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Landsat data to estimate a model of water quality parameters in Tigris and Euphrates rivers – Iraq

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ABSTRACT

Tigris and Euphrates are the two main rivers that supply the water demanded by all the cities in Iraq. However, due to contentious deterioration, monitoring the water quality of these two rivers has become a necessity. Hence, there is need for a study concerning water quality modelling using satellite data for the rivers of Iraq. The main objective of this study is to create a new simple and accurate algorithm for the extraction of water quality parameters for the rivers of Iraq using Landsat 5 satellite data as a cheap and effective method for the monitoring of polluted rivers in Iraq. The area of study is located in the central region of Iraq. The water quality data archive was acquired in August 2007, and it represents the daily values for six physical and chemical water parameters: Dissolved Oxygen DO_2, Total dissolved solids TDS, pH value, Orthophosphate PO_4, Electrical conductivity E.C and Water temperature T. The parameter data were compared with the reflectance values of Landsat 5 bands using different band combinations of empirical algorithms. The results of the analysis showed a significant correlation between these models and water quality parameters with $R^2 > 0.83$. The results of comparison between the predicted water quality parameters and those in the archive displayed more reliability for the models used, $R^2 = (0.73 – 0.97)$. The results of spatial analysis demonstrated the possibility of using the Landsat's spectrum bands for the evaluation of the water quality for rivers in Iraq.

1. Introduction

Water quality is a very complex and vast topic. Customarily water can be defined by several parameters (physical, biological and chemical). It has been widely accepted that the deterioration of surface water quality, coastal and ground water systems are mainly controlled by the geological structure and the lithology of the watersheds/aquifers, the chemical reactions that take place within the watershed/aquifer as well as the type of land uses and the anthropogenic activities (Alexakis, 2008). Moreover, there is a tendency of exposure of the quality of water resources to a wide range of chemical compounds such as organic pollutants, nutrients, salts, heavy metals sediments etc. (Gamvroula et al., 2013). In the past, based mainly on political motivation and to a lesser extent, it is based on adequate scientific data analysis. By measuring both the biological and physiochemical characteristics of the waterways, there would be more understanding for the protection of aquatic ecosystems. Monitoring of water quality also enables the supply of safe water for human consumption. More so, it can be used to develop a picture of the health of certain rivers and assistance in planning at a catchment level. Different variety of meters as well as sampling techniques are used for monitoring the physicochemical character of water. Within these water sampling techniques, there are several water quality parameters for monitoring water quality which include: Temperature, pH, Salinity, Turbidity, Suspended solids, Dissolved oxygen, Heavy metals and Nutrients. Several researches adopted dynamic

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modeling (This type of model shows the behavior of an object with time and is used where the best description of the behavior of the object is like that of a set of states that occur in a defined sequence.) and simulation approach to explore the potentials of monitoring of rivers. Dynamic modeling of water quality can be predicted in a clear and detailed manner the effects of the spatial and temporal variability of the receiving waters. Results of dynamic water quality models usually allow assessment and prediction of the impacts of nutrient loading on eutrophication in rivers, which lead to the design and management of water quality monitoring networks. Hence, a dynamic model is capable of providing a new avenue for understanding the hydrological and ecological processes in the region (Anand et al., 2018).

According to Kirk (1994), substances found in surface water can change significantly the backscattering characteristics of surface water. Techniques of remote sensing depend on their ability to measure the changes in the spectral signature backscattered from water and relate the measured changes by empirical or analytical models to a water quality parameter. The optimal wavelength used to measure a water quality parameter is dependent on the substance being measured, its concentration, and the sensor characteristics. The mathematical modeling of water quality is essential for developing management plans for watersheds. The integration of GIS, different computer technologies, remote sensing techniques, and water quality models act as a powerful tool for water quality management, especially with complicated surface networks in watersheds. Moreover, GIS assists in collecting, storing, analyzing, manipulating and displaying data that can be used easily to construct models for water quality management (Azab, 2012). The integrated model with the spatial capabilities of GIS together with temporal and spatial capacities of remote sensing can provide a powerful tool for the assessment and monitoring of the surface water quality problems (Ammenberg et al., 2002). In this view, the present work attempts to model the rivers water quality accurately based on optical remote sensing information acquisition.

Many authors have studied parameters affecting water quality using remotely sensed data. Past studies have shown strong relationships between standard lake water quality variables brightness data collected by satellite systems (Koponen et al., 2002; Kloiber et al., 2002; Hellweger et al., 2004; Tyler et al., 2006; Duan et al., 2007; Nas et al., 2009). Other studies used Landsat data for inland water quality mapping by many investigators. Hergenrader (1976) utilized multispectral data to study the distributions of pollutants and algae in oceans and inland waters. Klemas et al. (1971) used Landsat (MSS) to map concentrations of suspended sediments.

Kritikos et al. (1974) and Khorram (1981) used the same technique to map turbidity and total suspended solids. Landsat data has also been used to map salinity in estuarine systems. Kadhem, (2013) used ninety-six water samples collected from the Tigris River in Baghdad city and studied the chemical and physical parameters using GIS (spatial analysis). The results show high concentration of total dissolved solids (TDS), total hardness, electric conductivity (EC), Sulphate (SO_4), Iron (Fe) and Chloride (Cl), which indicate signs of deterioration. (Abdul-Razak et al., 2017) studied and assessed the spatial and temporal distribution and prediction of water quality and fish dominance in the Shatt Al-Arab River from December 2011 to November 2012, using geographic information system (GIS).

Landsat 5 provides multispectral images, a well calibrated continuous data set of moderate spatial resolution (30 m), a repetition rate of 16 days, since 1984 (Thematic Mapper sensor (TM5) (Rogan and Chen, 2004). Moreover, the TM5 images have reliable geometric integrity as well as validated radiometric quality. They are also freely available thus, making them perfect for the study of natural resources (Moran et al., 2001). Although the Euphrates and Tigris rivers run the length of Iraq and sustain life in the region, Iraq does not exercise sole control over these precious waters. The salinity of the water from the Euphrates River as it enters Iraq has more than doubled compared to that of 1973 (Al-Khateeb et al., 2016). In Iraq, the quality of water used for drinking and agriculture is poor and violates both Iraqi National Standards and World Health Organization guidelines (Al-Khateeb et al., 2016). The main goals of this study is to explore empirical algorithms for the retrieval value of Dissolved Oxygen (DO_2), Total dissolved solids (TDS), (pH) value, Orthophosphate (PO_4), Electrical conductivity (E.C) and Water temperature (T) for the area located in the central region of Iraq, which includes the two sections of the Tigris and Euphrates rivers from Landsat 5 TM images as well as to determine the temporal and spatial distributions of water quality. An additional aim was to map the parameters of water quality and show the possibility of using the developed models rather than that of the conventional methods in monitoring the water quality of rivers in Iraq.

2. Study area

Both the Euphrates and Tigris originate from the Turkey highlands and flow through a region between 45^0N and 25^0N latitude. The Euphrates flows through Syria and then flows into Iraq where it meets the Tigris (which also flows through Syria), thereby forming together the Shat Al Arab in the southern part of Iraq (Ismail and Abed, 2013). The area of current study is located in the central region of Iraq, which includes the two sections of the Tigris and Euphrates rivers (i.e., the subject of this study), where the geographical location lies between latitudes 32 ° 13 to 34 ° 6 N and between 42° 20 and 40 ° 40 E. Part length of the Tigris river is 120 km along the cities of Diyala and Baghdad, and the total part length of the Euphrates river is 277 km along the cities of Ramadi and Karbala (Fig. 1) (Abbas et al., 2015). The Tigris River is the major river of the capital of Iraq (Baghdad), and it flows through the center of the city, dividing it into two parts (Karkh and Rasafa districts). It is considered as the major source of water for the Baghdad city and its downstream cities.

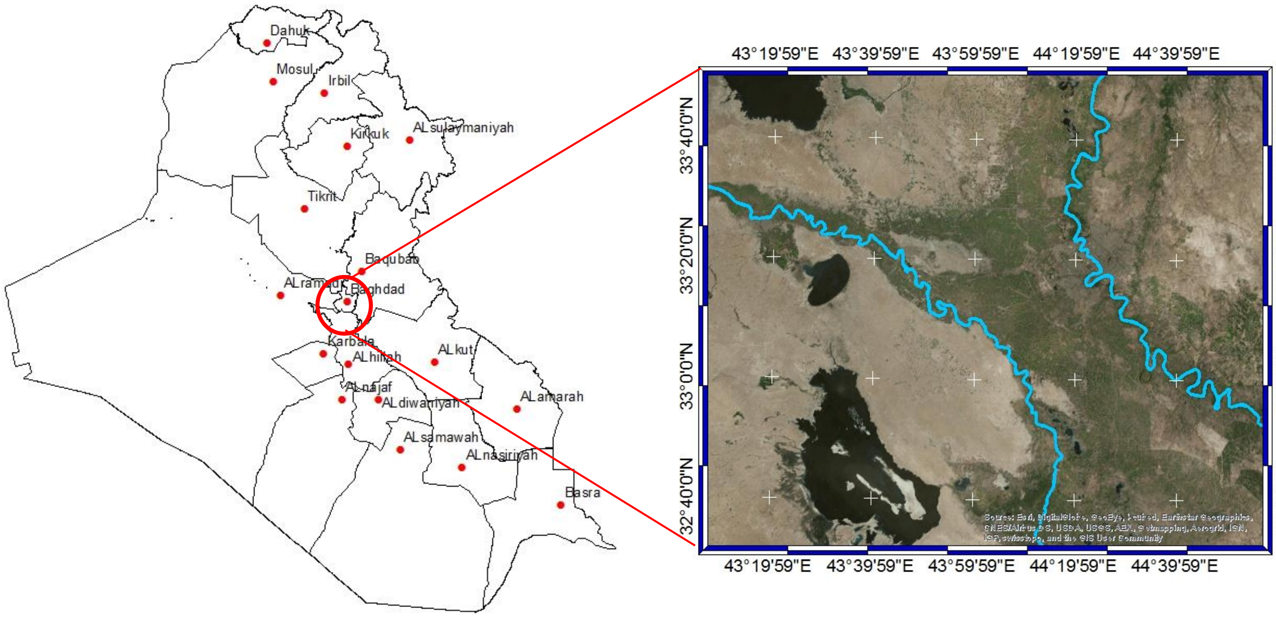

Fig. 1: The geographic location of the study area

3. Methodology of the study

In this study, Landsat satellite data and water quality samples were used to derive simple algorithms which are accurate for retrieving water quality parameters in the central region of Iraq, which includes the two sections of the Euphrates and Tigris rivers using Landsat 5 reflectance data.

3.1. Data collection and water quality parameters

Water quality data archive for the several parameters was collected from thirteen ground stations along the parts of Tigris and Euphrates Rivers Fig. 2. These stations were selected to carry out the present study along 120 km stretch of Tigris River situated in Diyala and Baghdad cites and along 277 km stretch of Euphrates River situated in Ramadi and Karbala cites. The data used in this paper were provided by Iraqi Ministry of Environment, which covers the study period (August 2007) and represent the daily values for six water parameters. These six parameters are; Dissolved Oxygen DO_2, Total dissolved solids TDS, pH value, Orthophosphate PO_4, Electrical conductivity E.C and Water temperature (T). The water quality data were analyzed in the laboratory using the standard procedures of (Eaton et al., 2005).

3.2. Satellite data processing

The satellite data and water quality parameters were used to derive the empirical formulas for the spectral properties of water. The Landsat 5 satellite data (equipped with TM5) was used to achieve this purpose. The image was acquired in August 2007 (Table 1).

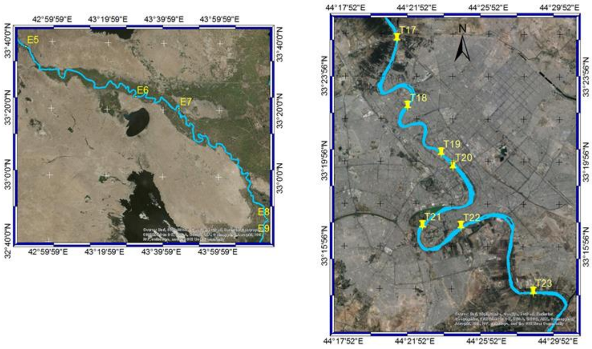

Fig. 2: locations of ground stations along parts of Tigris and Euphrates Rivers

The quality of these images was good not with a cloud. The instrument and satellite were selected due to their availability and spatial resolution as well as the existing techniques of using the instrument in water quality data determination. The Landsat 5 data was obtained from the United States Geological Survey (USGS) Earth Explorer which allows the user to view the image as a graphic (jpeg) prior to the ordering of the image. A feature with the advantage of allowing the investigator to choose the scenes with minimal cloud cover.

3.2.1. Atmospheric correction

The electromagnetic radiation reflected by the earth surface and sensed by satellite sensors passes through the atmosphere thereby producing overlap between the atmospheric effects (atmospheric components) and the reflected radiation. These atmospheric effects include the absorption and scattering operations of the energy, which are detected by satellite sensors (Tyagi and Bhosle, 2011; Jones, 2010).

Table 1: Attributes of Landsat 5 TM bands (15 August 2007)

Band	Wavelength(nm)	resolution (m)
1	450–520/450–520	30/30
2	530–610/530–610	30/30
3	630–690/630–690	30/30
4	780–900/760–900	30/30
5	1,550–1,750/1,550–1,750	30/30
6	10,400–12,500/10,400–12,500	60/120
7	2,090–2,350/2,080–2,350	30/30

Therefore, in order to obtain quantitative data precisely and accurately from the remote sensing sensors, atmospheric correction is required (Liang et al., 2001; Chander et al., 2009). Hence, in order to improve the quality of the images used in this study, the atmospheric correction was carried out on the satellite data (TM5) using an ACTOR module. The ACTOR modules include the ACTOR 2, ACTOR 3, and ACTOR 4, which are all used for calculating ground reflectance and emissivity images for the different spectral bands of satellite images. These modules were designed by Dr. Richter of the German Aerospace Center—DLR (San and Suzen, 2010). The processes of the modules include conversion of the digital pixel values of the original image into a percentage reflectance value. The resulting reflectance values represent the magnitude after the removal of distortions mainly due to the influence of haze (aerosol practices and water vapor) of solar energy sensed by the satellites (Jones, 2010).

3.3. Waterline extraction

The waterline is a basis for characterizing and measuring water and land through its involvement in applications like coastal erosion, watershed definition, coastal zone management, environmental pollution, as well as evaluation of water bodies (Bouchahma and Yan, 2012; Liu and Jezek, 2004). Different methods were developed for the extraction of the waterline from satellite images. The images that were captured during water quality sampling are the same images used to extract the waterline of rivers. In this study, Normalized Difference Water Index (NDWI) was used to delineate the surface water of the rivers. The NDWI is among the successful methods used for the extraction waterline from satellite images. The main goal of the arithmetic operation to find the spectral index is to produce a single number from two or more spectral bands (Ji et al., 2009). The NDWI equation used for TM5 image is as follows:

$$NDWI_{TM5} = (B_{GREEN} - B_{NIR})/(B_{GREEN} + B_{NIR})$$

where, B_{NIR} and B_{GREEN} are the reflectance of band 4 (the near-infrared), and band 2 (the green band), respectively. The NDWI of TM5 gives good result with dry sediment exposure (Murray et al., 2012). Hence, the $NDWI_{TM5}$ is appropriate for the extraction of the waterline from the TM5 images which were captured during summer (August 2007). The NDWI values are between −1 to 1. Values greater than 0 represent water area while values less than or equal to 0 represent non-water areas (McFeeters, 1996; Ji et al., 2009).

3.4. Regression analysis

Many algorithms were used in several literatures for examining the relationship between remote sensing data and water quality parameters (Yüzügüllü and Aksoy, 2011; Zhang et al., 2003). However, in this study, algorithms were created for the regression analyses to examine the relationship between reflectance of TM5 and water quality parameters of Tigris and Euphrates rivers in central of Iraq. As mentioned, the water quality parameters used in this analysis include; DO_2, TDS, (pH) value, PO_4, E.C and T in August 2007. The reflectance values of the TM5 bands were used after stage image correction, as mentioned in the previous paragraph. The performance of these equations was validated based on the R^2 values. The SPSS 11.5 software was used for the calculation of the mathematical parameters. The equations for the regression algorithms for the water quality parameters and the TM5 bands are presented in Table 2. The results of the analysis gave valid relational models based on the R^2. The spectral data of the bands used were significantly correlated with water.

3.5. DN to temperature conversion

Radiometric conversion of digital numbers (DN) to radiance, reflectance and temperature (physical variables) is very useful in interpreting images and comparison of data from the same sensor over time or between different sensors (Lamaro et al., 2013). Digital Image processing for this conversion involves two major steps: atmospheric correction (Cooper and Asrar, 1989) and radiometric calibration (Wukelic et al., 1989). The conversion of DN values to at-sensor radiance was done by applying the gain and bias coefficients of the detectors (Irish, 2000): L = LMin+ (LMax – LMin) * DN/ 255 Where: LMin = 1.238 (represent spectral radiance of DN value 1), LMax = 15.600 (represent spectral radiance of DN value 255), and DN represents Digital Number. The brightness temperatures (TB) (also called blackbody temperatures) can be derived by using the Plank's law: TB = K2/ ln ((K1/L) +1) Where: K1= Calibration Constant 1 (607.76), K2 = Calibration Constant 2 (1260.56), and TB= Brightness temperature.

4. Results and discussion

Relationships between spectral properties of TM5 satellite bands and water quality parameters, were obtained by applying regression analysis. The result of the regression analysis for the TM5 bands and the water quality parameters shows a strong relationship between the spectral properties of both the satellite bands and the water quality parameters, with $R^2 > 0.83$ (Table 2). In this research, the algorithm for total dissolved solids was proved with a linear equation ($R^2 = 0.95$), have been the ratio (TM_{b4}/TM_{b5}) of TM5 very closely related to TDS. Although satisfactory results were obtained, the ratio (TM_{b2}/TM_{b3}) of TM5 is closely related to E.C. The result of the analysis showed that the E.C was strongly correlated with TM_{b3}, and TM_{b2} the linear model was the best to simulate this relationship ($R^2 = 0.93$). The dissolved oxygen DO_2 correlated strongly with the ratio ($1/TM_{b5}$) $R^2 = 0.90$. The amount of dissolved oxygen has a lower reflectance in the band 5. The pH value was correlated with TM_{b5} ($R^2 = 0.83$). The linear regression model adjusts the relationship between PO_4 and bands 5 ($R^2 = 0.87$). In this study, the parameter DO_2 was correlated with $1/TM_{b5}$ and the parameters pH and PO_4 were correlated with TM_{b5} using linear regression, whereas in other studies these parameters were correlated with terms containing combinations of TM_{b1}, TM_{b2}, TM_{b4} (Sharma et al., 2018); TM_{b3}, TM_{b4}, TM_{b5}, TM_{b6}, TM_{b7} (González-Márquez et al., 2018) and TM_{b1}, TM_{b2}, TM_{b3}, Tm_{b4} (Alparslan et al., 2007) using multiple regression. The Brightness Temperature of Landsat 5 related to the water surface temperature of the rivers. This relationship was simulated mathematically using a linear model. With $R^2 = 0.97$. Normally, the thermal infrared bands are chosen to identify the precise location of thermal variation (Lagios et al., 2007; Qin et al., 2011). ArcGIS 10.3 was used to simulate the distribution values of water quality parameters that were calculated from spectral values of TM5 bands. For the purpose of validation, the results of the models were compared with a different data from ground stations. Fig. 3 shows the validations of models results for each water quality parameters used in this current study. Generally, the results displayed a significant correlation between the measured values and the predicted values measured values.

Table 2: Regression algorithms for TM5 and water quality parameters for the river

parameters	Equation	R^2
TDS	$= -257.44 * (TM_{b4}/TM_{b5}) + 849.81$	0.95
E.C	$= 3452.3 * (TM_{b2}/TM_{b3}) - 3749$	0.93
DO_2	$= -(0.389/TM_{b5}) + 13,069$	0.90
pH	$= 2.8496 * TM_{b5} + 7.9194$	0.83
PO_4	$= 3.6077 * TM_{b5} + 1.7414$	0.87
T	$= 1.7706 * (TM_{TB})^2 - 9.6586 * TM_{TB} + 1343$	0.97

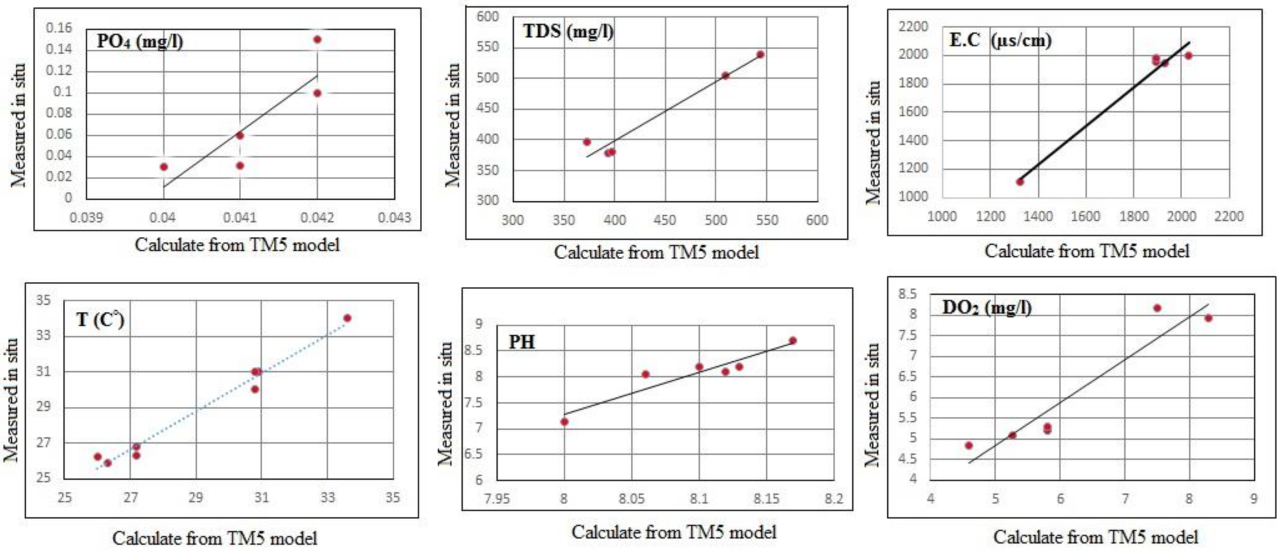

Fig. 3: Comparison between the water quality parameters obtained from TM5 models and the values measured in situ

4.1. Water quality mapping

Water quality parameters models based on a TM5 image from August 15, 2007, were used to forecast the spatial distribution of water quality parameters for Tigris and Euphrates rivers. The results of six water quality parameters for Tigris River are shown in Figs. 4-9. The parameters mapped include; TDS, E.C, pH, DO_2, PO_4 and T,

5. Conclusion

The present study indicates that there exists an empirical relationship between the in situ water quality data of Tigris and Euphrates rivers and the remote sensing data TM5. Linear models are used for establishing the relationship between water surface reflectance and water quality parameters concentrations collected in the temporary observatories. Water quality image maps allow the interpretation of spatial patterns of T, TDS, E.C, DO_2, pH, and PO_4 in the study area entirely, and the conditions of the water quality conditions appear to agree with the expected pollution sources. Where the estimated results obtained from TM5 have a close relationship with ground truth data. The maps are used to help in making decisions regarding the improvement of urban water management as well as identification of potential problems in water ecosystems and human health.

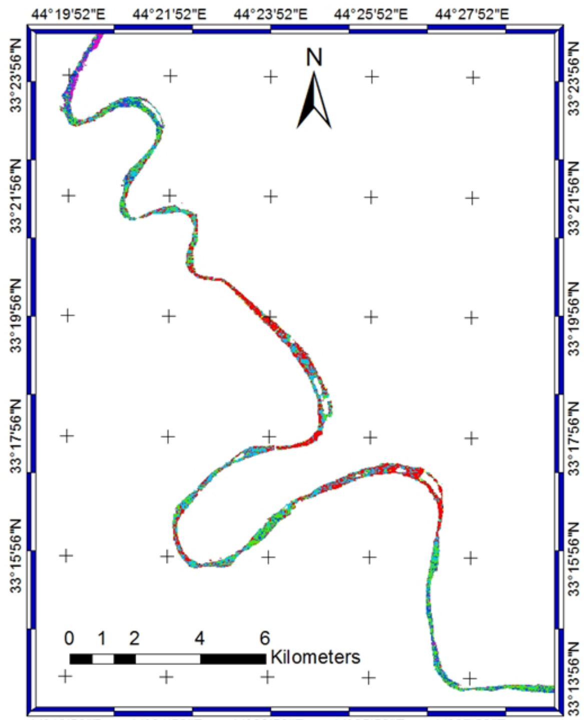

Fig. 4: Spatial distribution of TDS for Tigris River as predicted by the model based on TM5 data

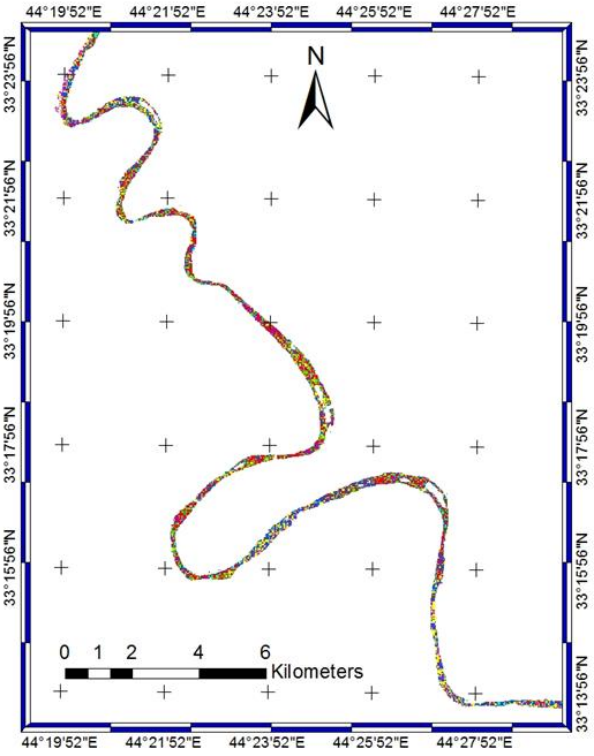

Fig. 5: Spatial distribution of E.C for Tigris River as predicted by the model based on TM5 data

Therefore, the results of this study show the feasibility of using Landsat data for monitoring water quality parameters concentrations of small-sized or narrow-width urban water bodies.

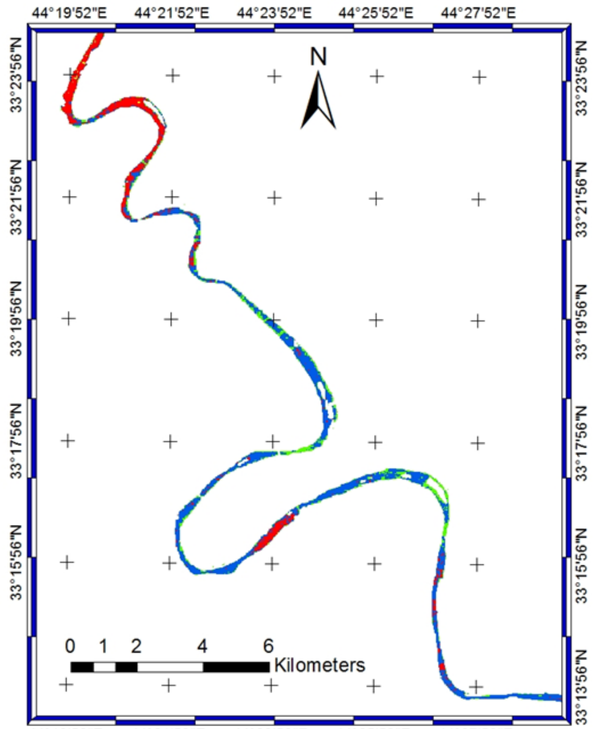

Fig. 6: Spatial distribution of pH for Tigris River as predicted by the model based on TM5 data

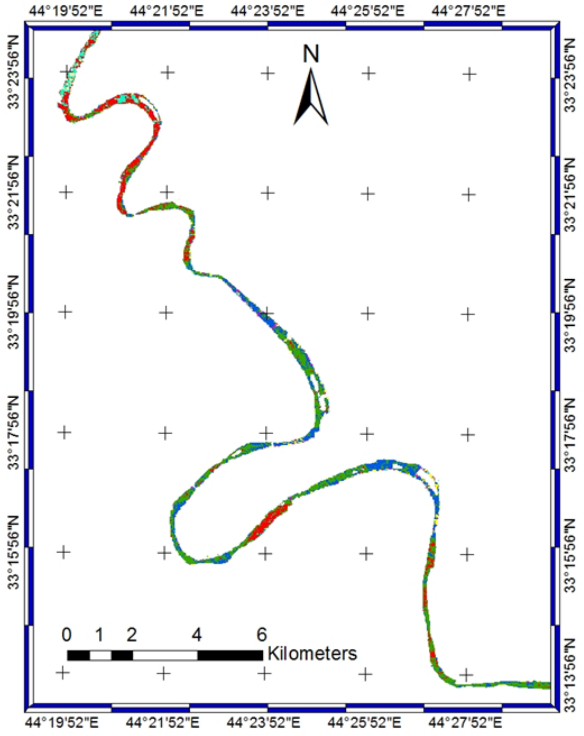

Fig. 7: Spatial distribution of DO_2 for Tigris River as predicted by the model based on TM5 data

The spatial analysis results indicate the potentials of remote sensing in initiating a cheap and effective method for monitoring of polluted rivers in Iraq on a routine basis.

Additionally, this study presents the technical potentials of Landsat data in estimating the concentration of water quality parameters in urban water bodies.

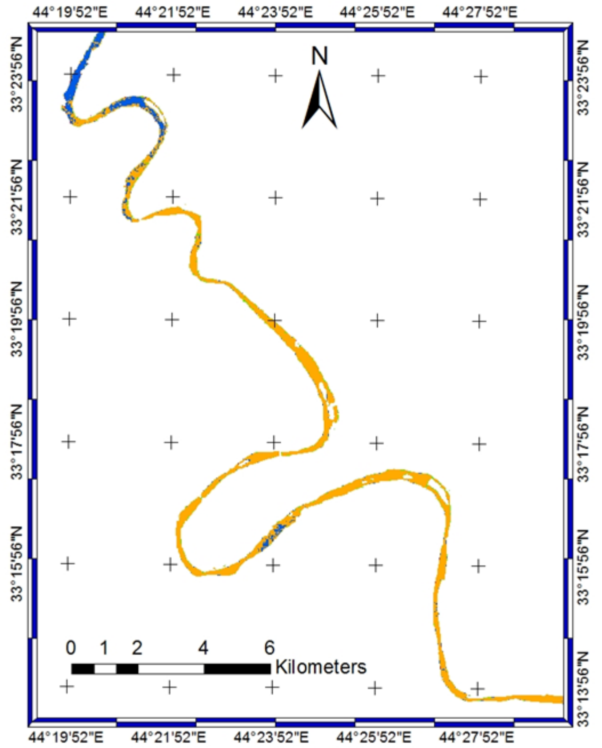

Fig. 8: Spatial distribution of PO_4 for Tigris River as predicted by the model based on TM5 data

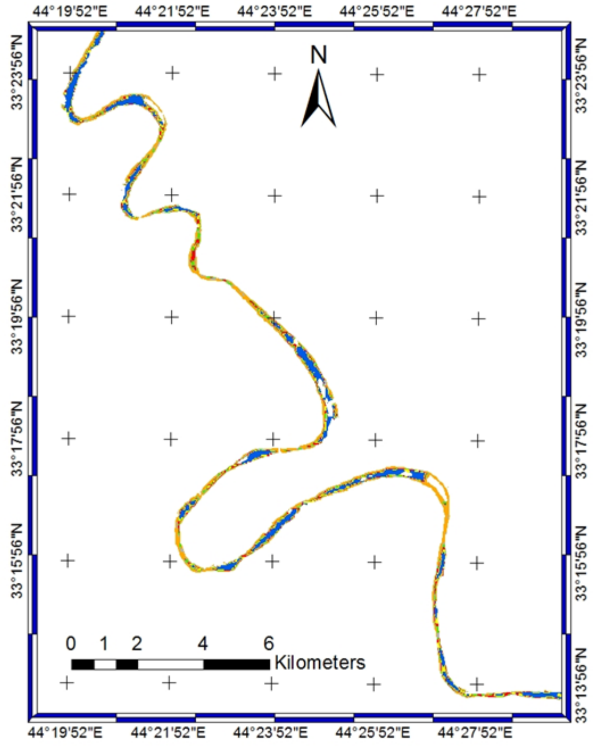

Fig. 9: Spatial distribution of T for Tigris River as predicted by the model based on TM5 data

As well as provide a scientific basis for inquiring the means for the extension of a limited set of field observations to times or areas where field data are unavailable. There is a need for further studies for the examination of pollutant determination from Landsat data over the study area and other urban water bodies.

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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