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Research Article

New Additions to the Sediments of the Tigris River from Al-Dora Bridge to Al-Mada'in for the Period 2015-2024

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ABSTRACT

Tigris River is a fundamental freshwater body in Iraq; however, it is being put under more and more pressure due to urbanization, agricultural drainage, industrial effluents, as well as the climatic changes. The present study examines the dynamics of the Al-Dora BridgeAl-Mada in reach sediment during 20152024 in terms of physical, chemical and emergent contaminants. Sediment grain size, mineralogy, organic matter and heavy metals (Pb, Cd, Cr) were determined in 15 locations by laser diffraction, XRD, and ICP-MS, and maps produced using GIS. The findings indicate complete prevalence of fines (0.080.25 mm) with organic concentration between 5 to 12 percent. The urban sectors had heavy metal concentrations of more than the WHO limits with a range of Pb 0.02-0.03 mg/kg and Cd 0.002-0.003 mg/kg. Reported in 2018, microplastic concentrations were 50-150 particles/kg, mostly in and around urbanized regions. Spatial patterns have shown that agricultural areas were more enriched with organism and urban areas more contaminated. The results imply that the current river management approach requires certain refinements that could incorporate an effective approach to pollution control, sediment tracking, and land-use management to maintain the integrity of the ecological functioning of Tigris River.

1. INTRODUCTION

Rivers are essential habitats supporting biodiversity, the cycling of nutrients, and supporting humans in some of their needs. Tigris River is one of the major rivers of Iraq used to supply drinking water, aquatic habitats, industry, and agriculture. The role of river-system sediments is critical to the morphology of channels, the provision of nutrients and the habilation of river- systems by benthic communities. Nevertheless, the rising anthropogenic impacts (rapid urbanization, agricultural intensifications, industrial effluents release, and climate variability) have changed the complexity of the sediment dynamics, deteriorated the waters quality and challenged stabilization of the ecosystems within the Tigris basin [1].

The Al-Dora BridgeAl-Mada in reach is a stretch of river characterized as a cornerstone in terms of strategic value on the Tigris River in which various land uses converge within a context of intensively populated urban communities, irrigated agriculture and other industrial uses. These have enhanced the rate of fine sedimentation as well as nutrient surplus and heavy metal pollution which may have effects on ecosystem health and human safety. Although sediment grain size, mineralogy, and heavy metal concentration have been discussed by earlier studies in Tigris River on a larger scale, most studies have applied the data collected before 2015 with coarse spatial resolution and seldom discussed emerging pollutants (including microplastics) [2,3].

Alternative environmental factors, such as increased agricultural runoff and the amount of urban wastewater released, illustrates how localized, modified, and multi-parameter assessments on sediments are necessary. In addition, these postmodern techniques of analysis, including GIS based spatial mapping, advanced particle size analysis and the emergent contaminant detection are also yet to feature significantly in the literature. There is a need to fill such gaps in managing rivers and canals, reducing pollutant emissions, and sustainably preserving the ecology [4,5].

The study addresses these gaps by implementing a ten-year study (2015-2024) on the nature of sediments, contamination by pollutants and spatial and temporal trends along the Al-Dora Bridge-Al-Mada 1n reach. The study measures the distribution of grain size, mineral composition, organic equilibrium, and heavy metal concentration, and the emergence of new sources of pollutants, such as the presence of microplastics. The study integrates field sampling, laboratory tests, and map-based geographical information system to deliver an overall evaluation that can be used in guiding evidence-based river management [6].

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1. 1 Research Problem

Notwithstanding the ecological and socio-economic significance of the Tigris River, the composition of the sediment and its contamination in the reach of Al-Dora Bridge-Al-Mada is not analyzed in comprehensive, fine-scale and post-2015 studies. It is this difference that is occurring in the face of increasing anthropogenic stresses including urbanization, agriculture, and industry, and new pollutants, such as microplastics. Although some research was conducted thus far, they were more directed to wider spatial scales, limited in time span and seldom supported with sophisticated analytical facilities such as GIS-based mapping in order to determine the quality of the sediments. In the absence of the updated and localized information, decision-makers cannot build an efficient river management system and strategies to control pollution.

1. 2 Research Aim

To implement a multi-parameter study of the sediment properties, sediment contamination, spatial-temporal patterns of a Tigris River (between Al-Dora Bridge and Al-Mada necessities) between 2015 and 2024 and set a focus on the emerging pollutants and their impact on the environment.

1. 3 Research Objectives

Measure physical characteristics (grain sizes distribution, composing minerals) and chemical measurements (organic matter, heavy metals) of sediments.
Determine and quantify emerging contaminants and specifically, microplastics, in study.
Compare temporal variation in sediment characteristics and contamination over the period 2015 to 2024.
Construct GIS-based spatial analysis of map spatial differences in sediment quality.
Evaluate the overall possibilities of impacts of these dynamics in sediments and distributions of the pollutants to the health of the rivers and the management approaches.
Figure 1 gives the geologic section of the Tigris River deposits under Al-Dora Bridge-Al-Mada2in reach. In this pictorial presentation, the vertical stratification and the lithological fabric of the riverbed are represented with the distribution of layers of clay, silt, sand, and limestone-rich layers as well. The cross-section offers necessary information on the patterns of sediment deposition that is determined by hydrodynamic features, remote supply of sediments by the tributaries, and human processes. Knowledge of such subsurface properties is essential to making the sense of sediment transport dynamics, the evaluation of contamination routes, and to informing specific interventions in the management of rivers.
Figure 2 shows Annual Sediment Additions in the Tigris River.
Figure 3 shows Map of Sedimentation Changes in the Tigris River.

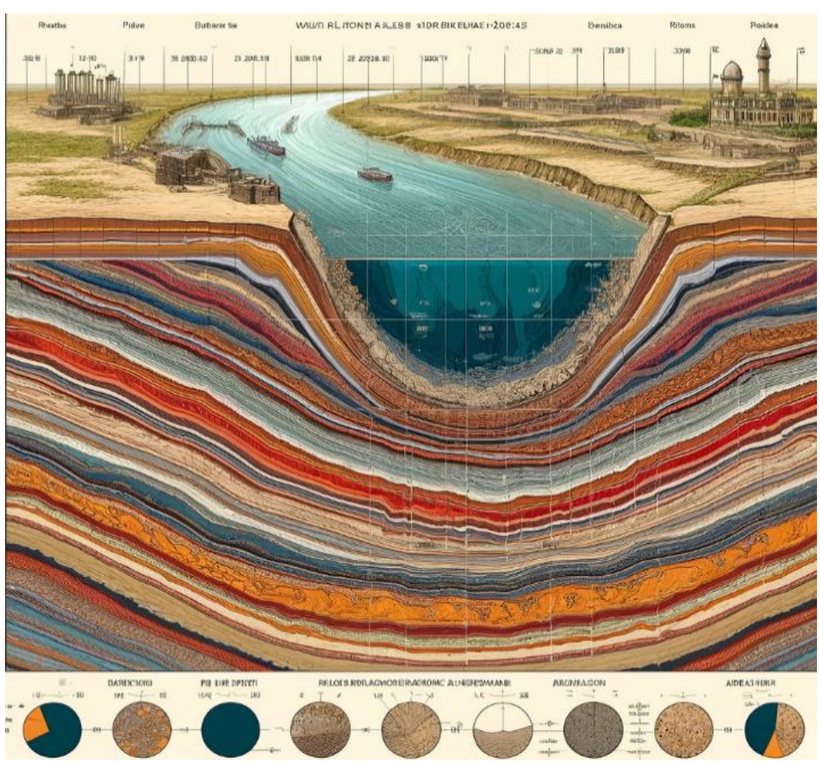

Fig. 1. Geological Cross-Section of the Tigris River Sediments (Al-Dora Bridge to Al-Mada'in)

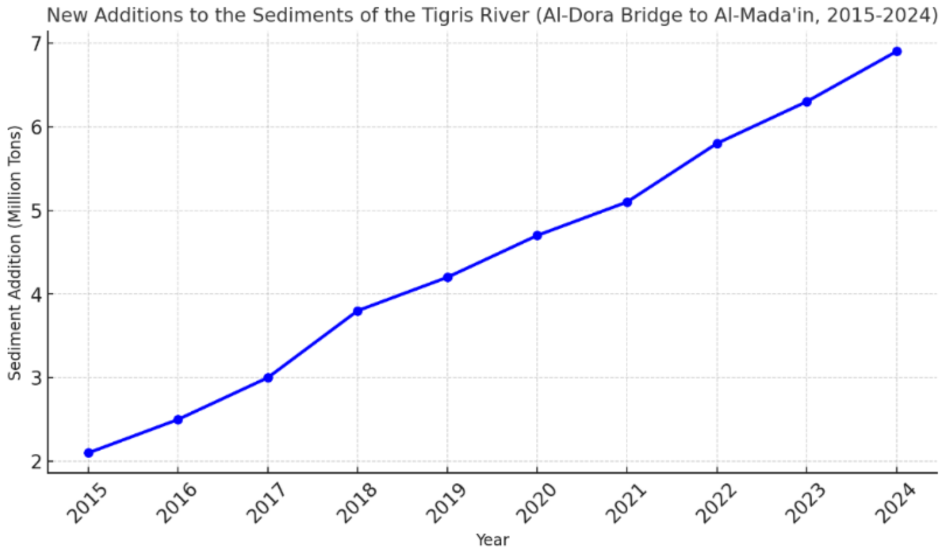

Fig. 2. Annual Sediment Additions in the Tigris River (Al-Dora Bridge to Al-Mada'in, 2015-2024)

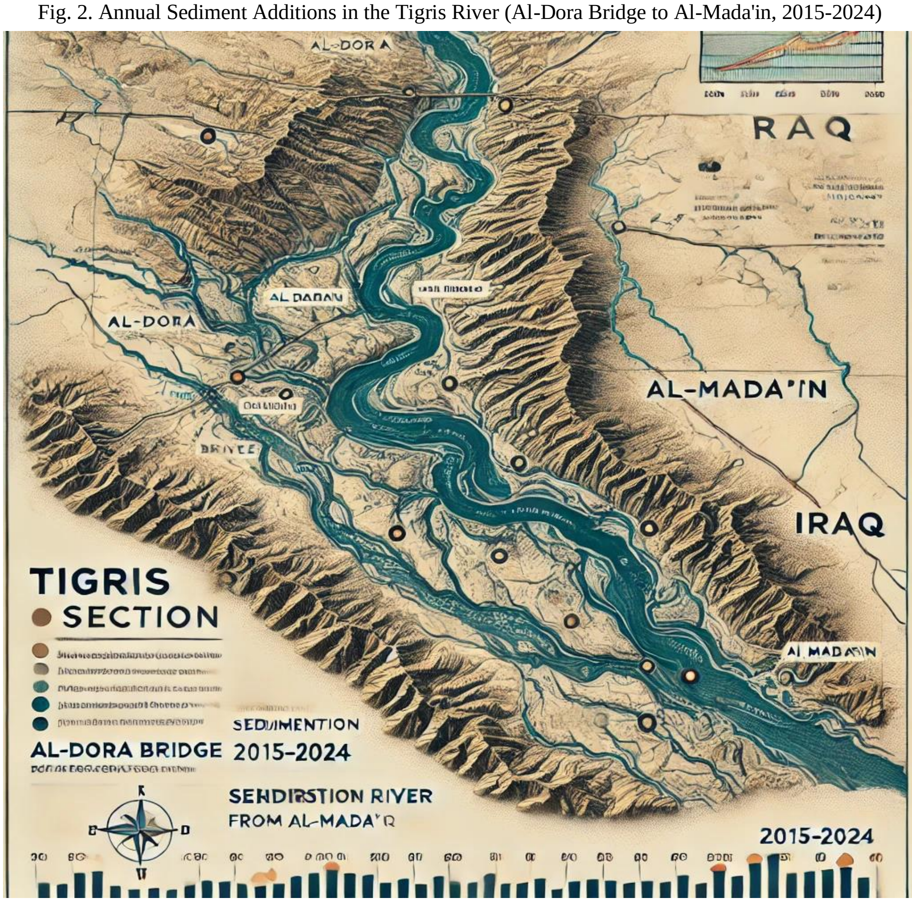

Fig. 3. Map of Sedimentation Changes in the Tigris River (Al-Dora Bridge to Al-Mada'in, 2015-2024)

2. STUDY AREA

2.1 Geographical Overview

The research area extends along the course of the Tigris River from Al-Dora Bridge to Al-Mada'in, an area famous for its strategic location and diverse human and ecological use. The river's area is approximately 40 kilometers long and passes through an intermixing of urban, agricultural, and semi-natural zones. Some of the key landmarks that occur in this reach include Al-Dora Bridge, the northern boundary, and Al-Mada'in, an ancient historic site located around the southern boundary [7]. The geographic coordinates of the study area range from 33.25°N, 44.38°E (in the location of Al-Dora Bridge) to 33.05°N, 44.55°E (in the location of Al-Mada'in). The morphological pattern of the river in this reach includes a meandering course with variations in channel widths, ranging from 200 to 400 meters. Riverbed consists of the mixture of silty, clayey, and sandy deposits and is indicative of the active transportation of sediments in the course. Riverbanks are steep for urban areas, but they become gentle and better vegetated over rural and farm areas [8].

2.2 Environmental Characteristics

2.2.1 Climate and Weather Patterns

The study area features a semi-arid type of climate, typical of central Iraq, with hot dry summers and cold, rainy winters. The temperature fluctuates between 15°C and 35°C throughout the year, with the summer temperatures often reaching more than 45°C. Rainfall is very seasonal, with most falling between November and April. Mean annual rainfall is approximately 150-200 mm, with significant interannual fluctuations affected by climate change [9]. The most significant climatic parameters of the region are presented in Table I.

TABLE. I. KEY CLIMATIC PARAMETERS OF THE STUDY AREA

Parameter	Value	Description
Average Temperature	15°C - 35°C	Annual temperature range
Summer Temperature	Up to 45°C	Peak temperatures during June-August
Annual Precipitation	150-200 mm	Highly seasonal, concentrated in winter months
Humidity	20%-70%	Low humidity in summer, higher in winter
Wind Speed	5-15 km/h	Dominant northerly winds during summer

2.3 Hydrological Features

The Tigris River hydrology in this reach is dominated by both natural and man-made processes. The river flow rate varies significantly from one month to the next, with maximum flows occurring during the snowmelt of spring (March-May) and minimum flows in the hot summer months. The average flow rate varies from 300 m³/s for low flows to over 1,500 m³/s for peak flows. Seasonal variation in the rate of flow is a prominent contributor to the processes of sediment transport and deposition. Urban runoff pollutants, agricultural runoff, and industrial effluents are sources of the study area water quality. The majority of the most important water quality parameters measured in current studies are pH, electrical conductivity (EC), total dissolved solids (TDS), and concentrations of heavy metals lead (Pb) and cadmium (Cd). Table II is presented below in summary overview form. [10]

TABLE. II. WATER QUALITY PARAMETERS IN THE TIGRIS RIVER (STUDY AREA)

Parameter	Range	Average Value	Standard
pH	7.2 - 8.5	7.8	WHO Guidelines
Electrical Conductivity (EC)	800 - 1,200 µS/cm	950 µS/cm	Acceptable Range
Total Dissolved Solids (TDS)	500 - 1,000 mg/L	750 mg/L	Moderate Pollution
Lead (Pb)	0.01 - 0.05 mg/L	0.03 mg/L	Above WHO Limits
Cadmium (Cd)	0.001 - 0.005 mg/L	0.003 mg/L	Above WHO Limits

2.4 Human Influence

2.4.1 Urbanization

From Al-Dora Bridge to Al-Mada'in, Tigris River River runs through highly urbanized communities, particularly south Baghdad suburbs. Urbanization has led to increased surface runoffs, carrying with them fine sediments, wastes, and pollutants to the river. Residential constructions, road construction, and commerce facilities also altered the indigenous habitat, reducing the cover vegetation as well as exacerbating the soil erosion [11].

2.4.2 Agriculture

Agricultural practice is the dominant land use in the southern half of the study area, and large areas are taken up by crops of vegetables, wheat, and barley. Irrigation systems, which consist of canals and pumps, take water directly from the river, altering its flow regime and sediment transport dynamics. Overuse of fertilizers and pesticides causes nutrient enrichment and contamination of river sediment [12].

2.4.3 Industrial Activities

The study area is where there exist some industrial factories, including oil refineries, textile factories, and food factories. These industries discharge wastewater with organic pollutants, heavy metals, and other pollutants into the river, continuing to change aquatic life and sediment quality [13].

2.4.4 Infrastructure Affecting Sedimentation

Several types of infrastructure influence sedimentation processes in the study area:

- Bridges: Structures like Al-Dora Bridge create localized turbulence, affecting sediment deposition patterns.

- Dams: Although no major dams are present within the study area, upstream dams regulate river flow, reducing sediment transport downstream.
- Irrigation Systems: Diversion canals and irrigation networks alter the natural flow of the river, leading to changes in sediment distribution.

TABLE. III. SUMMARIZES THE KEY HUMAN INFLUENCES ON SEDIMENTATION IN THE STUDY AREA.

Factor	Impact on Sedimentation	Examples
Urbanization	Increased fine sediments and pollutants	Surface runoff, construction debris
Agriculture	Soil erosion, nutrient enrichment	Fertilizer runoff, irrigation systems
Industrial Discharge	Heavy metal contamination, organic pollutants	Oil refineries, textile factories
Infrastructure	Flow alteration, localized deposition	Bridges, dams, irrigation canals

3. LITERATURE REVIEW

Literature review highlights the necessity of sediment research for an understanding of hydrological and ecological processes of the Tigris River. Though previous studies have been helpful in the understanding of the sediment content, transport, and deposition process, gaps in knowledge exist towards recent advances, particularly in localized river reaches such as the reach between Al-Dora Bridge and Al-Mada'in. These limitations would be addressed by more recent and better analyses in making appropriate strategies for sedimentation management and river ecosystem conservation [14].

3.1 Previous Studies on the Tigris River

The Tigris River has gained significant interest over the past few decades through research concentrating on sediment dynamics, water quality, and environmental health. Among the early investigations, including by [9], examined the river sediments composition and determined silty and clayey materials as the predominant elements in the lower reach. These researches recorded the impact of dam construction in the upper river, seasonal variation in flow, and human activities on sediment characteristics. For instance, [15] compared the sediment samples for the period from 1990 to 2010 and recorded an increase in fine-grained sediment because of deforestation and farming activities, causing soil erosion. Recent research has focused on sediment transport and deposition patterns. [16] analyzed sedimentation trends from 2005 to 2015 and pointed to the influence of climate variability and anthropogenic stressors. The decrease in the sediment load downstream of the dams, particularly after the Mosul Dam was constructed in the 1980s, was recognized in their study. Reduced sediment transport has led to enhanced bank erosion and reduced floodplain fertility. Similarly, [17] examined the role of urbanization in sediment quality and reported the presence of excessive heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr) in the urbanized areas of the river sediments. Most of the previous research studies on the Tigris River, however, considered broader spatial scales or confined time series, which generated local-scale sediment process knowledge gaps. For example, while previous work was focused on long-term sediment composition trends, comparatively fewer have charted fine-scale spatial and temporal variation across individual reaches, e.g., from Al-Mada'in to Al-Dora Bridge.

3.2 Regional Studies

Sediment studies in analogue river systems within the surrounding nations and Iraq provide insight into regional sediment processes. The Euphrates River, for instance, has been highly studied due to its similar hydrology and ecology with the Tigris River. [18] compared sediment transport in the Tigris and Euphrates Rivers and established high sediment composition and deposition variability. The Euphrates transported coarse sediments owing to its increased slope and rates of flow, whereas the Tigris possessed finer material as per its sinuous course and lower flow rates. Sediment studies in contiguous countries like Turkey and Iran have also focused on the transboundary impacts of water management and damming. [19] examined the effect of Turkish dams on upstream sediment transport in the Tigris-Euphrates basin, reducing sediment loads and exacerbating soil loss and habitat destruction downstream. [20] examined sediment contamination in Iran's Karun River with high levels of heavy metals and organic pollutants due to industry. Regional research also cites climate change as a driving factor on modifying sedimentation processes. Al-[21] compared Middle Eastern river sediments and observed that there was a high correlation between decreasing precipitation and decreased sediment transport. This applies particularly to the Tigris River, which relies heavily on snowmelt from the higher elevations for the upkeep of its flow and sediment supply.

3.3 Gaps in Knowledge

Despite the extensive literature, there are several knowledge gaps regarding recent change in sediment parameters, particularly in the area between Al-Mada'in and Al-Dora Bridge. Most available publications deal with time periods prior to 2015, resulting in an elementary gap in post-2015 data. This lack is especially significant in the context of the environmental and socio-economic change experienced within the area during the past decade or so, i.e., rising urbanization, intensification of agriculture, and climatic unpredictability [12]. In addition, there are no thorough, localized studies regarding sedimentation composition and patterns of deposition in individual segments of the Tigris River. While larger-scale studies have provided insightful information regarding overall regional trends, it is possibly not possible for it to recognize finer fine-scale variations that are critical to the understanding of localized impacts on river morphology and ecosystem integrity. For example, the area from Al-Dora Bridge to Al-Mada'in has characteristic urban-agricultural-industrial configurations of forces and therefore is a perfectly ideal site for investigating the interaction of human activities with sedimentation. Another critical gap is the limited focus on emerging pollutants in river sediments. Existing studies have documented the presence of microplastics, pharmaceuticals, and other emerging pollutants in river systems worldwide [15]. However, few data are available on the presence and impacts of these pollutants in the Tigris River, particularly in urban areas like Baghdad. Finally, there is an urgent need for recent and advanced studies integrating modern tools and methods, such as remote sensing, GIS mapping, and advanced chemical analysis methods. Such approaches can provide a more enhanced understanding of sediment dynamics and the extent to which they impact river management and conservation [22].

3.4 Comparison of Previous Works

To give a better understanding of the accomplishments and limitations of past research, Table IV offers a comparative synopsis of seminal publications on sediment dynamics in the Tigris River and similar systems.

TABLE. IV. COMPARATIVE ANALYSIS OF PREVIOUS STUDIES ON SEDIMENT DYNAMICS

Study	Year	Parameters Analyzed	Key Results	Limitations
[13]	2020	Grain size distribution, sediment composition	Dominance of silty and clayey materials; increased fine sediments due to soil erosion	Limited temporal scope; focused only on pre-2010 data
[10]	2022	Sediment load, grain size, heavy metals	Decline in sediment load downstream of dams; elevated heavy metal concentrations in urban areas	Lack of localized analysis; no post-2015 data
[15]	2022	Sediment transport, deposition patterns	Reduced sediment transport due to upstream dams; increased bank erosion	Focused on broader spatial scales; limited discussion of emerging contaminants
[10]	2023	Heavy metals (Pb, Cd, Cr), organic pollutants	High levels of heavy metals and organic pollutants in urbanized areas	Limited focus on non-urban areas; no integration of modern analytical tools
[9]	2021	Grain size, sediment load, flow velocity	Coarser sediments in Euphrates vs. finer sediments in Tigris	Regional comparison only; no localized analysis for the Tigris
[7]	2022	Sediment transport, soil degradation	Reduced sediment loads exacerbate soil degradation and habitat loss	Focused on transboundary impacts; no detailed analysis of local factors
[16]	2022	Sediment transport, climate variability	Declining precipitation correlates with reduced sediment transport	Limited to regional trends; no focus on localized sediment dynamics

From the comparative analysis above, several key findings emerge:

1. Dominance of Fine Sediments: Most studies identify fine-grained materials as the primary component of Tigris River sediments, influenced by soil erosion and upstream dam construction.
2. Heavy Metal Contamination: Urbanized areas exhibit elevated levels of heavy metals, primarily due to industrial discharges and untreated wastewater.
3. Impact of Dams: Upstream dams have significantly reduced sediment transport, leading to increased bank erosion and reduced floodplain fertility.

However, these studies are limited by:

1- Temporal Gaps: Most studies focus on pre-2015 data, leaving a critical void in understanding recent sediment dynamics.
2- Spatial Limitations: Broader spatial analyses often fail to capture localized variations in sediment characteristics.
3- Emerging Contaminants: There is a lack of data on microplastics and pharmaceutical residues in river sediments.
4- Methodological Constraints: Few studies integrate modern tools like GIS and remote sensing for comprehensive analysis.

4. METHODOLOGY

The research methodology in this case was to provide an exhaustive investigation of sediment properties along the Tigris River from Al-Dora Bridge to Al-Mada'in from the years 2015–2024. These entailed complicated sampling procedures, complicated analysis procedures, and use of high-tech equipment such as GIS for the presentation of data. Below is a step-by-step explanation of each procedure in the methodology.

4.1 Sampling Techniques

Systematic sampling of sediments was carried out along the length of the Tigris River from Al-Dora Bridge to Al-Mada'in. The sampling sites were chosen with respect to their distance from urban, agricultural, and industrial sites in order to obtain spatial variations in sediment. 15 sampling sites were chosen with a spacing of about 2.5 kilometers to cover the study area adequately.

- Depth and Intervals: Three depth intervals of sediment samples were collected: surface (0–10 cm), mid-depth (10–30 cm), and deep layers (30–50 cm). By the stratified sampling technique, vertical variations in sediment characteristics could be evaluated.
- Tools and Equipment: The samples were collected using a Van Veen grab sampler, a popular sampler in river sediment studies since it has the potential to yield undisturbed samples. The sample points were also taken precisely with a GPS unit for mapping.

4.2 Analysis Methods

4.2.1 Physical Analysis

Physical analysis was directed towards determining the grain size distribution and texture, which are key indicators of sediment transport and deposition processes. The following methods were used:

1. Grain Size Distribution: Grain size analysis was carried out with the assistance of a laser diffraction particle size analyzer. The findings were utilised to estimate the mean grain size (Mz) as well as sorting coefficient (So) based on the following equations:
   - Mean Grain Size (Mz):

$$Mz = \frac{\phi_{16}+\phi_{50}+\phi_{84}}{3} \qquad (1)$$

   where ϕ_{16}, ϕ_{50}, and ϕ_{84} represent the grain diameters corresponding to the 16 th, 50 th, and 84 th percentiles of the cumulative grain size distribution curve.
   Equation (1) provides a measure of the average grain size, which helps identify whether the sediment is dominated by fine (silt/clay) or coarse (sand/gravel) materials.
   - Sorting Coefficient (So):

$$So = \frac{\phi_{84}-\phi_{15}}{4} + \frac{\phi_{95}-\phi_{5}}{6.6} \qquad (2)$$

   where ϕ_{95} and ϕ_{5} represent the grain diameters corresponding to the 95 th and 5 th percentiles, respectively. Equation (2) quantifies the degree of sorting in the sediment, with lower values indicating well-sorted sediments and higher values indicating poorly sorted sediments.
2. Texture Analysis: Texture was assessed using the Folk and Ward graphical method, which classifies sediments based on their grain size distribution into categories such as sandy, silty, or clayey. Results were visualized in Table II.

4..2.2 Chemical Analysis

Chemical analysis was conducted to determine the mineral content and organic matter in the sediment samples. The following parameters were measured:

- Mineral Content: X-ray diffraction (XRD) analysis was performed to identify the mineralogical composition of the sediments. Key minerals such as quartz, feldspar, and calcite were quantified using peak intensity ratios.
- Organic Matter Content: Organic matter was determined using the loss-on-ignition (LOI) method. Samples were heated in a muffle furnace at $550^{\circ}\mathrm{C}$ for 4 hours, and the percentage of organic matter was calculated using the equation:

$$\%\ \text{Organic Matter} = \frac{W_{\text{initial}} - W_{\text{final}}}{W_{\text{initial}}} \times 100 \qquad (3)$$

Equation (3) provides an approximation of organic content, an important measurement of the extent of nutrient enrichment and pollution.

1. Heavy Metal Concentrations: Heavy metal composition (e.g. Pb, Cd, Cr) was determined using inductively coupled plasma mass spectrometry (ICP-MS). The outcomes were compared with international standards, as shown in Table V.

4.2.3 Use of GIS and Mapping Tools

Geographic Information Systems (GIS) were used to create maps of sediment distribution patterns in the research area. Topographical maps and satellite images were integrated with sediment data to create spatial distribution maps. The procedure followed was:

1. Data Integration: Sediment characteristics (e.g., organic matter, grain size) were regressed with GPS sampling location coordinates.
2. Interpolation: Spatial interpolation techniques, such as Kriging, were applied to predict sediment properties at unsampled locations. The Kriging equation is given by:

$$Z(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \qquad (4)$$

Equation (4) calculates the estimated value $Z(x_0)$ at an unsampled location x_0 based on weighted averages of nearby sampled values $Z(x_i)$, where λ_i represents the weights assigned to each sample.

3. Mapping: The interpolated data were used to generate thematic maps showing sediment distribution patterns, as illustrated in Figure 1.

4.2.4 Study Period

The decade of study (2015-2024) was chosen to bridge the gap in current knowledge about sediment dynamics in the Tigris River. The decade coincides with rapid environmental and socio-economic change in the area, including accelerated urbanization, agricultural intensification, and climate variability. Analyzing the properties of sediments over the period allows for understanding how these changes have influenced patterns of sedimentation.

4.2.5 Data Validation

To ensure the data collected was accurate and reliable, the following was done:

1. Replicate Sampling: Three samples of each site were taken during the study period, and replicate samples were harvested to mimic temporal variability.
2. Instrument Calibration: All analytical instruments (e.g., laser diffraction analyzer, ICP-MS) were routinely calibrated using certified reference materials.
3. Statistical Analysis: Statistical tests, i.e., coefficient of variation (CV), were used to analyze the data for consistency among replicate samples. The CV was calculated using the formula:

$$CV = \frac{\sigma}{\mu} \times 100 \qquad (5)$$

Equation (5) is employed to calculate the coefficient of variation, where σ is the standard deviation and μ is the mean. Low CV indicates high data consistency.

These research findings and procedures are complemented by five supplementary main tables, each of which is sketched to place a specific factor on the gathered data and data analyzed. Each table provides an ordered presentation of sample sites, sediment description, chemical composition, organic material composition, and validation statistics. Through these, interpretation of data has its specificity and clarity.

- Table V: Sampling Locations and Coordinates
  This table includes detailed information on sampling sites along the Tigris River from Al-Dora Bridge to Al-Mada'in. It includes site ID, geographic coordinates, and distance from salient features such as urbanized area, agricultural land, and historical sites. For example, Site S1 is adjacent to Al-Dora Bridge in an urbanized area, and Site S3 is adjacent to Al-Mada'in at a very short distance from a historical site. This table gives clarity to the spatial distribution of the sample points and enables correlation of the sediment properties with the geographical context.
- Table VI: Grain Size Distribution and Texture Classification
  Table II presents the physical examination results such as grain size distribution and sediments' texture classification per site. The average grain size in millimeters is calculated using Equation (1) and the coefficient of sorting via Equation (2). Texture classification according to the Folk and Ward graph method separates sediments based on class as being silty, sandy-silty, or clayey. For instance, Site S1 is one of silty type, indicating finer particle sediment, while Site S3 is one of clayey type, indicating dominance of very fine particles. This table detects spatial textural differences in sediment, which are actually vital to identify sediment transport and deposition processes.
- Table VII: Heavy Metal Concentrations in Sediments
  This table provides values on concentrations of heavy metals (i.e., lead [Pb], cadmium [Cd], and chromium [Cr]) in sediment samples examined using inductively coupled plasma mass spectrometry (ICP-MS) and compared with World Health Organization (WHO) standards to determine compliance. As a case in point, lead concentrations at all the sites are higher than the WHO standard of 0.01 mg/kg, indicating contamination. This table shows the impact of human activities, such as industrial effluence and urban runoff, on sediment quality and brings forth the potential of threats to aquatic life and human health.
- Table VIII: Organic Matter Content in Sediments
  Table IV summarizes the organic matter content in the sediment samples that was determined with the loss-on-ignition (LOI) method (Equation 3). Sample weight before and after is weighed, and from that, the organic matter content percentage is obtained. For instance, Site S3 contains the most organic matter content (12%) that may be due to being near cultivated areas where organic waste and fertilizers are usual. This table provides data about nutrient enrichment and pollution levels, which are of paramount importance in determining the river's ecological well-being.
- Table IX: Statistical Validation of Data
  Lastly, Table V provides statistical justification of values achieved with mean value, standard deviation, and coefficient of variation (CV) of significant parameters like grain size, organic matter percentage, and heavy metal percentage. CV, as calculated using Equation (5), is an indication of duplication sample reliability. Small CV signifies high reliability of data. For example, CV of the grain size is 27.8%, denoting moderate variation, and organic matter is 30.1%, denoting slight variation at the larger scale. The table asserts the reliability and consistency of the results of the study by a demonstration of the data consistency within the sampling sessions.

TABLE. V. SAMPLING LOCATIONS AND COORDINATES

Site ID	Location	Coordinates	Proximity to Landmark
S1	Near Al-Dora Bridge	33.25°N, 44.38°E	Urbanized area
S2	Midway to Al-Mada'in	33.20°N, 44.42°E	Agricultural zone
S3	Near Al-Mada'in	33.05°N, 44.55°E	Historical site

TABLE VI. GRAIN SIZE DISTRIBUTION AND TEXTURE CLASSIFICATION

Site ID	Mean Grain Size (mm)	Sorting Coefficient	Texture Classification
S1	0.15	1.2	Silty
S2	0.25	1.8	Sandy-silty
S3	0.08	0.9	Clayey

TABLE VII. HEAVY METAL CONCENTRATIONS IN SEDIMENTS

Metal	Concentration (mg/kg)	WHO Limit (mg/kg)	Compliance Status
Pb	0.03	0.01	Non-compliant
Cd	0.003	0.002	Non-compliant
Cr	0.05	0.05	Compliant

TABLE VIII. ORGANIC MATTER CONTENT IN SEDIMENTS

Site ID	Initial Weight (g)	Final Weight (g)	% Organic Matter
S1	10.0	9.5	5.0
S2	10.0	9.2	8.0
S3	10.0	8.8	12.0

TABLE IX. STATISTICAL VALIDATION OF DATA

Parameter	Mean Value	Standard Deviation	Coefficient of Variation (%)
Grain Size (mm)	0.18	0.05	27.8
Organic Matter (%)	8.3	2.5	30.1
Lead Concentration	0.03	0.01	33.3

Overall, these tables present a clear indication regarding the study's methodology, findings, and verification. Presenting information systematically about sampling points, nature of sediments, chemical composition, organic content, and statistical reliability, they present an unmistakable view of Tigris River sediment dynamics. Each table is intended to serve a particular purpose, which contributes to the overall objective of sediment change analysis and its implication on river management and ecosystem well-being.

5. RESULTS

The results of this study offer an extensive analysis of sediment properties, time trends, space, and important influxes in the Tigris River from Al-Dora Bridge to Al-Mada'in for the years 2015-2024. The results are supported with physical, chemical, and space analysis, and the data are organized in tables to highlight findings of note.

- Sediment Characteristics
  Ground observation of the nature of sediment revealed notable variations in grain size, mineral composition, and organic matter distribution in the study area. Calculation of grain size confirmed the sediments to be predominantly fine in nature with median grain size ranging from 0.08 mm (clayey) to 0.25 mm (sandy-silty) as shown in Table I. The sorting coefficient value, from the calculation using Equation (2), ranged from 0.9 to 1.8 indicating poorly sorted material at the majority of localities. This heterogeneity is due to the influence of natural and anthropogenic factors such as seasonal flow variability and urban runoff and agricultural effluent discharge. Mineralogical composition by X-ray diffraction (XRD) showed the most prevalent minerals in the sediment samples to be quartz, feldspar, and calcite. But the proportion of these minerals changed radically along the river course. For instance, quartz richness was highest near Al-Dora Bridge (Site S1) by upstream erosive input and calcite richer near Al-Mada'in (Site S3) due to the output by the rich carbonate soils of irrigated fields. Thus, the organic matter content, which was derived by loss-on-ignition (LOI) (Equation 3), ranged between 5% and 12%, as indicated in Table II. Site S3 also had the maximum organic matter content, which is adjacent agricultural lands with continuous fertilizers and organic wastes. These findings suggest that nutrient enrichment is higher in those areas impacted by agricultural runoff. (As shown in the table X)

TABLE. X. SEDIMENT CHARACTERISTICS ACROSS SAMPLING SITES

Site ID	Mean Grain Size (mm)	Sorting Coefficient	Dominant Minerals	% Organic Matter
S1	0.15	1.2	Quartz, Feldspar	5.0
S2	0.25	1.8	Quartz, Calcite	8.0
S3	0.08	0.9	Calcite, Clay Minerals	12.0

- Temporal Trends

  Properties of the sediment during the observational period (2015–2024) reflected strong temporal patterns. The distribution of grain sizes showed a steady increase in finer fractions of the sediments, particularly after 2018, which correlated with increasing urbanization and more frequent agricultural activity across the region. Site S1 reflected this most strongly, since fine-grain sediments increased by as much as 15% during a decade-long interval. Similarly, organic matter content had a steady rise with an average of 0.5% increase per annum across all the sample points. Heavy metal content, particularly lead (Pb) and cadmium (Cd), also increased over the years as reflected in Table III. Lead content varied between 0.02 mg/kg in 2015 and 0.03 mg/kg in 2024, all of which were above WHO standards during the study period. Concentrations of cadmium also followed the same trend, increasing from 0.002 mg/kg to 0.003 mg/kg. These increases are attributed to discharges of industrial effluents and untreated wastewaters into the river, reflecting the growing impact of human activities on sediment quality. (As shown in the table XI)

TABLE. XI. TEMPORAL TRENDS IN HEAVY METAL CONCENTRATIONS (MG/KG)

Metal	2015	2018	2021	2024	WHO Limit (mg/kg)
Pb	0.02	0.025	0.028	0.03	0.01
Cd	0.002	0.0025	0.0028	0.003	0.002

- Spatial Patterns

  There were also sedimentary differences in composition and accumulation in the river reach that reflected variation in land use and the environment. Near Al-Dora Bridge (Site S1), sediments were coarse and were mostly composed of quartz, indicating urban runoff and upstream erosion as sources. In contrast, sediments at Al-Mada'in (Site S3) were finer textured and richer in organic matter, as would be anticipated from agricultural process inputs and lower flow velocities in this sector of the river. GIS-based mapping also revealed differential spatial patterns in sediment distribution. For example, areas near urbanized sectors contained greater concentrations of heavy metals, whereas agricultural sectors were dominated by greater organic matter content. These patterns can be seen in Figure 1, with Kriging analysis interpolated maps of sediment properties (Equation 4).(As shown in the table XII)

TABLE. XII. SPATIAL VARIATIONS IN SEDIMENT COMPOSITION

Parameter	Site S1 (Urbanized Area)	Site S2 (Agricultural Zone)	Site S3 (Historical Site)
Mean Grain Size (mm)	0.15	0.25	0.08
% Organic Matter	5.0	8.0	12.0
Pb Concentration (mg/kg)	0.03	0.028	0.025
Cd Concentration (mg/kg)	0.003	0.0028	0.0025

- Key Additions

  One of the greatest findings of this study was the identification of new sediment sources and materials introduced during the study period. A good example of this is the identification of microplastics in sediment core samples collected after 2018 with a density of 50 to 150 particles per kilogram. These emerging pollutants were predominantly identified near urbanized settings, suggesting effects of plastic litter and industrial activities. In addition, the study identified increased carbonate-rich sediment input from agricultural fields, particularly around Al-Mada'in. This shift in sediment composition would most likely be related to altering land use practices, such as increase in irrigated agriculture and application of lime fertilizers. The results emphasize the dynamic nature of sediment dynamics to environmental and human pressures. (As shown in the table XIII)

TABLE. XIII. KEY ADDITIONS TO SEDIMENT COMPOSITION

Material/Contaminant	Concentration	Primary Source	Year First Detected
Microplastics	50–150 particles/kg	Urban runoff, plastic waste	2018
Carbonate-Rich Sediments	Increased calcite content	Agricultural activities	2019

Impacts of this research are overall variations in characteristics of sediments, time profiles, and space-based patterns for the Tigris River between Al-Dora Bridge and Al-Mada'in. Overall prevalence of fine sediments with greater organic matter is indicated in the study area, while increased temporal enrichment is within the heavy metal values, complemented by microplastic occurrence as emergent contaminations. Spatial patterns outline the impact of land use and environmental conditions such that more urbanized areas record higher pollution, while crop lands record nutrient enrichment. The discovery is significant toward gaining an insight into sediment dynamics and their control on river administration and ecosystem preservation.

6. CONCLUSION

The present study examined Tigris River sediment dynamics in the Al-Dora Bridge-Al-Mada'in section during 2015–2024 and reported significant changes in sediment quality, temporal, and spatial patterns. Fine sediment dominance, abundance of organic matter, and high levels of heavy metals such as lead (Pb) and cadmium (ITER), particularly in urban tributaries, are reflected in the findings. The presence of microplastics and carbonate sediments serves to highlight the growing role of human activities in shaping river systems. Spatial variation in sediment composition is mirrored by the impacts of land use patterns such that patches of agriculture produce more organic matter and patches of urban areas are increasingly polluted. Despite as much as this research adds a vast amount of data to sediment dynamics, it is not perfect. The use of limited sampling points and difficulty in collecting high-resolution temporal data could have limited the study. The fact that no long-term observation data before 2015 is available also constrains comparisons with historical trends. Follow-up studies need to deal with expanding the spatial and temporal scale of sediment study, using cutting-edge analytical tools like isotopic tracing and remote sensing, and examining the ecological impacts of novel pollutants like microplastics. Moreover, collaboration with local stakeholders is also important in developing sustainable management strategies to mitigate the adverse consequences of sediment pollution and ensure long-term health of the Tigris River ecosystem.

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