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Water Quality Monitoring of Tigris and Euphrates Basin by Using Geographic Weighted Regression (GWR)

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Water is a vital resource required for agriculture, industry, ecosystems and human life. However, Iraq faces severe water quality challenges due to pollution. Climate change urbanization and agricultural runoff which affected the Tigris and Euphrates rivers. This study uses geospatial tools for remote sensing. Including salinity, turbidity, soil pH, nitrogen data from Landsat 8, Sentinel-5P and other sources. Used to assess important water quality indicators. Including oxide (NO2) levels and chlorophyll concentrations. Areas at danger of eutrophication were indicated by amounts of chlorophyll, which is a measure of phytoplankton levels. Measurements of soil pH also revealed changes that can impact water chemistry and nutrient availability. The analytical hierarchy process

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(AHP) divides water quality into five risk levels from very low to very high. The findings revealed significant regional variation, namely downstream areas having high salinity levels. Meanwhile, turbidity measurements showed sediment accumulation in the central highlands. Areas with intense agricultural and industrial activity have increased. NO2 concentrations, signaling the point of pollution. Chlorophyll data points to risk of eutrophication in still waters. Variations in soil pH also affect nutrient availability and water chemistry. Affecting the aquatic ecosystem The study identifies high-risk areas that require immediate water management intervention. It provides important insights for developing a sustainable water resources strategy in Iraq.

Keywords: Natural resources; water quality; GWR; marine water; geographic information system.

1. INTRODUCTION

One of the most crucial natural resources for the continuation of life on Earth is freshwater. Of the 2.5% fresh water on Earth, just 1% is fit for consumption by humans [1]. Water is a precious natural resource that is necessary for both human survival and the wellbeing of ecosystems. According to Mantzafleri [2], water is made up of freshwater bodies like lakes, rivers, and groundwater as well as coastal water bodies. The intricate interplay between both human and natural processes in location and time determines the state of the water quality. The approximation and evaluation of the environmental state and trends of aquatic ecosystems (springs, streams, rivers, fiords, estuaries and marine water) is the goal of monitoring their qualitative and quantitative parameters.

The majority of Iraq's naturally occurring renewable water resources are imported, and the country's surface water from the Tigris and Euphrates rivers is its main supply of water. Iraq, Turkey, Syria, and Iran are countries that share the Tigris and Euphrates rivers [3]. The water quality of Iraq's rivers is influenced by both internal and external factors, both controlled and uncontrolled [4]. Climate change and its effects, such decreased precipitation and rising temperatures, are uncontrollable factors [5-10]. The Arabian Peninsula's total water resources fell between 0 and 250 mm between 2002 and 2015 [11]. Although their effects are more localized, the controlled factors have a substantial detrimental impact on water resources [8,12]. Building dams and implementing irrigation projects in the higher catchment areas are the primary examples of controlled factors [5,13,9,10]. Because Turkey provides nearly 80% of the water supply to the Euphrates and Tigris Rivers, dam construction within the higher portions of the Tigris and Euphrates catchments (Turkey, Syria, and Iran) has a considerable impact on surface water in Iraq [12].

Iraq's capacity to supply water started to steadily deteriorate by 2005. The nation will run out of freshwater by 2035, both in terms of quantity and quality, to meet its needs for development [14, 15]. Only a significant reform in water allocation and usage can stop this worrying trend. The population of the regions of Turkey, Syria, and Iran that are within the Euphrates and Tigris River watersheds is predicted to grow by more than nine million people over the course of the next 20 years [16].

With the ability to integrate geographic and temporal data to examine the distribution and causes of water contaminants, Geographic Information System (GIS) have become an increasingly useful tool in the evaluation and monitoring of water quality. GIS enables a thorough understanding of how many factors influence water quality across different regions by merging datasets such as land use, hydrological parameters, and pollution sources [2]. Geographic Information System (GIS) is a powerful tool for environmental management and policy-making because of its spatial analysis capabilities, which enable the identification of pollution hotspots and the visualization of trends over time [17]. Additionally, by taking into consideration geographical heterogeneity, GIS-based models like Geographic Weighted Regression (GWR) improve conventional water quality evaluations and offer more precise and focused insights into the variables influencing water quality [18]. These cutting-edge GIS uses assist focused interventions meant to preserve and replenish water resources in addition to increasing the accuracy of water quality evaluations.

To effectively deal with the complexities of water quality assessment, this study therefore incorporates the analytical hierarchy process

(AHP), a widely accepted multi criteria decision making tool. It has been successfully used in various environmental studies to classify risk levels and guide resource management strategies [19]; (Kumar & Jain, 2010). The use of AHP in this research ensures a structured framework for comparing indicators such as salinity, Turbidity, NO2 levels and chlorophyll concentration. It allows for a better understanding of individual and combined impacts on water quality. Previous studies such as those conducted by Whip et al (2020) and Khlif et al [20] have shown the effectiveness of remote sensing and GIS in water quality assessment. But a focused multi-criteria approach, such as AHP, is lacking to spatially classify water quality risks. In this study, AHP along with GIS enabled spatial risk maps and help prepare this guideline to ensure that water management efforts in the Tigris and Euphrates Basin are evidence-based and consistent with the need for efficient use of resources.

Although this study used the analytical hierarchy process (AHP) for water quality assessment due to its structured and multi-criteria method, but other productivity tools complementary insights can be provided. Methods such as DEMATEL (Decision Testing and Evaluation Laboratory) can be used to analyze cause-effect relationships between water quality factors, providing a deeper understanding of the variables. Additionally, fuzzy logic can handle uncertainty and inaccuracies in water quality data, making it suitable for evaluating complex environments where there may not be clear boundaries between risk levels. Future research could examine these other methods to compare results and further improve water management strategies.

Numerous research on the effectiveness of remote sensing as a technique for water quality monitoring have been published [20,21]. The science and art of gathering data about an object, region, or phenomenon by analyzing images taken by a device that is not in close proximity to the object, region, or phenomenon being studied is known as remote sensing.

Significant differences in the Euphrates River's water quality have been noted in earlier investigations. Studying the changes in water quality within the Iraqi borders between 2009 and 2010, [22] discovered rising pollution concentrations and erratic water release, primarily caused by upstream control from Turkey and Syria, which led to declining water quality downstream. In 2015, a study was carried out by Al-Obeidi [23], to determine the Total Dissolved Solids (TDS) concentration in the Euphrates River within the governorates of Al-Qadisiyah and Al-Muthana. The results showed a significant variation in TDS concentrations, ranging from 527 to 8020 mg/L, indicating significant regional variations in water quality.

By utilizing remote sensing and GIS-based methodologies, this study aims to close this gap by offering a thorough evaluation of the basin's water quality. The study is to determine the main sources of pollution, examine the temporal and spatial trends of important water quality indices, and create spatial maps that can direct focused management actions. In doing so, the study hopes to support the creation of more sensible and evidence-based water management plans that will guarantee the preservation and sustainable use of water resources in the Tigris and Euphrates basin. These goals make this research both topical and vital because they are critical for maintaining the socioeconomic well-being of the local population as well as for protecting the health of the environment.

2. MATERIALS AND METHODS

2.1 Study Area

The Euphrates River inside the borders of Iraq is the subject of the research area as can be seen in Fig. 1 Because of its vital relevance to residential water supply, industry, and agriculture, this region has been the subject of multiple water quality evaluations. The Tigris and Euphrates basin is an important lifeblood that spans many countries, particularly between 29°N and 41°N latitude and 36°E to 46°E longitude [7]. These rivers, which have their source in the highlands of southeast Turkey, are vital to the survival of human populations, agriculture, and ecosystems across their whole journey.

The Tigris and Euphrates rivers, which rise in Turkey and run through Syria and Iraq before joining the Shatt al-Arab to empty into the Persian Gulf, are included in the research area. While the Tigris, fed by tributaries from the Zagros Mountains, supports extensive agricultural activities across its basin, the Euphrates is essential for industry and agriculture, especially in the arid regions of the Syrian Desert and the fertile plains of Iraq [7,24]. The normal flow patterns of these rivers have been greatly disrupted and the quality of the water has been deteriorated due to dam construction projects like the Greater Anatolia Project (GAP) in Turkey, excessive water withdrawals, and industrial pollution. Reduced river flows, more frequent droughts, and increased water scarcity are all consequences of climate change [25,26]. For the transboundary water resources to be managed sustainably, these issues must be resolved.

2.2 Methodology

An integrated geospatial approach was used in the present study for assessing the water quality of Tigris and Euphrates basins, using different data sources as well remote sensing techniques. Different environmental factors affecting water quality are ascertained by using data from multiple global datasets, including Landsat 8, Sentinel 5P and GCOMC. Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM) helps in deriving these topographic information which are required to study the water flow and other related geophysical process of a watershed. Advanced satellite-based indices are used for generating Key water quality indicators. Landsat 8 images are used to calculate the Normalized Difference Turbidity Index (NDTI), which is an index of water turbidity and salinity levels that are important for understanding water usability as well environmental health. Using data from Sentinel-5P to track nitrogen dioxide (NO2) levels a rapidly changing pollution response, which signal the extent of air pollutions effect on water systems Atmospheric deposition of this gas can cause nutrient pollution in water bodies and is toxic to aquatic life.

In addition, data on water pH levels were analyzed as well to determine the effects of soil acidity which may lead to the escape of (i.e. leaching) harmful substances into aquatic ecosystems obtained from Open Land Map datasets. The presence of phytoplankton is rated and high plant pigments based on chlorophyll concentrations termed from Global Change Observation Mission (GCOM-C) are applied as a key water quality bio-logo. This information is then finally combined, processed and reclassified to give a whole water quality assessment. The Analytical Hierarchy Process (AHP) is then applied to prioritize these factors based on their impact on water quality, allowing for a balanced and integrated evaluation. This approach ultimately aids in making informed decisions for water management and conservation efforts in the Tigris and Euphrates basins.

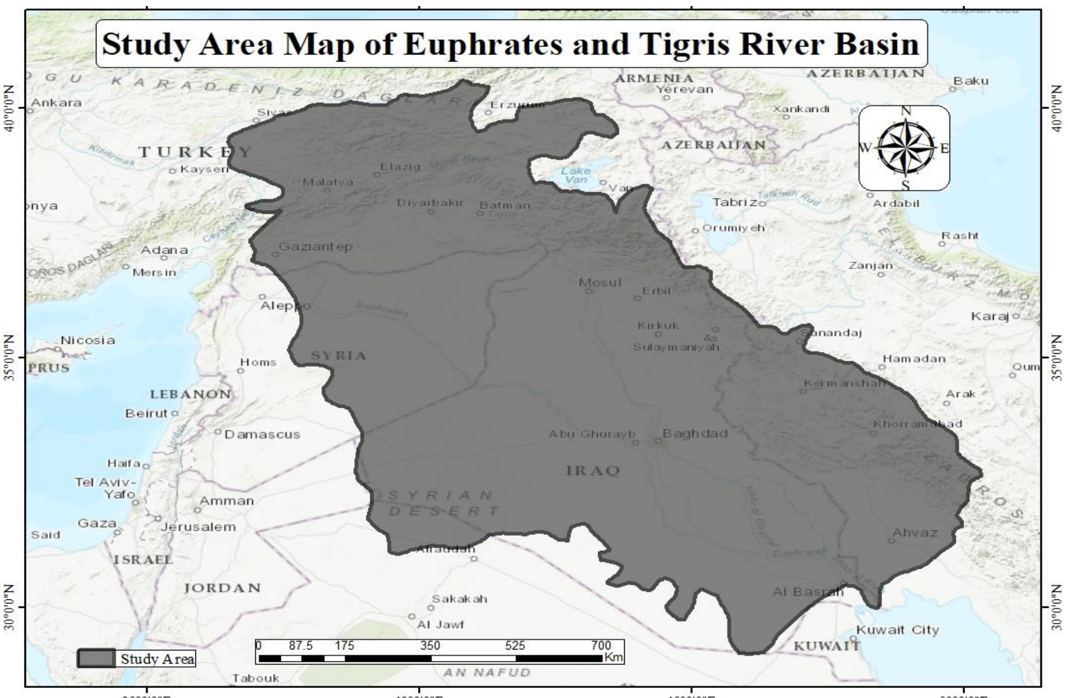

Fig. 1. Study area map of euphrates and tigris basin

2.3 Datasets Used in the Study

The datasets used in this work are essential for evaluating the Tigris and Euphrates basin's water quality and provide important insights into the dynamics of the river ecosystem. These datasets, which come from reliable sources, comprise high-resolution Digital Elevation Models (DEM) from Copernicus, Landsat 8 imagery from Google and the USGS, and measurements of chlorophyll-a from the Global Change Observation Mission (GCOM). The thorough analysis is made possible by additional data on soil pH from EnvirometriX Ltd. and nitrogen dioxide (NO_2) concentrations from the European Union/ESA/Copernicus. This allows for a full understanding of environmental conditions throughout the region. The detailed description of data is listed in Table 1.

2.4 Image Preprocessing

A thorough preprocessing step was performed on Landsat 8 imagery to guarantee the accuracy of the ensuing water quality indexes. Preprocessing included radiometric calibration to account for sensor errors and atmospheric correction utilizing the Dark Object Subtraction (DOS) approach to reduce atmospheric interference. According to Chander [27], these procedures were necessary in order to obtain consistent reflectance values, which were necessary in order to accurately represent different water quality metrics throughout the study area.

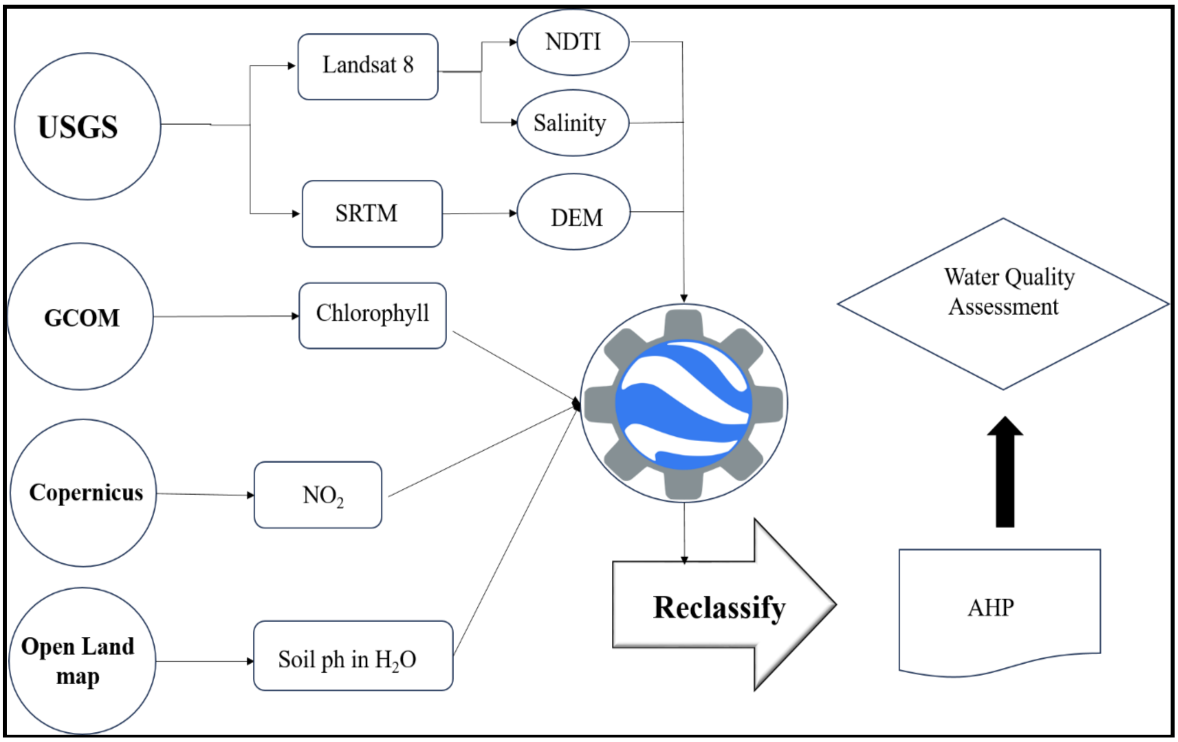

Fig. 2. Flow chart of methodology

Table 1. Datasets used in the study.

Datasets	Data Sources	Resolution
DEM(SRTM)	Copernicus	30 Meter
Landsat 8 Image	USGS/Google	30 Meter
Chlorophyll-A	Global Change Observation Mission (GCOM)	4638.3 Meter
Soil PH	EnvirometriX Ltd	250 Meter
NO2	European Union/ESA/Copernicus	1113.2 Meter

2.5 Salinity Assessment

Using Landsat 8 data, salinity levels a measure of the concentration of dissolved salts in the water were determined. The salinity index was calculated using the Equation 1.

$$\text{Salinity Index} = \frac{\text{SR\_B4}}{\text{SR\_B3} - 1} * 1000$$

where SR_B4 and SR_B3 represent the reflectance values of Bands 4 (red) and 3 (green), respectively. This index showed areas of the river basin with higher salt levels, which could be the result of saline water incursion or agricultural runoff. It also gave a spatial picture of salinity fluctuations within the river basin [28].

2.6 Normalized Difference Turbidity Index (NDTI)

Turbidity, which measures the amount of suspended sediments in the water, was measured using the Normalized Difference Turbidity Index (NDTI) [29]. Equation 2's formula was used to calculate the NDTI.

$$\text{NDTI} = \frac{SR_{B4} - SR_{B3}}{SR_{B4} + SR_{B3}}$$

SR_B4 and SR_B3 corresponding to the reflectance values of the red and green bands, respectively. In areas affected by erosion or by human activities that lead to sedimentation, this measure is especially important for tracking water clarity and identifying sediment plumes.

2.7 Reclassification and Analysis

All derived metrics (DEM, NDTI, salinity, chlorophyll a, soil pH, and NO2) were classed into standardized groups based on pertinent water quality standards in order to facilitate a thorough investigation. This categorization made it possible to combine various datasets into a coherent framework and provide a multifaceted understanding of the water quality in the Tigris and Euphrates basin. The dynamics of the water quality in the area were then thoroughly understood by layering and analyzing these data collectively using Geographic Information Systems (GIS) technologies [30].

2.8 Analytical Hierarchy Process (AHP)

An analytical hierarchy process (AHP) was used in the research area to assess the general quality of the water as a tool for decision-making. The application of Analytic Hierarchy Process (AHP) enabled the prioritization of areas that needed immediate care by evaluating various water quality metrics and allocating weights according to their relative importance. The findings of AHP provided a hierarchical understanding of the variables influencing water quality, which aided in the development of focused management plans meant to reduce pollution and maintain the health of the river ecosystem [19]. Table 2 facilitates comprehension and use of the relative importance scale.

Table 2. Fundamental scale of absolute numbers for evaluating importance

Intensity of Importance	Definition
1	Equal Importance
2	Weak or Slight
3	Moderate Importance
4	Moderate Plus
5	Strong Importance
6	Strong Plus
7	Very Strong or Demonstrated Importance
8	Very, Very Strong
9	Extreme Importance
Reciprocals of Above	Reciprocal Values
1.1–1.9	Reasonable Assumption

3. RESULTS AND DISCUSSION

The Tigris and Euphrates basins' water quality dynamics were thoroughly evaluated in this study by utilizing a variety of datasets. The Shuttle Radar Topography Mission (SRTM) produced the Digital Elevation Model (DEM), which was significant in illuminating the topography of the river basins. Significant elevation changes and steep gradients, especially upstream, were shown in the investigation to have an impact on sediment movement and water flow.

A thorough understanding of the changes in water quality throughout the river basins was supplied by the assessments of salinity and turbidity obtained from Landsat 8 imagery. Higher evaporation rates and decreased upstream flow were found to be consistent with higher salt concentrations in downstream regions as indicated by the salinity index. The salinity's regional distribution highlights how hydrological changes affect the quality of the water. The Normalized Difference Turbidity Index (NDTI), which measures the influence of human activity on sediment load, showed higher turbidity levels close to industrial and agricultural sectors. Moreover, substantial nitrogen pollution was found through real-time monitoring of nitrogen dioxide (NO_2) using Sentinel-5P data. This pollution was found mostly in urban and industrial areas, where it contributed to nutrient enrichment and possible eutrophication. Measurements of the pH of the soil revealed variations in acidity related to farming activities; more acidic soils in regions with intensive farming could increase the leaching of metals into water bodies. High nitrogen inputs caused enhanced phytoplankton population and algal blooms, according to data on chlorophyll concentration from GCOM-C. By incorporating these variables into the Analytical Hierarchy Process (AHP), it was possible to conduct a thorough evaluation of the water quality and pinpoint the regions that needed focused management actions. This multifaceted approach offers insightful information about the intricate relationships between anthropogenic activities and natural processes, which is crucial for creating practical plans to improve the ecosystem health and water quality in the Tigris and Euphrates basins.

3.1 Digital Elevation Model (DEM) Analysis

The examination of the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data yielded significant information about the topography of the Tigris and Euphrates basins. Understanding the elevation variations as mapped in Fig. 3 throughout these river basins is essential for comprehending the hydrological processes and sediment transport mechanisms that affect water quality. The 30m resolution of the DEM data made this possible.

Significant height differences are a feature of the terrain of the Tigris and Euphrates basins, especially in the upper sections where the rivers begin. These areas' high gradients are a sign of swift water flow, which exacerbates erosion and raises the amount of silt that rivers carry. When carried downstream, these sediments raise turbidity levels, which impacts aquatic ecosystems and water quality [7]. Additionally, the DEM study pinpointed crucial locations where these steep slopes give way to flatter terrain and sediment deposition zones. Understanding how sediments settle and build up—possibly building sedimentary barriers or changing the flow of a river—is essential for determining how to reduce the danger of flooding and increase agricultural production. These deposition zones play a major role in this process. The topography is often flatter at the lower portions of the river basins, where sediment accumulation is permitted by a more stable flow regime with lower velocity, as seen by the DEM data. In the Mesopotamian plains, where the Tigris and Euphrates rivers meet to form the Shatt al-Arab, this deposit is especially noticeable. This region's flat topography facilitates widespread agricultural practices, but it also renders the area vulnerable to salinization and waterlogging, which are made worse by higher evaporation rates and decreased flow velocity [25]. As a result, the DEM analysis offers fundamental knowledge about how topography affects sediment movement, hydrological patterns, and water quality, providing crucial information for creating efficient water management plans.

3.2 Analysis of Salinity Levels in the Tigris and Euphrates Basins

In findings of the spatial distribution of salinity levels in the Tigris and Euphrates basins, there are differences in salt concentrations in different areas. The regions which have the lowest salinity values especially from -0.31 to -0.19 are found on the northern and central zones of the basin more nearer to the upstream sources and fresh water inputs in specific rural areas. Such salinity zonation is favorable for agricultural practices and for domestic water supply as it signifies areas with fresher water resources which are less or not affected by salt water intrusions. The pattern indicates that such regions receive relatively adequate amount of water throughout the year with subdued factors that are likely to introduce water pollution such as agricultural runoff or evaporation. This helps assess how proper irrigation should be processed in these areas without having significant salinity problems affecting the regional ecosystems.

Now the southern regions of the basin, particularly those extending toward the lower reaches of the rivers, near Iraq and Kuwait, display extremely high values of salinity, particularly in the 1.01 to 5 range. This higher salinity concentration is located over geographical regions where salt is concentrated due to agricultural return flows at high evaporation rates and low river productivity. The map illustrates how these factors further increased salinity in these southern regions where the salinated waters are already unsuitable for crops irrigation or even for human beings. The spatial trends indicate that more salinity intrusion is expected in the downstream areas which might be detrimental to the ecosystem as well as agriculture in the region. This pattern highlights the need for proper water management in order to avoid loss of water quality and soil salinization in these areas.

3.3 NDTI

An important tool for determining water turbidity and the amount of suspended material in a body of water is the Normalized Difference Turbidity Index (NDTI). NDTI values were obtained for this investigation using reflectance values from Bands 4 (red) and 3 (green) on Landsat 8 images. The Tigris and Euphrates basins' many regions could all be consistently examined for turbidity thanks to this uniform metric. Five classes were created from the NDTI data, each of which represented a different turbidity level.

In accordance with the map available on the axial distribution, turbidity across the Tigris Euphrates River Basin and subsequent analysis of water quality, a distinct water quality gradient can be observed. The regions situated upstream NDTI range 0.57 to 0.31 contains the lowest values of turbidity. Such areas are usually clean which would have low human activity and would be favorable to farming and ecology. These regions mainly occur within the northern parts of the basin, extending into Turkey and Northern Iraq, which are not heavily silted and contaminated therefore better water quality is achieved.

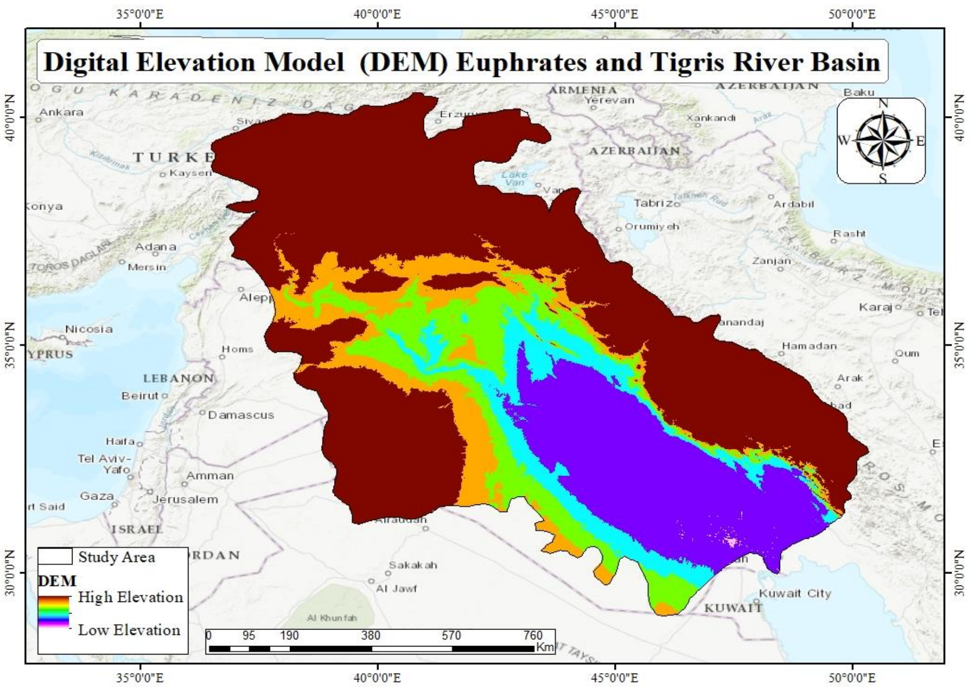

Fig. 3. Digital Elevation Map

Downstream directional flow increases turbidity values with average values estimated at 0.31 to 0.99 occurring within the middle parts of the basin which could be due to moderate surface runoff from agricultural lands and urban activities. However, the inland southern regions especially in Iraq are highly turbid 0.99 to 5.0 due to the increased impact of industrial effluents, migration and over cultivation. The most polluted regions, which have a range of 3.0 to 5.0, are heavily loaded with silt and pollution from anthropogenic activities thus they are the most sensitive areas for the deterioration of water quality in the basin. Such levels of turbidity are a threat to water resources, aquatic plants and animals, and also agriculture. The findings underscores the urgent need for water management strategies, particularly in the southern and central parts of the basin, where interventions are essential to mitigate the effects of increasing turbidity and ensure sustainable water use.

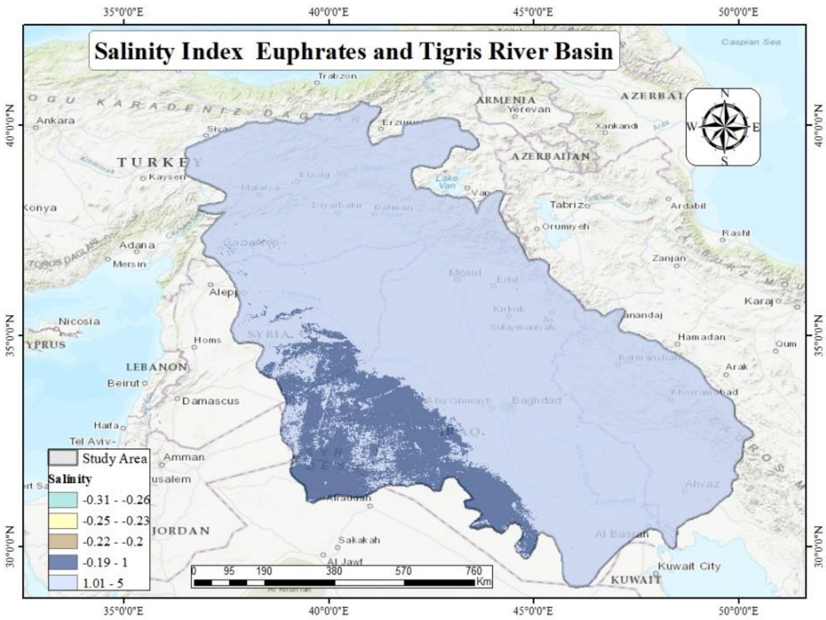

Fig. 4. Salinity Index Map

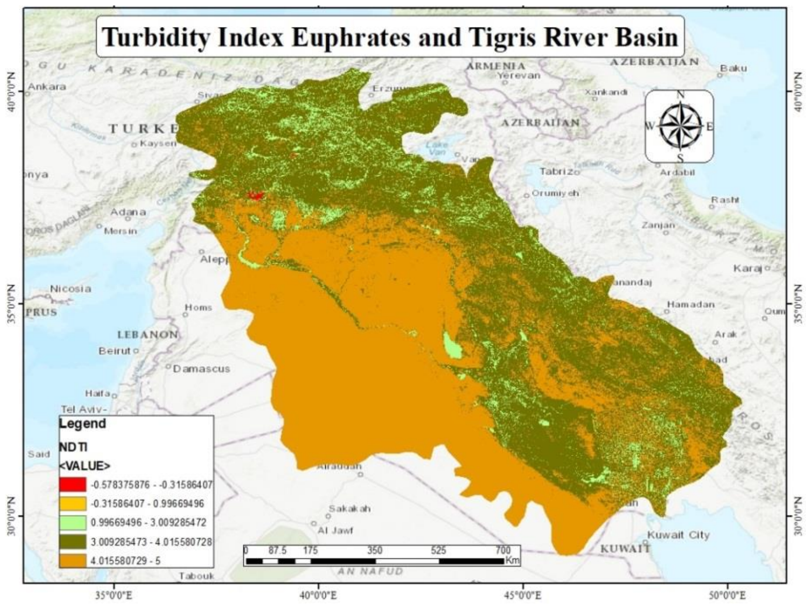

Fig. 5. Turbidity Index Map

3.4 Soil pH

Since soil pH has a direct impact on nutrient availability and the general health of aquatic habitats, it is a critical indicator for evaluating water quality. In order to shed light on the acidity or alkalinity of the soils in the Tigris and Euphrates basins, this study used soil pH data. The information was acquired from EnvirometriX Ltd., a company that provides high-resolution soil pH measurements that are essential for comprehending how soil characteristics and water quality interact [31].

To draw attention to regional differences, the pH values in the research area were divided into distinct ranges. To standardize the data for comparison with other water quality measures, the pH values of the soil were multiplied by ten. The ensuing categories make it possible to understand soil acidity levels more clearly, which has an impact on the chemistry of the water and the biological activity in river systems.

For example, lower pH values as can be seen in Fig. 6, which indicate more acidic soils, may enhance the solubility of various contaminants and heavy metals, which may contaminate water supplies and have an adverse effect on aquatic life. On the other hand, higher pH levels, which indicate more alkaline soils, might affect how readily available vital nutrients are and how aquatic vegetation grows. Through the examination of these soil pH values, the research offers a thorough understanding of the ways in which soil properties interact with parameters related to water quality, providing light on possible sources of pollution and regions in which management actions could be required to preserve or enhance water quality. In order to improve the ecological health and sustainability of the river basins, this analysis encourages the creation of focused strategies for soil and water management.

3.5 Chlorophyll-A

An essential measure of phytoplankton abundance in water bodies is the concentration of chlorophyll, which has a direct impact on the wellbeing of aquatic ecosystems and the likelihood of algal blooms. The Chlorophyll Index was utilized in this work to evaluate the amount and distribution of chlorophyll in the Tigris and Euphrates basins, offering important information about the ecological health and productivity of these water systems. Satellite photography from the Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission - Climate (GCOM-C), which is renowned for its great sensitivity to chlorophyll-a and other related pigments, was used to collect the data for chlorophyll concentration.

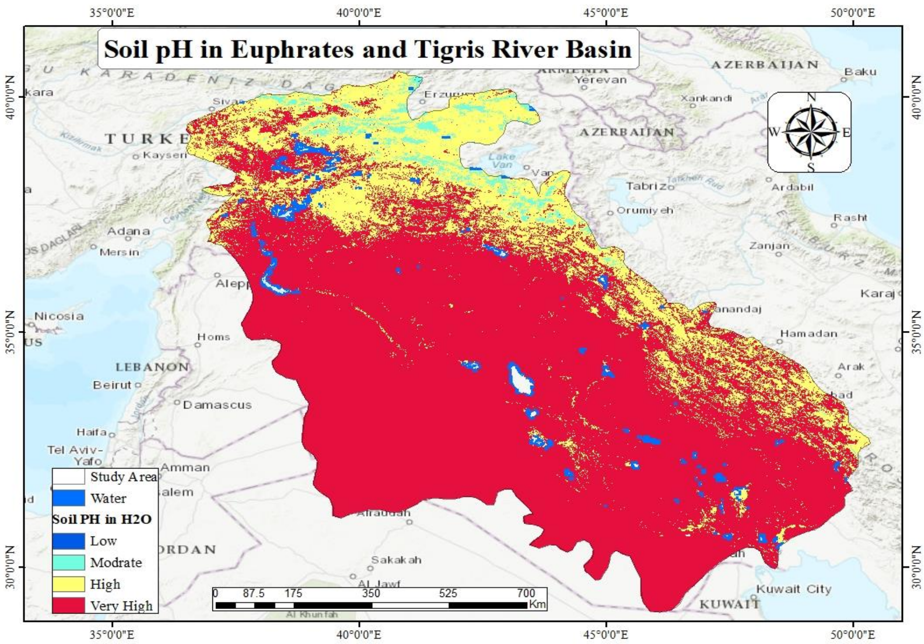

Fig. 6. Soil pH in water Map

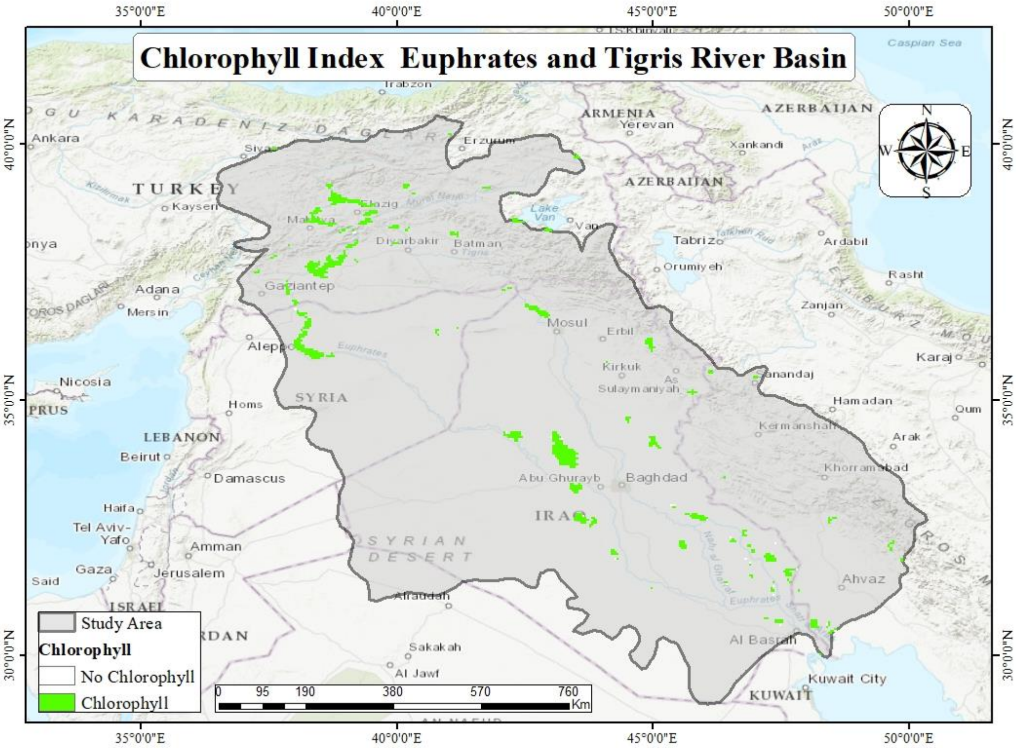

Fig. 7. Chlorophyll Index Map

The research region was divided into two distinct categories by the chlorophyll index map generated by this analysis, areas in Fig. 7 with significant chlorophyll presence, shown in green, and areas with no detectable chlorophyll. The areas devoid of chlorophyll signify bodies of water with little to no phytoplankton activity. This could be because of a number of things, including inadequate nutrient supply, improper water temperature, or other environmental elements that impede phytoplankton growth. Conversely, the portions of the map that are colored green indicate areas that contain chlorophyll, which indicates that phytoplankton growth is active and may result in increased primary productivity. In order to prevent negative environmental effects, the chlorophyll index map is a crucial tool for controlling the ecological health of the Tigris and Euphrates rivers. It helps identify locations that may need closer observation or intervention.

3.6 Nitrogen Dioxide

Nitrogen dioxide (NO_2) is a dangerous air pollutant that has a big impact on the quality of air and water. Elevated atmospheric NO_2 concentrations have the potential to cause nitrogen pathogen development in aquatic environments, hence exacerbating nutrient pollution and endangering aquatic ecosystems. This study used data from the Sentinel-5P satellite, which provides precise and comprehensive measurements of atmospheric NO_2, to monitor NO_2 levels in near real-time. (Veefkind et al., 2012).

According to the findings results the distribution of NO_2 levels within a river basin such as the Euphrates and the Tigris basin has been found to be closely related to the process of urbanization and industrialization. In these instances, extremely low concentrations can be attributed to rural juveniles especially in southern Iraq and western Iran, which have little industrial population. As one advance westward into more lowland northern Iraq and certain parts of Turkey, NO_2 levels increase to low and moderate levels owing to more cities being built. The regions painted red within the palette contain the heaviest concentrations of NO_2, particularly around the cities of Baghdad and Mosul as well as industrial regions of southern Turkey where emissions from vehicle and factory traffic are enormous posing serious threats to air and water health. The phenomenon that there are very huge concentration limits around oil fields located in southern Iraq and densely populated cities in

Syria has provided areas of great concern with risk of nitrogen deposition harming aquatic environments. It is this spatial perspective which is vital for formulating strategies targeting infection control measures or threats to waters in the vicinity.

3.7 Analytical Hierarchy process

By giving each criterion a relative weight, the Analytical Hierarchy Process (AHP) is a structured tool for decision-making that helps assess and rank various criteria. AHP was used in this work to evaluate and categories the water quality in the Tigris and Euphrates basins while taking into account a number of environmental factors, including soil pH, topography, salinity, turbidity, and concentrations of chlorophyll and nitrogen dioxide. A thorough evaluation of these variables was made possible by the AHP framework, which resulted in the creation of an extensive water quality index [19].

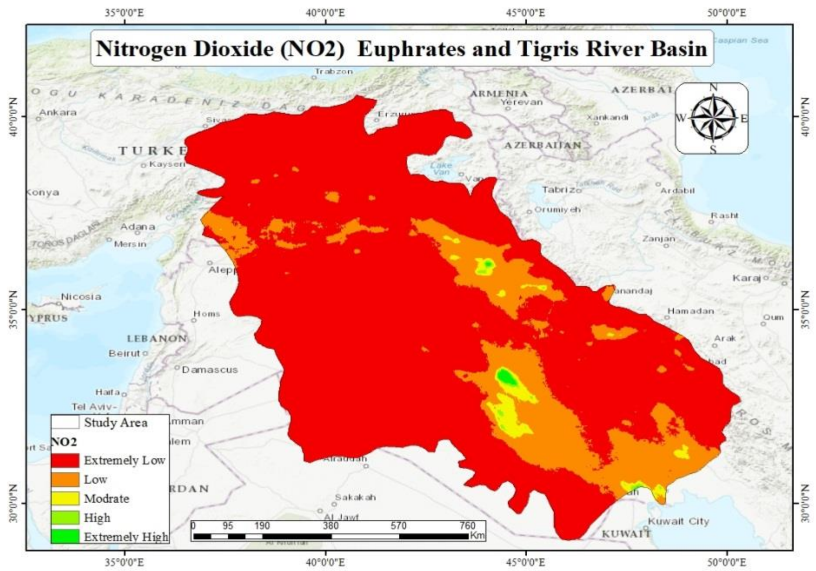

Fig. 8. Nitrogen Dioxide in River Basin

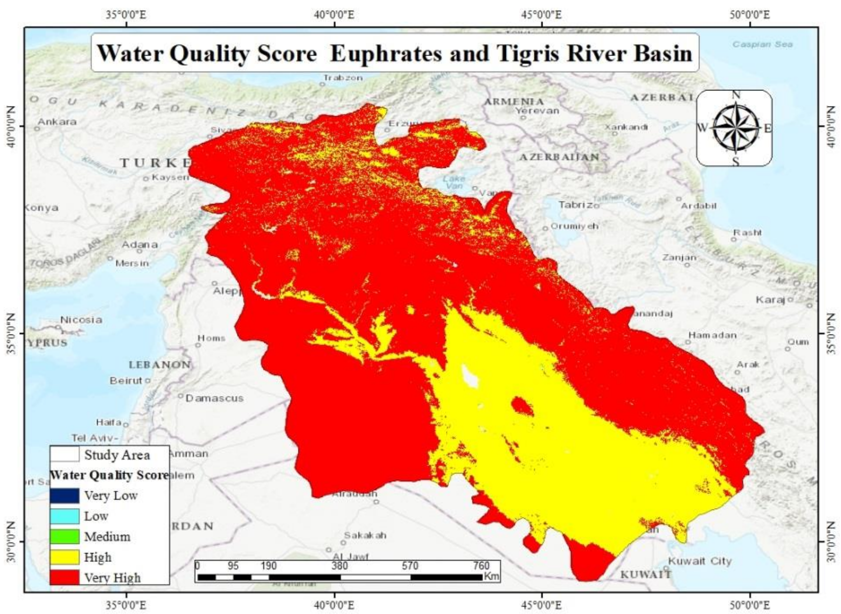

Fig. 9. Water Quality Score Map

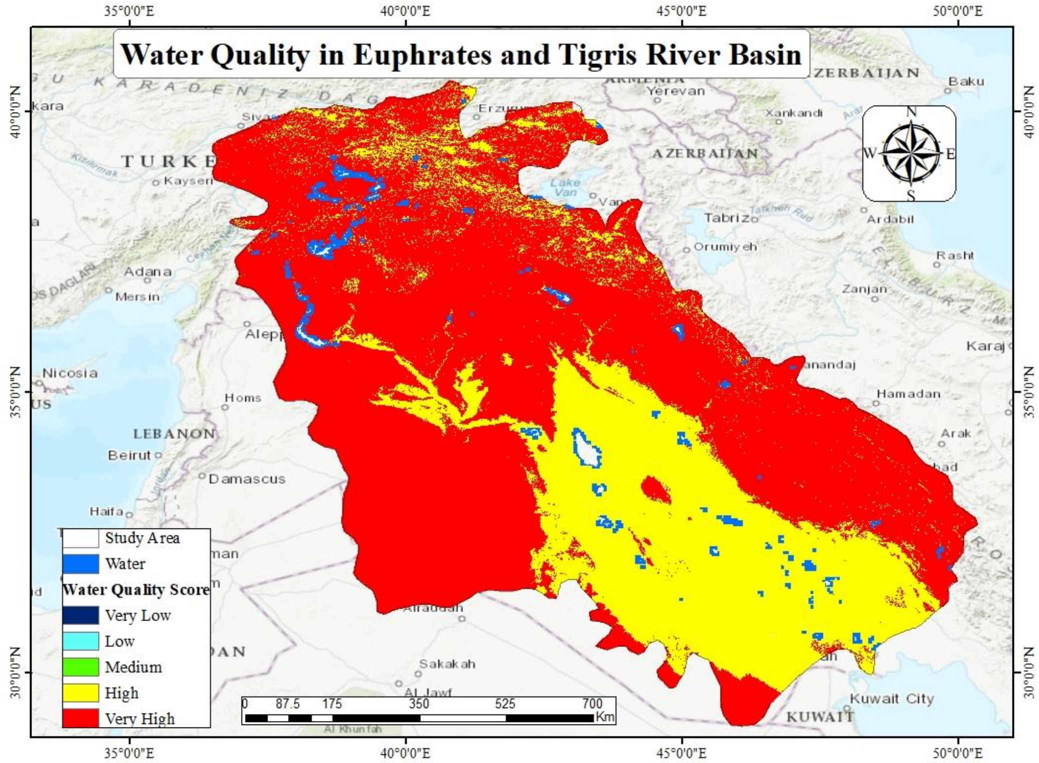

Fig. 10. Final Result of Water Quality in Tigris and Euphrates basin

Five separate groups were identified, as can be seen in Fig. 9, as a result of the analysis: very low, low, moderate, high, and very high. The "very low" category denotes areas where water quality is seriously harmed, most commonly as a result of high pollution levels and unfavorable environmental circumstances. These classifications represent the general health of the water bodies. On the other hand, "very high" denotes locations with immaculate water quality, where all environmental factors are well within allowable bounds and so promote a robust aquatic ecosystem. The three intermediate categories (low, moderate, and high) represent different levels of water quality and offer a more complex picture of how different basins' water health is distributed geographically [32].

The final map at Fig. 10, shows an assessment of the quality of the waters of the Euphrates and Tigris River Basin and this places some areas with very low water quality and others with very high water quality. Areas with very high water quality (blue colors in the maps) are generally found around the large water bodies in the northern regions mostly around Turkey and Syria partly due to the natural flow of water and the low level of industrialization. And large zones especially southern Iraq (red colors) are very low quality water areas especially due to the urban runoff, agriculture and industrial pollution. Areas shown yellow, which indicate medium-quality water are found in areas that are intermediate between heavily polluted zones and cleaner zones, implying some human activities. Using the AHP method, decision makers are able to identify sensitive regions within the map that warrant urgent attention for instance regions marked very high risk with the intention of enhancing environmental management in the water basin.

4. CONCLUSION

This study highlights the effects of numerous environmental factors on these vital water resources and offers a thorough assessment of the dynamics of water quality in the Tigris and Euphrates basins. Key water quality metrics such as salinity, turbidity, soil pH, nitrogen dioxide (NO_2), and chlorophyll concentration were assessed by combining remote sensing data, geospatial analysis, and the Analytical Hierarchy Process (AHP). The results showed that there was considerable regional variation in the quality of the water throughout the river basins, with certain areas being more vulnerable to pollution as a result of industrialization, urbanization, and agricultural runoff. The findings highlight how vital it is to keep an eye on the water quality in these river systems, especially in light of the continuous demands from the environment. Certain areas were found to have high salinity, increased turbidity, and notable NO_2 concentrations, all of which could be dangerous for human health and the aquatic ecosystem. The most serious water quality problems can be found in priority regions for intervention thanks to the AHP's classification of water quality into five risk categories. Availability and resolution of the remote sensing dataset limited this study, since it is likely that complete variability in river basins was not captured. Further, the AHP model is based on biased subjective weighting of a variety of parameters. Future work can be performed in the direction of temporal analysis to adjust for seasonal and long term behaviour in water quality. Finally, this might help to validate remote sensing results by acting in validating ground data for supporting accuracy of evaluation. Using these models we can attempt to predict how in the future water quality is affected under different scenarios, making it possible for us to become proactive rather than reactive managers of our waters.

The knowledge gathered from this research highlights the necessity of focused water management plans in order to minimize pollution, lessen the effects of industrial and agricultural operations, and safeguard these essential water supplies. Adopting sustainable methods for managing water resources is essential if we are to meet the demands of an expanding population, agriculture, and the environment. The sustainability and health of the Tigris and Euphrates rivers, which continue to be crucial lifelines for Iraq and the wider region, will require constant observation and policy actions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology Details of the AI usage are given below:

1. Take help for introduction.
2. Take knowledge about the study area.
3. Research questions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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