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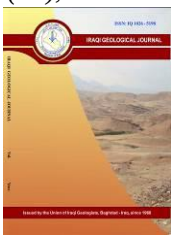

Remote Sensing Approach for Monitoring and Assessing the Turbidity Variation: A Study in the Tigris River, Upstream Al-Kut Barrage

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Abstract

Controlling water turbidity is a significant problem facing water treatment plants. Therefore, using the remote sensing approach via satellite images is the aim of overcoming this problem. This research explores the turbidity variation upstream of Al-Kut Barrage on the Tigris River. The change in the surface reflectance of the water in this area was calculated using Green Band (band 3) and Red Band (band 4) of Landsat-8 level-1, which are the most sensitive bands that could be used to estimate the surface reflectance. Then, the reflectance was calibrated against 24 in situ turbidity measurements (R2=0.89) using MATLAB software, which was used to analyze the results. This fitting is then applied for the 2020 year to study the monthly turbidity variation using satellite images to explore the turbidity variation. The result showed their maximum monthly turbidity in April (34.18 NTU (Nephelometric Turbidity Unit)), with high flow was due to suspended flow particles that caused by exceeding the shear stress and the minimum in October (18.82 NTU) with low discharge, which has an average (28.61 NTU). Therefore, this study confirmed that satellite observations can be used to estimate the surface turbidity.

Keywords: Turbidity; Remote sensing; Normalized difference water index (NDWI); Tigris River; Al Kut Barrage; Eastern Iraq

1. Introduction

Water turbidity is a crucial indicator of water quality, influencing aquatic ecosystems, sediment transport and the efficacy of water treatment operations. It arises from suspended particulates, including sediments, organic debris and contaminants, which affect water clarity (Sherwood et al., 1990). Turbidity in river ecosystems is affected by hydrodynamic circumstances, seasonal changes and human activity. Monitoring turbidity levels is crucial for efficient water resource management, especially when sediment movement and water treatment are significant issues (Obeid and Elkholy, 2021).

Rivers are essential natural resources and indispensable for the continuation of human life. Natural processes such as land use and sediment concentration may increase the pollution in the river. Land use may change land cover, which can lead to increased pollution. Pollution is a significant challenge to the water quality (Obaid, 2022; Hussein, 2024; Hussein and Al-Fatlawi, 2025). Furthermore, the erosion in the river banks and river bed which is caused by high flow due to increase shear stress is a significant reason for increasing the turbidity in the rivers in which it indicates the water quality (Hussein and Al-Fatlawi, 2025). The ability to erode the river banks and bed with high flow is extremely high because of the high speed, (Hussein and Al-Fatlawi, 2025). The transporting and distribution of sediment significantly influence human life. The variation in the river sediment and flow helps for controlling

erosion, deposition, and sediment transportation that reshape the morphology of this river (Sherwood et al., 1990; Geyer et al., 2001; Doxaran et al., 2003; Hussein and Kasim, 2024). Therefore, the turbidity region occurs due to the accumulation of sediment particles in such locations (Geyer et al., 2001; Hussein, et al., 2018). Since the sediment particles are affected by human activities such as illegal sewage and waste disposal, as well, because they include organic matter and nutrients (Al-Ridah et al., 2020; Obeid and Elkholy, 2021) the turbidity in these areas will be high due to the high concentration of organic materials (Talke et al., 2009).

Water treatment plants are designed to carry out the dissolved materials, not suspended sediments. However, it cannot remove all suspended particles from the raw water. Turbidity is mainly caused by particles suspended in the water during high turbulence, such as high flow. Turbidity, in general, indicates the amount of suspended sediment particles in the river and the discoloration of the river is mainly caused by turbidity (Obeid and Elkholy, 2021). Talke et al. (2009) studied the water discoloration issue due to turbidity by simulating of 18-month data. Their data showed that the hydro condition is an active way to decrease the risk of discoloration.

Although, turbidity plays an important role in system operations, assessing and analyzing spatial patterns of turbidity continues to be challenged (Jay et al., 2015; Al-Fatlawi and Hussein, 2024a). Satellite observations can offer restrictions of in situ measurements by getting instantaneous images of marine regions with higher spatial resolution (Hudson et al., 2017; Hussein et al., 2024). Satellite observations have been used widely to estimate water turbidity in the last decades since around the 1970s when satellite images appeared on the surface (Husband et al., 2015; Al-Fatlawi and Hussein, 2024 b; Khalil et al., 2024; Shamkhi and Enad, 2023). Several studies have demonstrated the potential of satellite observations to monitor turbidity by linking remote measuring of suspended sediment with spatial patterns of turbidity (Doxaran et al., 2003; Palacios et al., 2009; Hussein, 2024). Satellite observation technology has been widely used to explore the characteristics of the water by examining the effect of suspended sediment on water elements (Doxaran et al., 2003). Therefore, due to the link between the percentage of suspended sediment in the water and turbidity, this study will explore and assess the turbidity using satellite images.

In the site, the data were obtained by taking the average of three turbidity readings which was closed to the Al-Kut Barrage. Al-Kut Barrage is located on the Tigers River, considered the main water resource in Wassit province, Iraq. Many studies have addressed turbidity as part of water quality with other water quality indexes such as alkalinity, total hardness, calcium, magnesium (Mg), chloride, and total dissolved solids (TDS) (Al-Ridah et al., 2020; Mashaan et al., 2015; Khadim and Oleiwi, 2021; Al-Fatlawi and Hussein, 2024 c; Hoang et al., 2018; Abed et al., 2024; Aziz et al., 2020). However, there is no any study for measuring the turbidity index by using satellite observations in Iraq.

The present study focuses on asses and determines the monthly trends in turbidity variation in the Tigris River, upstream of Al-Kut Barrage by analyzing Landsat-8 surface reflectance (SR) data in the 2020 year. This functioning will be done by calibrating the satellite observations with in-site data. Furthermore, we will display and compare the minimum, maximum, and average monthly turbidity readings using MATLAB software to predict color maps along the river near Al-Kut Barrage.

2. Study Area

The study area is located between the Latitude of 32˚29'56" N and the Longitude of 45˚49'01" E, as shown in Fig. 1. Al-Kut Barrage is located on the Tigris River in Wassit province, in eastern Iraq, which was built to control floods and irrigation flow. This City is divided by the Tigris River into two areas. The direction of the flow in this river is from the north to the south. The population of the Wassit province is (515315) according to the 2010 census, with a 3% annual growth rate (Mashaan et al., 2015, Al-Fatlawi and Hussein, 2024a). The climate of Al-Kut City is classified as relatively hot and dry in

summer to cold and wet in winter. The temperature averages 45°C in July and 7°C in December (Mashaan et al., 2015; Chinh, 2023).

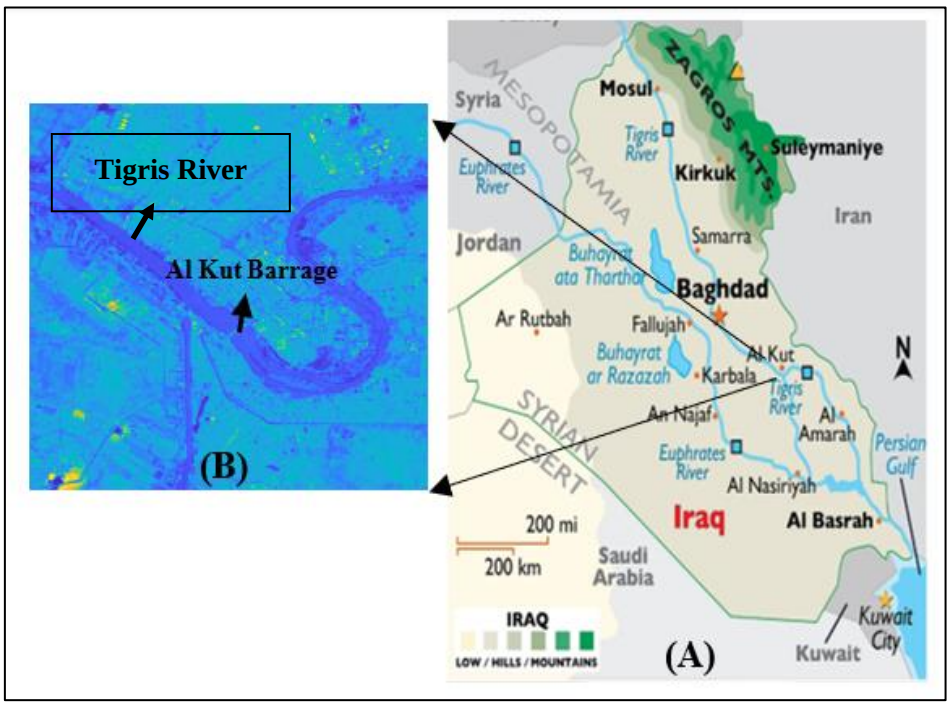


Fig.1. (A)The Location of the study area on the Tigris River - Al Kut City (Mashaan et al., 2015), (B) Landsat image- Green Band level showing the location of Al-Kut Barrage

3. Materials and Methods

3.1. Water Samples

The samples were taken from the Tigris River near Al-Kut Barrage. One sample was collected and taken at a depth of 0.1 m from the surface of the water from the study area each month. To analyze the river turbidity, modeling equipment was used to conduct the physical characteristics of the water samples. After that, the samples were sent to the laboratory for measuring their turbidity using a turbidity meter (Mashaan et al., 2015).

3.2. Satellite Image Processing

Remote sensing data were collected using Landsat-8 level-1 (path 168 and raw 38) for the year of 2020. Table. 1 shows the information of the Landsat 8 and their bands that were used in analyzing and estimating the turbidity.

Table 1. Landsat 8 data from satellite images

Satellite	Path/Raw	Spatial resolution	Spectral Resolution	Used Bands
Landsat 8	168/38	30 m	Multispectral	3,4, and 5

3.3. Calibration

Satellite observations can offer appealing possibilities for determining and monitoring turbidity by comparing it with in situ reading data. Fieldwork of the in situ data was collected by taking the average of three stations along Al-Kut Barrage. Then, in situ turbidity data was calibrated using satellite

observations (SR) (Hudson et al., 2017). The reflection in this work is determined by using Band-3 (Green Band (GB)) and Band-4 ((Red Band (RB)) from Landsat-8 level-1 images that are downloaded from USGS Earth Explorer (Mondejar and Tongco, 2019), given as:

$$SR = GB/RB \quad (1)$$

Where (SR) is the surface reflectance

The reflectance in the RB is higher than GB in with turbid water, while in pure clear water, RB shows higher lower reflectance than GB (Obaid, 2022; Hussein et al., 2019; Topp et al., 2020). Then, linear regression was used to find the turbidity between in situ turbidity data and reflection with a correlation coefficient of (89%).

$$Turbidity = 40.748 * SR - 15.94 \quad (2)$$

Afterwards, the calibration was applied to the upstream Al-Kut Barrage to find minimum, mean, and maximum values of their turbidity variation.

3.4. Mask of Land

The land has been masked by using the Normalized Difference Water Index (NDWI) formula by using GB and RB (Haibo et al., 2011; Mondejar and Tongco, 2019):

$$\text{NDWI} = \frac{\text{GB}-\text{NIRB}}{\text{GB}+\text{NIRB}} \quad (3)$$

Where: NIRB is Near Infrared Band, which represents Band-5

Masking of the land is done by using the threshold value equal to 0 and removing all the NDWI values greater than the threshold value.

4. Results and Discussion

4.1. Turbidity Model

To develop calibrated turbidity distribution models using MATLAB, integrating in situ and remote sensing data for spatial analysis of 2020, is used. Satellite observations of Landsat-8 (Bands 3,4, and 5) were used to analyze and estimate the turbidity distribution upstream of Al-Kut Barrage. Table 2 shows the mean, minimum, and maximum turbidity. The turbidity values were revealed as ranging between 18.28 to 34.81 NTU, with a mean value of 28.21 NTU. It was noticed that minimum turbidity occurred in October, whereas the maximum was in April. River discharge is one of the factors that affect the river sedimentation, and then the turbidity, so lower turbidity refers to that lower discharge in October which is around 220 m^3/s. In April, the discharge is high in which it is around 360 m^3/s; therefore, the sediment is higher, leading to an increase in the water turbidity. Fig. 2 shows the 25th, 50th, and 75th percentile of estimated turbidity variation. Water turbidity is elevated by increasing suspended sediment concentration due to resuspended particles with higher discharge. The variation in the suspended quantity will change the light falling into the water (Al-Wahid et al., 2022, Duy Vinh et al., 2018; Mancino et al., 2009).

Figs. 3 and 4 show the turbidity distribution in the study area as (rectangular), upstream of Al-Kut Barrage. It was noticed that the turbidity which increased with increasing discharge and, as a sequence, increasing eroded sediments by increasing the bed stress during the high discharge, where increasing suspended sediment in the river is one of the main reasons for turbidity (Al Chalabi et al., 2023; Su et al., 2008; Kaiser et al., 2023).

Table 2. Monthly mean, minimum and maximum turbidity

Month	Turbidity NTU		
	mean	min	max
Jan	28.60	20.92	30.35
Feb	31.02	21.33	32.89
Mar	28.19	24.97	30.91
Apr	33.27	24.64	34.81
May	29.00	24.72	32.03
Jun	29.22	22.19	34.19
Jul	28.01	23.71	31.21
Aug	30.13	26.09	33.60
Sep	25.54	23.07	30.73
Oct	26.06	18.82	31.19
Nov	25.33	21.52	26.76
Dec	28.95	20.55	30.67

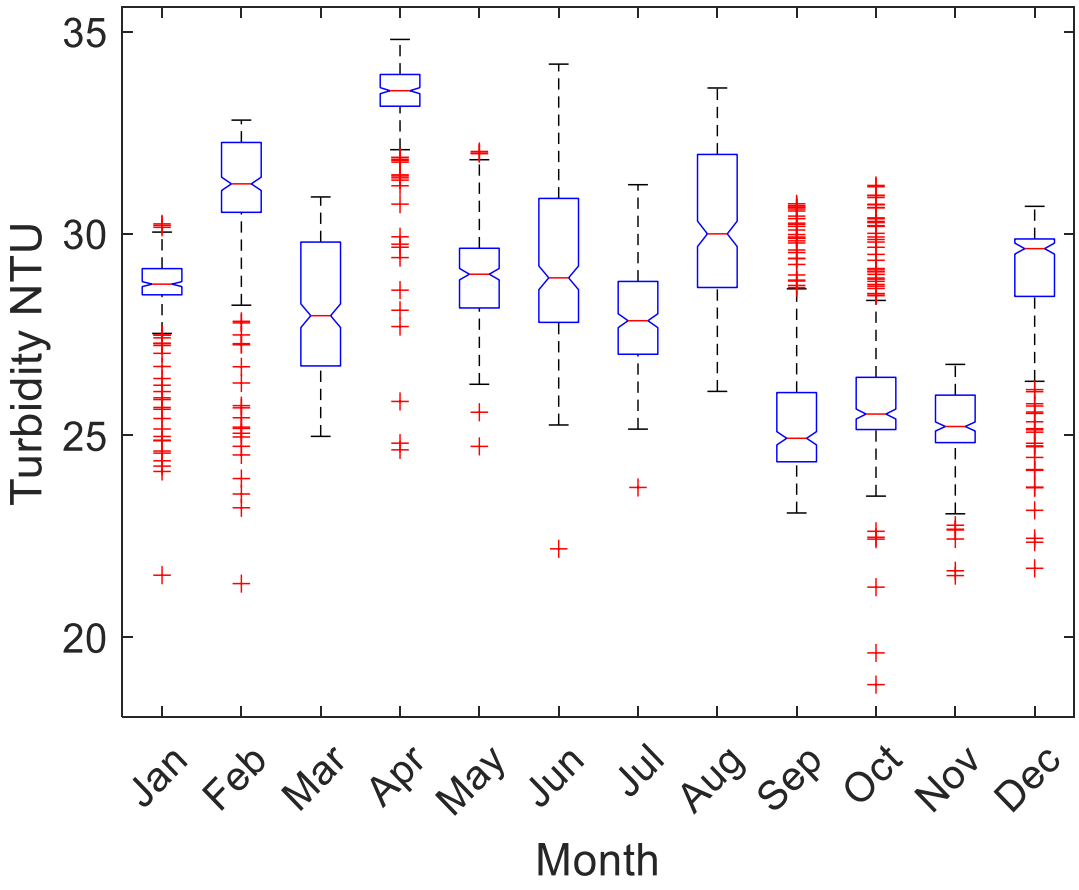


Fig.2. 25th, 50th, and 75th of turbidity variation upstream Al-Kut Barrage

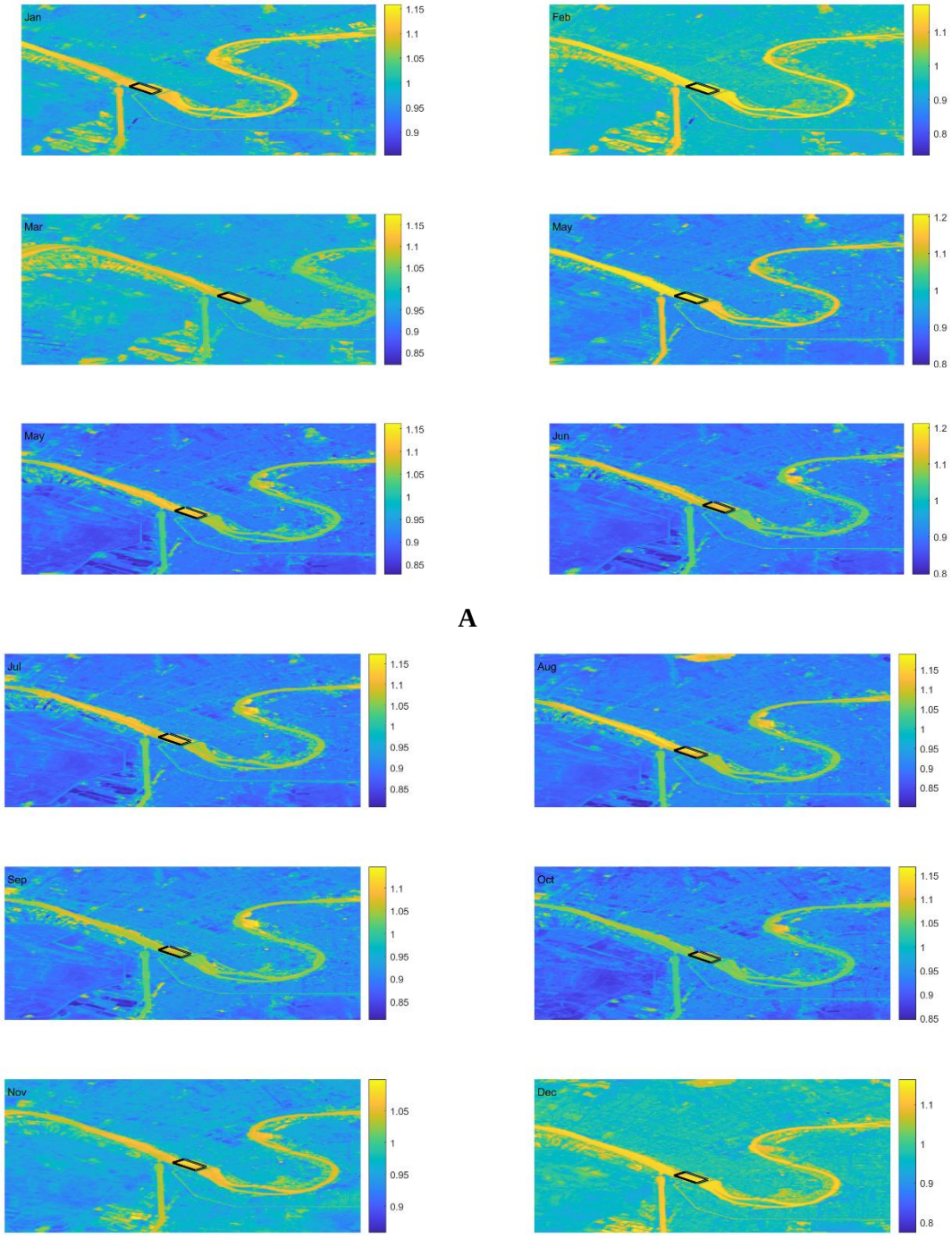
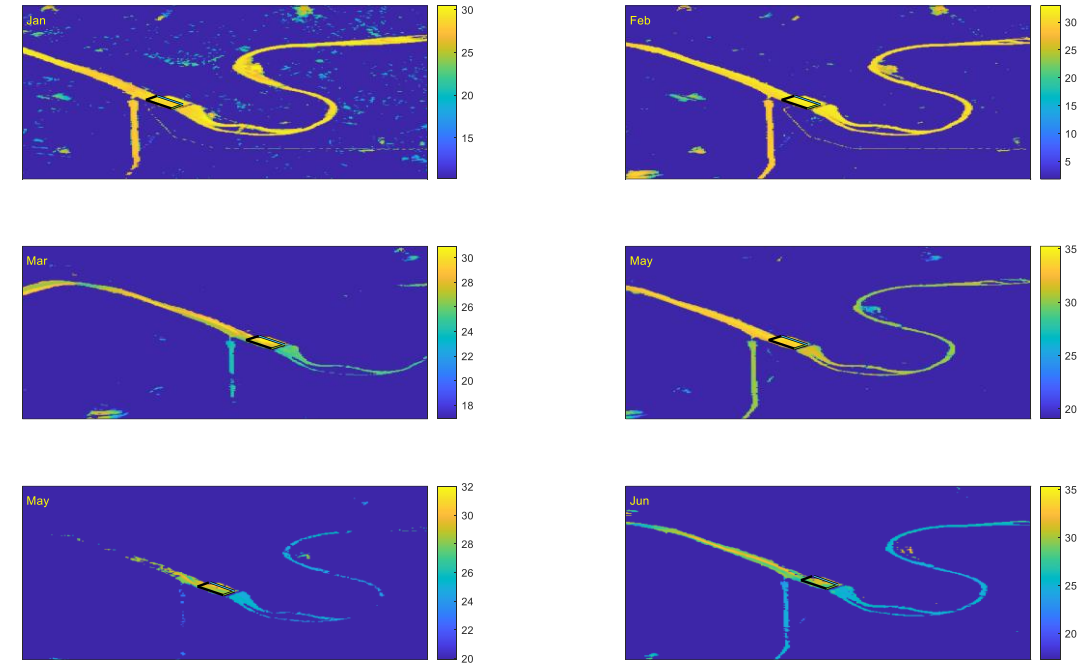


Fig.3. Surface water turbidity at upstream Al-Kut Barrage: (A) January to June (B) July to December

4.2. Statistical Analysis for Turbidity Model

After setting up the turbidity model, the following steps were involved in processing the satellite observations: setting up the clouds less than 10%, processing the surface reflection of the images, calibrating the real turbidity with reflection, building the turbidity model, and estimating the turbidity. Fig. 5 shows the fitting of actual and model turbidity for the data of 2020, which was a linear regression: $y= 0.84 x + 3.46$ with an excellent correlation coefficient (R^2=0.92).



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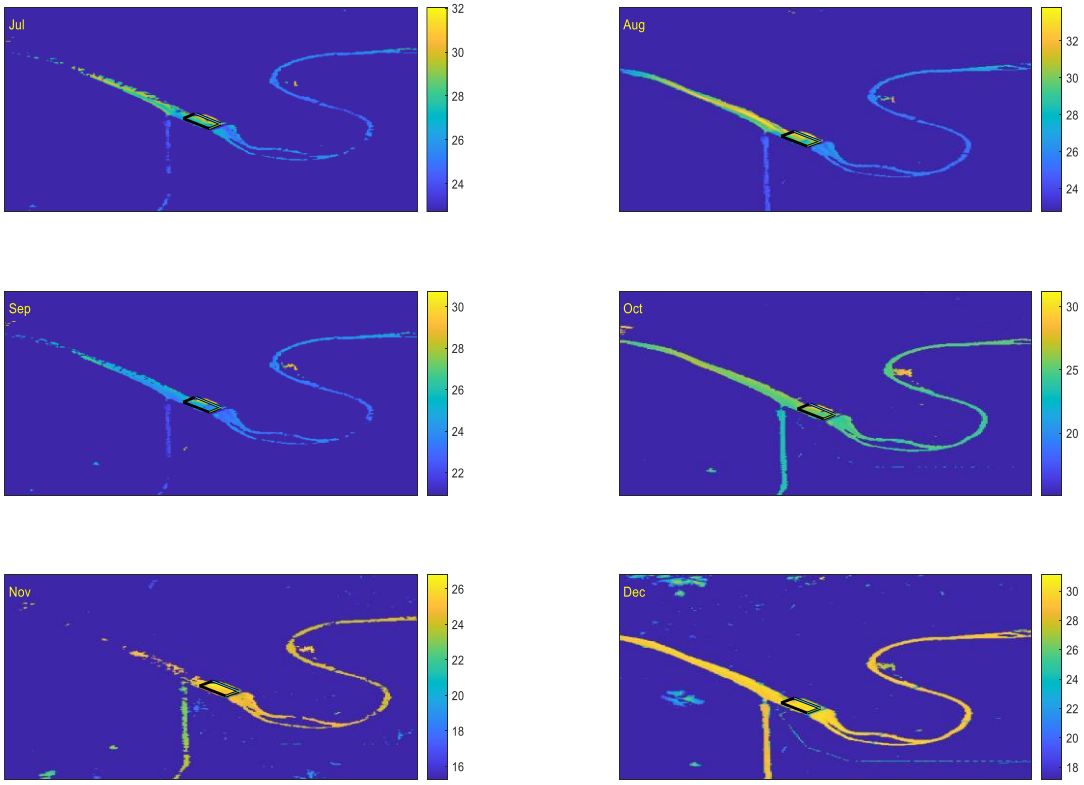

B

Fig. 4. Mask land of surface water turbidity upstream Al-Kut Barrage: (A) January to June (B) July to December

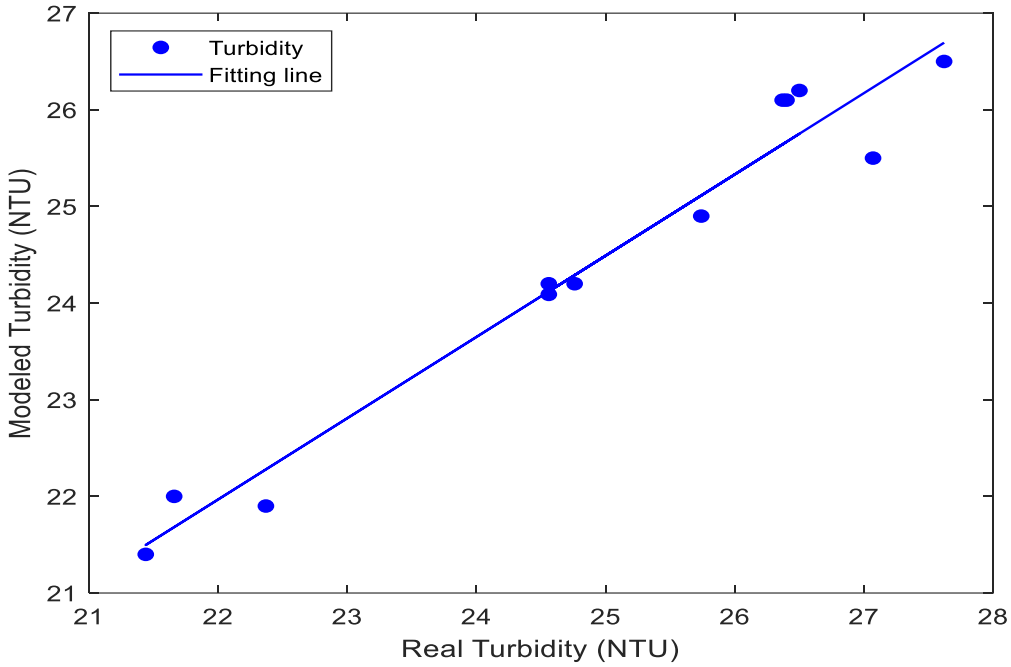

Fig.5. Turbidity model vs real turbidity

One of the significant statistical processing is to evaluate the accuracy and reliability of the calibration of the real data with model data (Obead, 2025). Therefore, the significant statistical factors are used to assess the statistical performance of the turbidity model as follows:

Correlation coefficient (R^2)

$$R^2= \left[\frac{\sum(x_i-\overline{x}_i)(y_i-\overline{y}_i)}{\sqrt{\sum(x_i-\overline{x}_i)^2}\sqrt{(y_i-\overline{y}_i)^2}}\right]^2 \quad (4)$$

Root Mean Square Error, RMSE

$$RMSE=\sqrt{\frac{\sum(x_i-y_i)^2}{N}} \quad (5)$$

Mean Square Error, MSE

$$MSE= \frac{1}{N}[\sum(x_i - y_i)^2] \quad (6)$$

Standard Error, SE

$$SE=\frac{\sigma}{N} \quad (7)$$

The evaluation of the statistical parameters is summarized in Table 3. The model revealed a strong (R^2) with excellent (p-value < 0.05); furthermore, the statistical findings even revealed acceptable values for MSE, RMSE, and SE.

Table 3. Coefficient Parameters evaluating for turbidity model

Parameter	Value
Correlation coefficient R	0.92
Mean square Error	0.15 (NTU)
RMSE	0.38
SE	0.69
P Value	0.002

5. Conclusions

This study uses satellite observations to analyze the river turbidity parameter upstream of the Tigris River, Al Kut Barrage. By assessing the findings of the monthly turbidity values for the year of 2020, the results were given in short as:

To carry out turbidity analyses, it was necessary to calibrate the in situ data with remote sensing reflection. The fitting showed an excellent calibration of (0.89%).

The turbidity ranged between 34.28 10 and 18.81 NTU, with an average of 28.21 NTU.

The minimum turbidity was found to be occurred in October with low flow, while the maximum was occurred with high flow in April.

The turbidity values at the upstream of Al-Kut Barrage are higher than the standard of water drinking specifications (5 NTU), therefore, this is the main reason for people's declining use of water for drinking.

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