

Applying Remote Sensing and Artificial Neural Networks for Water Quality Index Modeling in the Euphrates River



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ABSTRACT

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The Water Quality Index (WQI) is an effective water test that assesses water quality, identifies contaminants, and aids in decision-making. However, it is inefficient to analyze water samples in laboratories due to high costs, time-consuming processes, and limited ability to record temporal or geographical oscillations. Recently, the use of modern technologies such as Remote Sensing (RS) data, Geographic Information Systems (GIS), and Artificial Neural Networks (ANN), in combination with survey data, has confirmed an efficient tool to generate the WQI map of the Euphrates River in Ramadi, Iraq. In the present study, the RS data, such as Landsat 8 and Landsat 9 images, and laboratory tests of samples were used to develop a database for WQI based on spectral reflectance using the radial basis neural network model. The result of this model was then manipulated within ArcGIS 10.8 using the spatial analyst model to generate a digital map of WQI. This model was evaluated using seven criteria, which are correlation coefficient (r), mean absolute error, normalized mean absolute error, lowest absolute error, maximum absolute error, and root square equation of the coefficients (RMSE). The correlation value of the WQI was 0.93, which shows remarkable prediction accuracy. Therefore, this calculation method is effective in calculating the WQI and producing precise digital maps of water quality.

1. INTRODUCTION

Rivers, crucial natural resources for mankind, are being polluted by uncontrolled sewage, industrial waste, and other human activities. This pollution impacts the physical, chemical, and microbiological indicators of river quality. To protect human health and preserve the original value of irreplaceable freshwater resources, spatial and temporal water quality data are needed [1]. Water quality is a combination of all relevant physical, chemical, biological, and bacteriological properties expressed in quantitative terms as suitability for human consumption. For efficient management, the prevention and control of river pollution must be as important as reliable statistics on water quality [2]. Numerous initiatives have been made to use water quality monitoring to support decision-making. A comprehensive monitoring program is essential for preserving the quality of river water because it measures the extent of pollution and controls its effects. However, evaluating quality becomes challenging when dealing with a large number of samples that have different concentrations of various attributes [3]. Therefore, safeguarding the public's health and the preservation of priceless freshwater resources is becoming very vital.

The availability of fresh water resources globally is enough based on current consumption levels, but the uneven distribution of water on Earth poses a challenge. The Euphrates River, while historically significant, has been

impacted by various problems. Changes in the river, such as decreased discharge levels, have caused an increase in non-native organisms and chemical concentrations, leading to significant ecological changes [4, 5]. Sewage is a primary contributor to water quality deterioration, as it contains harmful microorganisms and toxins. Salty drainage water from agriculture, industrial waste, and improper disposal of waste from various sources further contribute to pollution [6, 7]. Water purification plants produce sterile water but release highly conductive waste back into the river. Entertainment venues also contribute to pollution by dumping waste and connecting drainage systems directly to the river. The detrimental impact of waste dumping on rivers is evident at recreational sites near the river. Despite the sufficiency of global fresh water resources, the uneven distribution and pollution from various sources pose significant threats to water quality and ecosystems, highlighting the urgent need for effective measures to protect and preserve freshwater sources like the Euphrates River.

The Water Quality Index (WQI) is a mathematical technique that simplifies large databases of water quality data into a single numerical value, providing managers with a reliable indicator of water quality [8-11]. Conventional laboratory testing methods for calculating WQI are time-consuming and costly, while remote sensing (RS) offers a viable substitute to expand current water survey datasets. Moreover, this data is easy to analyze and can be used in

environmental impact evaluations [12-14]. In a geographical context, RS can be applied to complement WQI by using several different electromagnetic spectrum bands in the forecast of water quality parameters.

Over the past few decades, the application of remote sensing techniques has become vital in resolving global climate change-related issues as well as the continuous degradation of aquatic ecosystems. The demand for clean water is rising along with the population, but this growth is being restricted by pollution from point and non-point overland drainage that threatens fish and other species [15]. The advent of sophisticated sensor technology makes it possible to quickly and simultaneously monitor changes in land cover across large areas [16, 17]. The availability of remote sensing data and the use of GIS capabilities provide new tools for large-area in data-limited regions of the world [18-20]. Techniques for remote sensing are widely used to assess the quality of water [15, 21-30]. Many publications describe how different satellite sensors are used to check the quality of the water [21, 24, 31-37]. It is essential to comprehend the spectrum properties of contaminants and water to monitor and evaluate the quality of the water. The hydrological, biological, and chemical properties of water, as well as other influencing elements, provide the spectrum characteristics that are displayed in the signal obtained from water [23, 29, 38, 39].

It is challenging to anticipate the characteristics of water quality employing physical theoretical approaches due to the variable reflectance spectrum. The phenomenon of water reflection is complicated [40]. Thus, especially across large areas, it is vital to design a system that can reveal the complex relationships between reflectance and water quality. Artificial neural networks (ANNs) are advantageous in water quality index applications for various reasons. They can capture complex relationships between water quality parameters, enhancing prediction accuracy [41, 42]. ANNs are adaptable to evolving conditions, integrate data from multiple sources for comprehensive evaluations, and handle missing data effectively. Their use in WQI applications results in more robust and accurate water quality assessments, supporting informed decision-making in water resource management.

This work demonstrates a methodology to determine the WQI, which integrates RS, Geographic Information Systems (GIS), and ANNs. Artificial Intelligence (AI) is applied to enhance the digital mapping of WQI, while the GIS integration provides comprehensive coverage of the entire region. This methodology proves its effectiveness in large-scale contexts where data may be bounded. Hence, this method was applied to the Euphrates River in Ramadi City, located in the Anbar Governorate of Iraq.

2. STUDY AREA

The longest river in the Middle East, the Euphrates, rises in Turkey's eastern highlands and is tucked between Lake Van and the Black Sea. Roughly 25% of the river's course passes through Syria, and the remaining 40% passes through Turkey. As it meanders down the river, Iraq and Syria split the remaining 35 percent [43, 44]. The Euphrates River is a key fresh water source connecting Turkey, Syria, and Iraq. It supports agriculture, industry, fishing, transportation, and electricity generation in Iraq. The river is crucial for wildlife and plants, attracting diverse species to the region, making it environmentally significant. It is a major electricity generator

in Iraq." The river can't go as far as it can, though, because of fluctuations in the natural water flow. Unfortunately, the basin's irrigation demands are not sufficiently met by the allocation of available water [45, 46]. Iraq's largest river, the Euphrates, has an entrance point and basin in the western part of the nation. It travels through the Mesopotamian alluvial plain in the Al-Anbar area for around 337 kilometers. The main study has been implemented on the Euphrates River in Al-Ramadi city within Al-Anbar province, western Iraq, between Longitude 43°16'11.9" to 43°19'47.0" E; Latitude 33°26'24.5" to 33°27'11.2" N as shown in Figure 1. Ramadi city sits on the Euphrates River about 110 kilometers west of Baghdad, has a historic urban layout with markets, mosques, and homes. Economy thrives on trade, agriculture, and services due to its strategic location. Land use includes residential, commercial, agricultural, and institutional zones with basic infrastructure [47-49]. This region has hot, dry summers and chilly winters, with a climate that is classified as dry to semi-arid. The lowest level of temperature was recorded during January (2.5°C), whereas the highest level was recorded during July (42°C). The amount of precipitation diverges between (50–200) mm annually. The Euphrates River in Iraq is affected by extreme temperatures, low rainfall, and high evaporation rates, leading to increased water loss. Overall, the climate's impact on evaporation and water loss significantly affects the water quality in the study area [50, 51].

During the typical year, the river attains its maximum flow in the winter months of April and May [52]. The normal low-water season, which runs from July to December, is in August and September. It reaches its lowest point in August and September when the water is heavily used to irrigate the region's winter crops. The Euphrates monthly hydrograph shows seasonal variations that range from 33 to 275 percent of the yearly average [53-55].

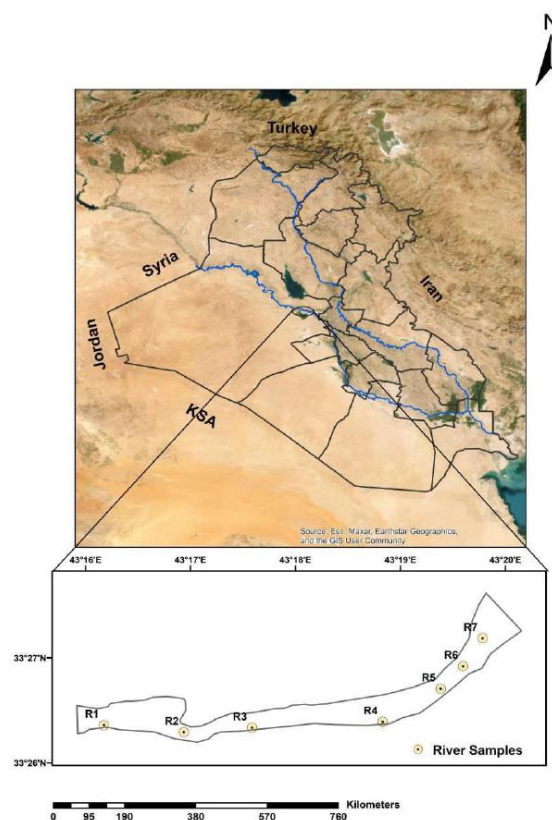


Figure 1. Study area

3. MATERIALS AND METHODS

We use a technique that includes many steps of data preparation, gathering, and modeling in order to meet the study’s goal. Figure 2 provides an illustration of these stages. The following is an outline of the methodology:

First step: Involved gathering satellite images of the study area from Landsat 8 and Landsat 9, spanning from October 2022 to June 2023.

Second step: During the water sampling process, we chose seven sample locations (three sample locations represent clear water while four locations were chosen based on polluted sources identified through field surveys). Figure 3 shows the sample location. These sources represented sewage is a primary contributor to water quality deterioration and salty drainage water from agriculture, industrial waste, and improper disposal of waste from various sources further contribute to pollution. We collected 105 samples period from October 2022 to June 2023, which were taken at the same time as the satellite images, and conducted laboratory tests using water analysis to assess water contamination, as shown in Table 1.

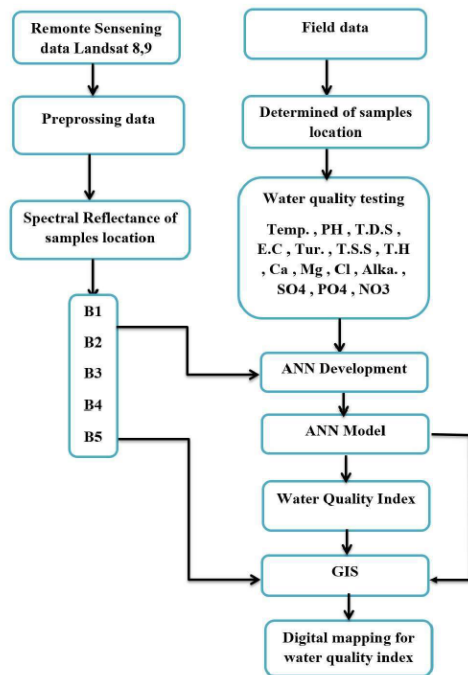


Figure 2. Flowchart of the proposed methodology



Figure 3. Euphrates River basin and the sample locations

Table 1. Water parameters, test methods, and standards used

Parameter	Symbol	Teste Methods	Water Quality Conservation Law of Rivers and Public Waters (Law Iraqi No. 25/1967)
pH	pH	PH meter	8.5
Temperature	Temp.	Thermometer	25°C
Total dissolved solids	T.D.S	TDS meter	- (It was imposed 1000) *mg/l
Electrical Conductivity	E.C	Conductivity meter	- (It was imposed 2000) *µs/cm
Turbidity	Tur.	Nephelometric	10 NTU
Total suspended solids	T.S.S	Drying Method 2540 D	25 mg/l
Hardness	T.H	EDTA Titrimetric	300 mg/l
Calcium	Ca	Flame photometric	75 mg/l
Magnesium	Mg	Calculation method	30 mg/l
Chloride	Cl	Argentometric	250 mg/l
Alkalinity	Alka.	EDTA Titrimetric	200 mg/l
Sulphate	SO ₄	UV Spectrophotometer	200 mg/l
Phosphorus	PO ₄	UV Spectrophotometer	0.4 mg/l
Nitrate	NO ₃	UV Spectrophotometer	50 mg/l

* Depended on Iraqi drinking water quality specifications standard IQS/417, 2001. Because the river is a source of drinking water.

4. RESULTS AND DISCUSSION

While assessing the quality of water, one must consider its intended uses, natural circumstances, and human impact while analyzing its physical, chemical, and biological characteristics. In this work, we have developed the WQI that allows us to evaluate the quality of water for various public uses, such as recreational and drinking water supplies. Additionally, the WQI helps assess how well water quality management initiatives are working. We can explain the current state of the water quality, better comprehend it overall, and demonstrate the efficacy of preventive actions with the use of the WQI. For the reasons you indicated, we would want to create a river index or water quality index.

The study area was chosen based on water pollution. Four sample locations were selected to represent clear water (R2, R5, R6, R7), while three locations were chosen based on polluted sources identified through field surveys (R1, R3, R4), as shown in Figure 3.

We performed a sensitivity analysis as part of our investigation to look at the connection between reflectance and the WQI. The visual representation of the WQI's sensitivity to various bands is provided in Figure 4. As can be seen from Figure 4, band 1 (0.45–0.52 µm) has no effect on the WQI. In contrast, band 2 (0.52–0.60 µm) has the highest WQI sensitivity. In terms of sensitivity, bands 4 (0.76–0.90 µm) and 5 (1.55–1.75 µm) are closely followed, whereas band 3 (0.63–0.69 µm) has little effect. The bands and the spectral reflectance of the WQI have a complex connection in which

each band has a distinct function of changing significance.

The reflectance variance across the bands can be a good starting point for creating an extremely accurate model to estimate the WQI. Consequently, it is imperative that the Artificial Neural Network (ANN) model incorporate all of the bands.

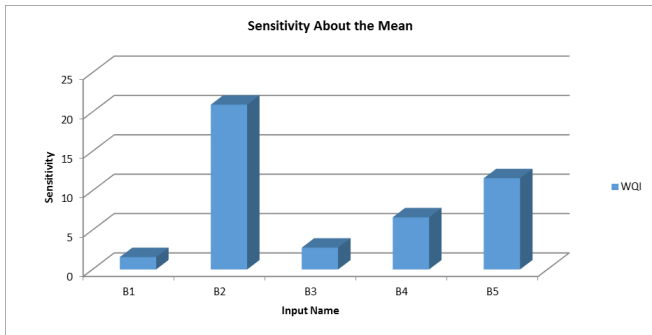


Figure 4. WQI sensitivity with bands reflectance

The actual and anticipated values of the ANN model are shown in Figure 5. The WQI for the research region is shown in this figure. It also shows that there is a greater degree of accuracy between the estimated and real WQI values. A mathematical model using bands as inputs and the water quality index as the output was developed after taking 28 points for the estimated values.

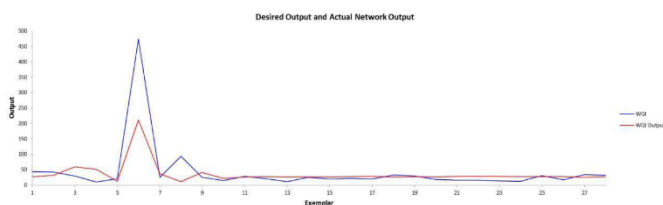


Figure 5. Estimated and actual values of WQI of tested samples

To evaluate the performance of the Artificial Neural Network (ANN) model in estimating the Water Quality Index (WQI), seven criteria were considered: RMSE, NRMSE, MAE, NMAE, minimum absolute error, maximum absolute error, and the correlation coefficient (r). The results revealed that the correlation coefficient for WQI, as shown in Table 2, is the highest at 0.93.

Table 2. Performance criteria of Neural network model for WQI

Performance	WQI
RMSE	53.65671766
NRMSE	0.242244315
MAE	22.49976681
NMAE	0.101579836
Min Abs Error	1.28693089
Max Abs Error	262.3010894
r	0.933806536
Score	90.19598885

As mentioned before, the main goal of this paper is to create a map that shows the WQI for the Euphrates River. To predict the WQI, we used the spectral reflectance data from 120 different points in various locations using the ANN model. These data were processed within a GIS using a spatial

analysis model, resulting in a digital map of the WQI. As shown in Figure 6, the distribution of the WQI for the Euphrates River in Ramadi city, located in the Anbar Governorate of Iraq. Four periods were taken with different dates as shown in Figure 6. These periods were taken depending on the weather condition. The weather in the summer was hot and dry. It leads to an increase in the salt concentration of the river water with an increase in evaporation, and therefore pollutants are concentrated as a result of the slowdown in the movement of the river. However, in the winter, the condition of the river was good, especially during the period of rainfall, as the river level rose, the rate of evaporation decreased, and its movement increased, which led to a reduction of pollutants, and the quantities of rainfall reduces the salinity of the river.

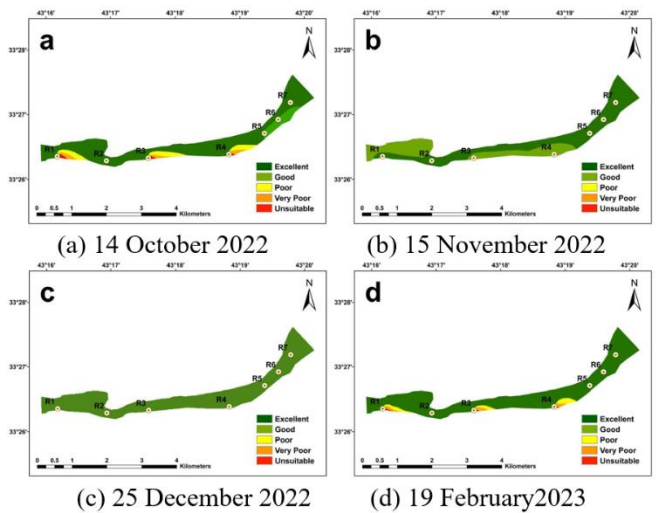


Figure 6. GIS plot for four periods of the water quality index

5. CONCLUSIONS

The WQI is monitored, detected, and mapped in large part because to remote sensing. It offers recurring, economical, quick, and timely data. Our goal in this work was to use the correlation between WQI and spectral reflectance to predict the WQI. The WQI facilitates rapid decision-making in resource planning and water management by acting as a platform for a variety of modeling and applications. In order to produce the WQI in this study, we integrated the use of GIS, Remote Sensing data, and ANN. We looked at the difference between the actual and anticipated numbers to assess the efficacy of this technique. This study revealed that the band 2 (0.52-0.60 μm) has the highest WQI sensitivity. Also, this study show that the actual and anticipated values of the ANN model is a greater degree of accuracy between the estimated and real WQI values. This study monitors water quality data in real time by combining a number of physical and chemical characteristics. This study finds that, in comparison to conventional approaches, the neural network methodology exhibits a significant improvement with respect to the tested values. This work focuses on the weight value calculation and training backpropagation technique. According to the Root Mean Square Error (RMSE) and correlation coefficient (r), the prediction of WQI produces higher estimate performance. With $r = 0.93$, the water quality index exhibits a high association. This study concluded that the strengths of the integrated approach using GIS, remote sensing data, and ANN

can offer recurring, economical, quick, and timely monitoring, detecting, and mapping for large parts.

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