor” and “very poor”. The results of the annual average of the WA-WQI (without turbidity) showed that the WQR of the Al-Abbasiyah River was “poor” in all locations along the river.
  - b. The results found that turbidity had a significant effect on the computed WA-WQI results, especially for locations that had turbidity values greater than the WHO standard. In contrast to the CCME-WQI results, where turbidity had the same effect as other parameters.
  - c. The findings indicated that the Al-Abbasiyah River's water needed to be treated before use because it was contaminated and was not fit for direct consumption during any season due to the high values of some parameters that exceeded the permissible standards, especially TH, Ca, Mg, SO<sub>4</sub>, turbidity, and some other parameters for specific seasons and locations.

- d. One of the disadvantages of the WA-WQI method is that it gives a high weight to one of the parameters compared to the other parameters as a result of its calculation method, which gives a very high weight to parameters whose permissible standards are low. Therefore, it is preferable to use WA-WQI when the standard specifications of the parameters used are close to each other numerically.
  - e. Both WA-WQI and CCME-WQI can be used to evaluate the water quality of the Al-Abbasiyah River without significant differences in results, especially when turbidity is excluded from the calculations.
  - f. Al-Abbasiyah River water quality for irrigation purposes according to the WQIFIR ranged between low restriction (LR) and moderate restriction (MR) for all locations and seasons. Thus, the river water was suitable for plant irrigation throughout the study period with some limitations due to high salinity in some locations due to local geological characteristics and agricultural irrigation activities.
4. Linear regression models created by the SPSS software gave high and acceptable  $R^2$  values and can be used in estimating the water quality of the Al-Abbasiyah River for drinking and irrigation purposes. The  $R^2$  values were 97%, 91%, and 75% for the best estimation models for the WA-WQI (with turbidity), WA-WQI (without turbidity), and WQIFIR, respectively.
  5. The linear regression models generated by SPSS were validated using MSE and RMSE, where the RMSE values for the WA-WQI models (with turbidity) were 3.558 and 5.379, respectively. While for the WA-WQI models (without turbidity), it was 4.507 and 3.943, respectively. The RMSE value for the WQIFIR models was 0.83 and 0.659, respectively. This means that these models give acceptable results that are close to the true value of the WQIs and can be used to predict the water quality of the

Al-Abbasiyah River in the future and under the same conditions as the current study.

6. The spatial distribution maps drawn by the IDW method in the GIS software showed that the annual average water quality of Al-Abbasiyah River for drinking purposes was classified as “PWQ” and “VPWQ”, respectively. The river water quality for irrigation purposes was classified as “MR” and “LR”, respectively.
7. The IDW models used in spatial distribution mapping were validated using MSE and RMSE, where RMSE values ranged between 3.789, 2.502, and 0.9 for WA-WQI (with turbidity), WA-WQI (without turbidity), and WQIFIR, respectively. This indicates that the IDW models give very acceptable results when predicting WQI values along the Al-Abbasiyah River within the study period.

## 5.2 Recommendations

The following recommendations can be useful for future studies:

1. If the Al-Abbasiyah River's water discharge returns to normal levels, it will be essential to conduct a new assessment of the river's water quality because, during the research period, it was at its lowest level (30 m<sup>3</sup>/sec) as a result of Iraq's recent water scarcity issue.
2. Future research should account for the impact of heavy metals on the WQ of the river, as this was not done in the current study, and should make up for the absence of prior studies that addressed the water quality of the Abbasiyah River generally.
3. It is recommended to develop this study in the future by creating models to estimate the values of water quality parameters and the WQI methods using remote sensing techniques. Where, in this study, the dates of water sampling were synchronized with the dates of the Landsat OLI 9 satellite images at each season.

4. Using other statistical methods (such as nonlinear regression models) to create estimation models for the water quality based on the strongly correlated water quality parameters, to obtain more accurate regression models with a higher  $R^2$  than obtained in this study.
5. Recommending the need to increase the discharge of the river, as it irrigates large agricultural areas, and the current discharge limits are sufficient for only a small percentage of the total agricultural lands. In addition to addressing the reasons for the high concentrations of some pollutants in the river water by activating the strict laws that regulate the disposal of wastewater into the river.
6. It is recommended to add a softening stage when designing water treatment plants on the Al-Abbasiyah River in the future due to the high concentrations of TH in the river water. The river bottom consists of a limestone layer, which leads to high concentrations of Ca, Mg, and  $SO_4$  ions.

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