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Physicochemical and mineral properties of suspended sediments of the Tigris and Euphrates rivers in the Mesopotamian Plain

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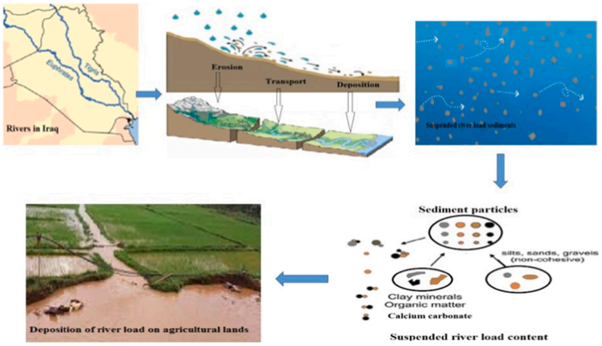
HIGHLIGHTS

- Presence of clay particles increased while silt and sand decreased along the rivers.
- pH and total and active calcium carbonate minerals have been measured for both rivers.
- Presence of non-clay minerals at a rate of 83 % (calcite, quartz, albite, dolomite, etc.).
- Clay minerals (chlorite, illite, montmorillonite, etc.) found at a rate of 17 %.
- Rivers showed distributions of clay and non-clay minerals that vary along the rivers.

GRAPHICAL ABSTRACT



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ABSTRACT

Most of the suspended river load from the Tigris and Euphrates rivers is deposited in the Mesopotamian Plain in Iraq. This suspended river load comprises sediments consisting of minerals and organic particles generated from weathering, erosion, transport, and sedimentation. Therefore, it is crucial to analyze, either quantitative or qualitatively, the types of minerals in the sediment particles transported by the suspended river load, in addition to the potential value they may add to the agricultural lands irrigated by the Tigris and Euphrates rivers. Herein, samples of suspended sediments were collected from both rivers for physical, chemical, and mineral assessments. The results revealed the predominance of silt particles, followed by clay, and then sand. The presence of clay particles increased while that of silt and sand decreased with further travel into the rivers. The pH values ranged from 7.39 to 7.70 and the electrical conductivity ranged from 1.39 to 2.16 ds m^{-1}. The values of the total and active calcium carbonate minerals were 352.87–336.12 and 172.64–194.56 g kg^{-1} for the Tigris and Euphrates rivers, respectively. The mineral analysis identified the presence of non-clay minerals at a rate of 83 %, including calcite, quartz, albite, dolomite, and gypsum. Clay minerals, including chlorite, illite, montmorillonite, palygorskite, vermiculite, and kaolinite, were found at a rate of 17 %. Both rivers exhibited distributions of clay and non-clay minerals that vary as they move along the rivers.

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1. Introduction

The suspended river load is defined as the content of suspended particles transported by the river current up to the riverbed layer. The quantity and quality of sediments can change with time (Salih et al., 2020; Yates et al., 2022; Zhang et al., 2021), and the suspended river load constitutes the largest proportion (>78 %) of the total river load (Xu et al., 2016). It comprises soil mineral particles, such as silt and clay, that are easily transported by even low levels of water currents (López Weibel et al., 2022). Further, the suspended river load is deposited in regions with calm water conditions or when the momentum of the water current decreases because of special hydrological conditions, such as river torsion or the entry of the river in large areas, such as marshes. Engineering constructions, such as dams or reservoirs built along the river, also play a significant role in the deposition of suspended river load (Wilkes et al., 2019). In addition, the use of sediment-laden water for the irrigation of agricultural land or flood land leads to the deposition of suspended sediments on the soil surface (Dong et al., 2018; Mingzhou et al., 2007; Mirzaei et al., 2022; Sha et al., 2018).

Studying the suspended river load is crucial because it carries fine particles containing minerals and organic materials, as well as dissolved substances that can act as fertilizers and pollutants (Badrzadeh et al., 2022; Balasubramanian et al., 2020; Carpanez et al., 2022; Esmaeilian et al., 2022).

Sediments transported by rivers include organic compounds and primary minerals resistant to weathering, such as quartz and zircon, as well as secondary minerals, such as clay minerals, carbonates, and oxides, which arise from the physical and chemical weathering of the base rocks (Badrzadeh et al., 2022; Balasubramanian et al., 2020; Carpanez et al., 2022; Li et al., 2023; van der Perk and Vilches, 2020). Jarallah and Essa (2012) revealed that, in the sediments of the Tigris and Euphrates rivers, clay particles had a predominant concentration of expanded minerals such as smectite, chlorite, kaolinite, illite, and palygorskite. Ali et al. (2013) identified differences in the mineral ratios of sediment deposits in agricultural lands compared to that of river sediments in Baghdad. Furthermore, agrarian regions reported a higher percentage of chlorite and montmorillonite, and other types of clay minerals dominated Baghdad's urban areas. Similarly, non-clay minerals, such as quartz, calcite, and feldspar minerals, were observed in the river sediments. The same non-clay minerals (quartz, calcite, and feldspar), along with gypsum and dolomite, appeared in the surface and sub-surface sediments of soils adjacent to the rivers; further, the dolomite and gypsum minerals vanished in the river sediments.

Water scarcity and the construction of reservoirs and dams have dramatically reduced the sediment loads in many rivers worldwide (Kondolf et al., 2018; Li et al., 2020; Syvitski et al., 2005; Wang et al., 2022; Wang et al., 2016). The decline in the water supply of the Tigris and Euphrates rivers in recent years has affected the mineral contents of their sediments (Liu et al., 2022; Viers et al., 2009). Further, the lack of studies on the suspended river load in the Tigris and Euphrates rivers, especially those focusing on the mineral composition of their deposits, is the impetus for this research. This study explores the delivery of sediments to the agricultural lands irrigated by river channels, including the riverine load sediments.

Specifically, this study intends to characterize the nature and content of the river load of suspended sediments and the quality and quantity of the mineral contents of the suspended sediments in the Tigris and Euphrates rivers in the sedimentary Mesopotamian plain area of Iraq. The qualitative and quantitative contents of the suspended river load indicate the proximity or distance of the sediment sources from the river load. This suspended river load is transferred to the agricultural lands via river waters by deposition after settling on the soil surface during irrigation.

2. Materials and methods

2.1. Study area

Experiments were conducted to characterize the composition of the riverine load of suspended sediments from the Tigris and Euphrates rivers in the Mesopotamian plain in Iraq. Study areas included the governorates of Baghdad, Kut, and Amarah, where the Tigris river flows, and the governorates of Karbala and Diwaniyah, where the Euphrates river flows. Fig. 1 shows sampling sites of suspended sediments. Samples were collected between January 16, 2020, and January 15, 2021. They were collected after rainfall, when peak concentration periods of the sediments occur, using a submersible pump. Samples were drawn from the middle of the river channel at 4 m below the surface water level.

Suspended sediments were collected by filtering the water solution (Doulton Ceramic Filter, Ultra Fluoride water, UK); four filters were installed to withdraw samples for each site, in both the Tigris and Euphrates Rivers, for the purpose of obtaining sufficient and comprehensive samples at each site. The process of collecting samples took 15 days, because obtaining suspended sediment samples from rivers is time-consuming and requires accuracy. About 0.8–0.7 kg of suspended sediment were collected for each site and laboratory analyses for the physical and chemical properties of sediments were conducted as follows. Samples were air-dried and then disassembled by using a wooden rod and sieved to 2 mm. 10 g of a soil sample was weighed to estimate certain physical properties. The particle size distribution was determined by decantation using the pipette method (Pansu, 2006). The electrical conductivity and pH were measured using standard methods according to (Page et al., 1982), in an extract (1:1) of 50 g of soil:50 ml of water. Total carbonate minerals were estimated using the methodology from a previous study (Hesse, 1971). Active carbonate minerals were estimated using a method proposed by Galet (1972). Organic carbon was determined by wet oxidation using the Walkley and Black method (Black, 1965), and then converted to organic matter. Gypsum content was determined using the acetone precipitation method (Thorne, 1954). The cationic exchange capacity was analyzed using the Papanicolaou (1976) method.

2.2. Mineralogical analysis

The mineral content was determined in the bulk samples of suspended sediments, where the procedure for preparing them for the X-ray diffraction analysis of soil samples is summarized as follows (Carver and Douglas, 1972; Folk, 1980): 10 g of the sample were taken and dried in an oven at a temperature of 60 °C. Then, the sample was disassembled by using a wooden rod. The sample was inserted into a holder of the XRD Instrument; The Shimadzo-6000 X-ray diffraction instrument was used. The results of X-ray diffraction were interpreted using a computer program that calculated the percentages of each mineral peak in the chart.

2.3. Morphological features of minerals

A scanning electron microscope (SEM) was used to examine the morphological features of minerals. 10 g of soil samples were taken, and the soil particle binders were removed through the following steps: the salts were disposed of from the sample according to the method followed by Kunze and Dixon (1986); carbonate minerals were disposed of according to the method followed by Rabenhorst and Wilding (1984); the organic matter was disposed of using the method proposed by Anderson (1963)); and finally, iron oxides were removed from the soil sample according to the method adopted by Mehra and Jackson (2013)).

After the removal of the soil particle binders, the soil sample was leached with distilled water. The sample was shaken and then 1 ml was placed in the holder of the SEM instrument, which was then air-dried and tested. The scanning electron microscope model used was 450 QUANTA.

3. Results and discussion

3.1. *Particle size distribution and chemical properties of suspended sediments*

Table 1 shows the particle size distribution of suspended sediments for each of the sampling sites. There is a clear dominance of silt particles (>70 g kg^{-1}), followed by clay particles (>21 g kg^{-1}). These results are consistent with those in previous studies (Hall, 2006), which found that the suspended river load comprises mainly silt and clay. The similarity in the distribution of suspended sediments in the study sites is attributed to the similarity in the sediment-generating rocks of the source area. Along with certain conditions that are identical, the source area was subjected to weathering, erosion, transport, and sedimentation, despite the variations in the physiographic locations of the Tigris and Euphrates rivers. The low percentage of sand particles in the river load is due to their large size and specific weight, in addition to their spherical shape, which makes it difficult to carry them within the suspended river load over large distances, especially when the intensity of water currents decreases. Therefore, they prevail within the riverbed load. The increase in the fine sediment particles in the suspended river load contributes to increasing the fertility of the agricultural lands on which they may be deposited (Bhattacharya et al., 2019).

Table 1 suggests that the distance from the source area and the distance between sites leads to differences in the textural values. The results show a decrease in sand and silt particles in sediments with increases in the distance in the Tigris river between Baghdad, Kut, and Amarah. Further, clay particles increase with distance for both the Tigris and Euphrates rivers, especially between Karbala and Diwaniyah. It is clear that the distance traveled by the sediments affects the nature of its content. The hydrological conditions, represented by tortuosity, changes in cross-sections, and engineering constructions (dams and reservoirs) along the Tigris and Euphrates rivers affect the speed of the river flow; at the same time, they control the deposition of the particles (Charoenlerkthawin et al., 2021).

Table 1
Particle size distribution of suspended sediment.

	River	Location	Sand	Silt	Clay
			g kg^{-1}		
	Tigris	Baghdad	41	740.5	218.5
		Kut	26.7	722.9	250.4
		Amarah	18.7	709.7	271.6
	Euphrates	Karbala	35.4	730.3	234.3
		Diwaniyah	26.3	706.9	266.8
min	–		18.7	706.9	218.5
max	–		41	740.5	271.6
mean	–		29.6	722.1	248.3

Table 2 shows the selected chemical properties of the suspended sediments. The pH values for suspended sediment were between 7.39 and 7.70, indicating a similarity in the chemical and mineral compositions of the source materials that contribute to the suspended sediments. Carbonate minerals account for >30 % of the source area, playing a significant role in the slightly alkaline behavior, along with the fact that most Iraqi soils are calcareous (Sá et al., 2021). Further, the high or low pH values of sediments affect the process of adsorption, release, and sedimentation of some nutrients, such as phosphorus, iron, zinc, and manganese, as well as pollutants transported with sediments, such as cadmium, copper, and lead (Chen et al., 2020; Zhai et al., 2021).

Electrical conductivity values ranged from 1.39 to 2.16 ds·m^{-1}, with the lowest value in Baghdad and the highest in the Diwaniyah governorate. Electrical conductivity values were higher for the Euphrates river than the Tigris river. This may be attributed to the higher salinity of the Euphrates river compared to the Tigris river due to reduced inputs of water and the construction of dams and reservoirs in the Euphrates river (Montazeri et al., 2023). Table 2 illustrates the increase in salinity of sediments with distance from the source for both rivers. This salinity increase occurs due to the higher return of water from cities and drains from agricultural fields adjacent to the rivers (Zhou et al., 2021). As high electrical conductivity values may contribute to the process of flocculation of suspended sediments, especially clay particles, their sedimentation will be affected and, thus, their percentages within the suspended

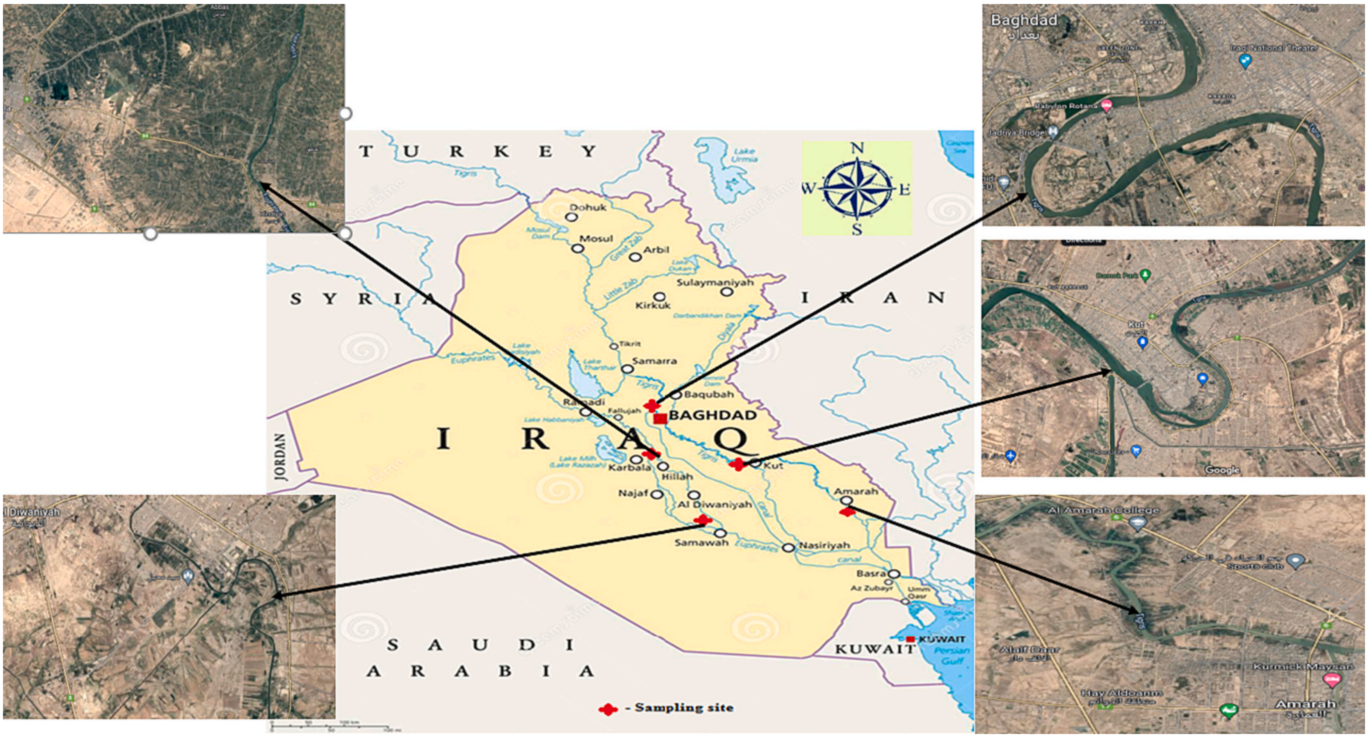

Fig. 1. Sampling locations of sediments from suspended river load.

Table 2

Selected chemical properties of suspended load sediments.

	River	Location	pH	EC	$CaCO_3$	$CaCO_3$	OM	$CaSO_4$	CEC
					Total	Active			
				$ds.m^{-1}$	$g\ kg^{-1}$				$cmol\ kg^{-1}$
	Tigris	Baghdad	7.39	1.39	336.12	172.64	16.54	none	25.67
		Kut	7.51	1.57	338.53	179.65	11.41	none	25.11
		Amarah	7.57	1.98	340.10	184.70	14.80	none	27.92
	Euphrates	Karbala	7.62	1.92	341.37	185.76	13.31	2.40	24.10
		Diwaniyah	7.70	2.16	352.87	194.56	12.19	1.50	26.21
min			7.39	1.39	336.12	172.64	11.41	1.50	24.10
max			7.70	2.16	352.87	194.56	16.54	2.40	27.92
mean			7.56	1.80	341.80	183.46	13.65	0.78	25.80

river load decrease (Li et al., 2020).

The total calcium carbonate content was in the range of 352.87–336.12 g kg^{-1}, with higher values for the Euphrates river. This result may be related to the source areas of carbonate minerals and the distance of the source area for both rivers (Kharitonova et al., 2019). The total calcium carbonate content increases with the distance traveled by the sediments in the river load in the Tigris and Euphrates rivers. The transportation of these minerals with the bottom load sediments for long distances from the source causes the breakdown of these particles to the size of clay and silt particles, which leads to their increased values with distance (Al-Kaysi, 2000; Chen et al., 2022). The values of active calcium carbonate were in the range of 172.64–194.56 g kg^{-1}. The Euphrates river had more active calcium carbonate minerals than the Tigris river. Their values increase with distance because their sizes are often similar to the size of clay and silt particles due to their association with clay and silt (Yang et al., 2021). This association favors their travel over long distances with resistance to sedimentation due to their small size, even exhibiting an increasing concentration with distance. This may manifest in the form of coatings around the clay particles. The high values of calcium carbonate in suspended river load sediments, as shown in Table 2, may indicate the role of these sediments in influencing the properties of agricultural land soils if deposited on them, such as the soil water holding capacity and the availability of nutrients for plants, in addition to the issues of soil surface hardening (Umer et al., 2020).

Gypsum was present in the range of 1.5–2.4 g kg^{-1} in the sediments of the Euphrates river, but it was not observed in the Tigris river sediments at any of the study sites. This absence is explained by the fact that the land through which the Euphrates river passes has a high percentage of gypsum. The land through which the Tigris river flows contains no gypsum (or very little), especially in the Mesopotamian plain area. This finding was confirmed by most studies on gypsum distribution in Iraqi lands (Al-Saoudi et al., 2013). The values of gypsum in river load sediments, as shown in Table 2, are low or insignificant and, therefore, have no effect on the characteristics of the agricultural lands on which it may be deposited, especially in the Tigris River. An increase in gypsum by >10 % affects agricultural lands, leading to a reduction in their fertility and productivity. However, small percentages of gypsum are necessary for agricultural lands, as they prevent the formation of sodic soils. In addition, both calcium and sulfates are important nutritional elements for plants (Jassim, 2019).

The measured values of organic matter in the suspended river load were about 11.41–16.56 g kg^{-1}. No specific trend was found with distance or the graphical location. These results are likely to be related to a difference in the distribution of vegetation cover areas and the density of vegetation cover from one region to another in the area of the source sediment supply to the river. Moreover, the difference in the density and quality of vegetation cover along the river channel, as vegetation is the most essential source of organic matter, is also responsible for this trend (Mhaina, 2017). The low content of organic matter in the river load, as shown in Table 2, indicates that the source area from which the sediments were transported has a low content of organic matter. This is because the prevailing climate of those areas, especially Iraqi lands, has high temperatures and low rainfall rates. Increasing the organic matter content in river load sediments improves the physical, chemical, fertility, and biological properties of the land on which the suspended river load may be deposited. Further, the presence of decomposed organic matter with the suspended sediment particles contributes to the process of flocculation of the fine sediment particles and, consequently, their sedimentation (Ho et al., 2022).

The cation exchange capacity varies from 27.92 to 24.10 cmol kg^{-1}. The slight increase with distance is associated with an increase in clay in the river sediments. Many studies have demonstrated the effects of the size of the particles and the mineral composition in controlling the cationic exchange capacity of the sediments (Aprile and Lorandi, 2012). Increasing the quantity of organic matter in the sediments inside a river correspondingly enhances the cation exchange capacity of those sediments. In contrast, increasing the quantity of carbonate of calcium within these sediments reduces the cation exchange capacity. Cation exchange capacity values in the suspended river loading sediments were determined by the proportions of clay separators, the types of clay minerals present, and the percentages of calcium carbonate and organic matter in the sediments. The cation exchange capacity values at the different study locations were controlled by those variables. Increasing the cation exchange capacity of suspended sediments is a beneficial attribute, particularly when these sediments are deposited on agricultural fields that get irrigation with sediment-laden water. It increases the fertility of the soil (Razzaghi et al., 2021).

3.2. Mineralogy of suspended sediments

The x-ray diffraction charts of the sediment samples (Appendices) are summarized in Table 3, indicating the presence of calcite, quartz, albite, dolomite, gypsum, chlorite, illite, montmorillonite, palygorskite, vermiculite, and kaolinite. These results are consistent with those in previous studies (Jarallah and Essa, 2012), with non-clay minerals found at a rate of 83.3 %. These values also match the values of silt and sand particles for suspended sediments, as shown in Table 1, where the percentages of both silt and sand were >75 %. The reason for the high values of non-clay minerals is their dominance in the source area, in addition to the ability of the river load to easily transport these sediments within the suspended load (Tian et al., 2021).

Quartz minerals represent 35.1 % of the non-clay minerals. The amount of quartz minerals decreases with the distance traveled in the Tigris and Euphrates rivers because of their high resistance to weathering. As quartz minerals maintain their size, they do not break, and may be deposited when the flow velocity decreases with distance (Górska et al., 2022).

Calcite minerals were the second-most prevalent non-clay minerals, making up 34.7 % of the total mineral content, with higher values observed in the Euphrates river than in the Tigris river. For the Euphrates river, the rate increased with distance. There are several reasons for this, including the variation in the size of the particles in both

Table 3

Mineralogy of suspended load sediments.

	River	Location	Calcite	Quartz	Albite	Dolomite	Gypsum	Total non clay mineral (%)	Chlorite	Illite	Palygorskite	Montmorillonite	Vermiculite	kaolinite	Total clay mineral (%)
			Non clay mineral (%)						Clay mineral (%)						
	Tigris	Baghdad	32.1	39.6	9.5	-	-	81.2	8.6	7.4	2.4	2.5	0.8	-	21.7
		Kut	33.9	35.1	9.1	-		78.1	9.7	8.8	-	0.7	0.4	2.7	22.3
		Amarah	31.6	30.0	8.0	8.9	-	78.5	6.9	8.7	2.1	-	0.4	3.3	21.4
	Euphrates	Karbala	36.2	38.2	12.7	-	-	87.1	1.5	6.0	-	-	-	5.4	12.9
		Diwaniyah	39.8	32.7	7.7	7.9	3.5	91.6	5.9	7.8	1.5	-	-	3.2	18.4
min			31.6	30.0	7.7	7.9	-	78.1	1.5	6.0	1.5	0.7	0.4	2.7	18.4
max			39.8	39.6	12.7	8.9	-	91.6	9.7	8.8	2.4	2.5	0.8	5.4	22.3
mean			34.7	35.1	9.4	8.4	-	83.3	6.5	7.7	2.0	1.6	0.5	3.7	19.3

rivers, as well as variations in the percentages of calcite minerals where the carbonic rock fragment minerals comprise limestone, aragonite shell, and fossil grains. Moreover, calcite minerals increased within the fine-sized sediment particles (Albadran, 2006). The increase in calcite minerals in river load sediments to 34.7 % could be attributed to the fact that most Iraqi land is calcareous (because the parent material generating these soils is of calcareous origin); this is confirmed by the results for calcium carbonate in Table 2, where the percentages of calcium carbonate were >34 % (Muhameed and Saleh, 2014). Albite minerals corresponded to 9.4 % of the non-clay minerals. The low percentage of albite minerals in the river load could be due to the instability of these minerals and their transformation into clay minerals owing to their presence in the source area (Al-Kaaby and Albadran, 2020). A decreased percentage of albite minerals with the distance traveled in both rivers was also noted. Dolomite and gypsum minerals constituted 8.4 and 3.5 % of the non-clay minerals, respectively. An increase in the proportion of carbonate minerals in the sediments transported by rivers may affect the properties of agricultural lands on which these sediments are deposited because of irrigation with sediment-laden water. It can result to increasing the pH value of sediments, decreased cation exchange capacity, and limited availability of macroelements like phosphorus and microelements. In addition, the absence of water retention and the increased firmness of the soil due to the availability of this mineral in its dry state impede the growth of seedlings (Taalab et al., 2019).

Table 3 shows that clay minerals in suspended sediments made up 19.3 % of the total soil minerals, with illite minerals at a rate of 7.7 %. The percentage increases with distance in both rivers. Illite is a mica mineral characterized by a lamellar shape that allows for transportation over longer distances in the river load (Das and Vasudevan, 2022). The percentage of illite mineral is greater in the Tigris river than in the Euphrates river. This higher percentage results from a difference in the content of the source area of this mineral for both rivers, along with the variation in the distance and hydrological conditions for the river load in both rivers. The increase in the proportions of mica (illite) minerals in the suspended river load sediments is an advantageous characteristic of these sediments, especially if they are within the proportions of clay minerals, as the mica (illite) minerals are a good mineral source of potassium in the soil, which enters the soil due to the weathering process (Wakeel et al., 2022). As shown in Table 3, chlorite mineral is 6.5 % of the total. Guyot et al. (2007) reported that the prevalence of mica or chlorite minerals inside the clay minerals is evidence of the sediments of recent formation. Furthermore, particles from predominant physical weathering are transferred by nearby sources. The Tigris river had a higher percentage of chlorite materials than the Euphrates river. Its proportions increased with distance and then decreased for the Tigris river. However, their percentages decreased as they moved farther into the Euphrates river. This behavior was similar to that observed for calcite minerals. This result may be explained by the variance in the size of chlorite particles in the river loads of both rivers. Table 3 shows that kaolinite minerals were 3.7 % of the clay minerals. The percentage of kaolinite minerals decreased as they moved further into the Tigris river, but increased with distance in the Euphrates river. The Euphrates river has a higher rate of kaolinite minerals than the Tigris river. This finding can be attributed to the higher percentage of kaolinite minerals in the western region of Iraq than in the eastern region (Tamar-Agha et al., 2019). The reason for the low percentages of kaolinite mineral in Iraqi soils is because the climatic and natural conditions in Iraqi land are not suitable for its formation. This is because kaolinite is a product of the acid weathering of rocks (Heimann et al., 2021), while the nature of Iraqi soils is calcareous and has a degree of reaction close to alkalinity. The quantities that appear in the results are a consequence of the geological deposits resulting from the decomposition and disintegration of acidic igneous rocks (Al-Tamimi, 2021; Khalaf, 2022). Further, palygorskite mineral was 2 % and was more prevalent in the Tigris river. This could be due to the presence of palygorskite in the fine clay particles (Al-Temimi et al., 1988). Montmorillonite mineral has a percentage of 1.6 %, while vermiculite mineral was 0.5 %. Larger concentrations of montmorillonite and vermiculite minerals were observed in the Tigris river than in the Euphrates river; their percentages were little or negligible in the Euphrates river. Increasing the proportion of vermiculite and montmorillonite minerals in river load sediments increases the cation exchange capacity of the soil on which these sediments may be deposited and, thus, improves its chemical and fertility characteristics (Saidi et al., 2022). Sediments transported by the Tigris river are more affected by weathering processes because they are created from materials that are more susceptible to weathering than the ones from the Euphrates river (Garzanti et al., 2016; Montazeri et al., 2023). The findings of this investigation agree with the conclusions drawn in the majority of other investigations(Al Taee et al., 2020; Esaa and Kassim, 2021), they found clay minerals often found in Iraqi soils, especially in the Iraqi alluvial plain region, consist primarily of smectite, chlorite, and illite minerals. Additionally, there are smaller amounts of palygorskite and kaolinite minerals present as secondary constituents. According to Warr (2022), the variation in clay minerals can be explained by differences in the origin of rocks and the impact of climatic fluctuations.

An examination of clay sediment samples with an SEM device can help determine the shape, size, and crystalline structure in which the clay minerals appear, as it gives a clearer picture of the nature of the surface characteristics, the degree of deformation, and the change occurring as a result of the processes of erosion, weathering, transportation, deposition, and interactions with organic materials (Lin and Cerato, 2014). A scanning electron microscope was used to examine suspended sediment from two sites (Baghdad and Amarah) in the Tigris river. The distance between the two sites is about 320 km.

Fig. 2 highlights the differences in size for sediment particles between both sites. The Baghdad site had larger particles than the Amarah site. The effects of the decreased water flow of the Tigris river with distance led to the deposition of larger particles, increasing the number of fine particles in the suspended sediment load with distance. This is also in agreement with data from Table 1 regarding the particle size distribution of suspended sediments. Studying the sizes of suspended sediment particles and comparing them is a suitable indicator for understanding their impacts on weathering, erosion, transport, and sedimentation (River and Richardson, 2019). Therefore, the dominance of fine particles in the river load with distance evidences the prominent role of the sorting of particles by size, while weathering does not play a significant role in decreasing particle sizes with distance. Fig. 2 shows the difference in the shape, edges, and balling of clay mineral particles in

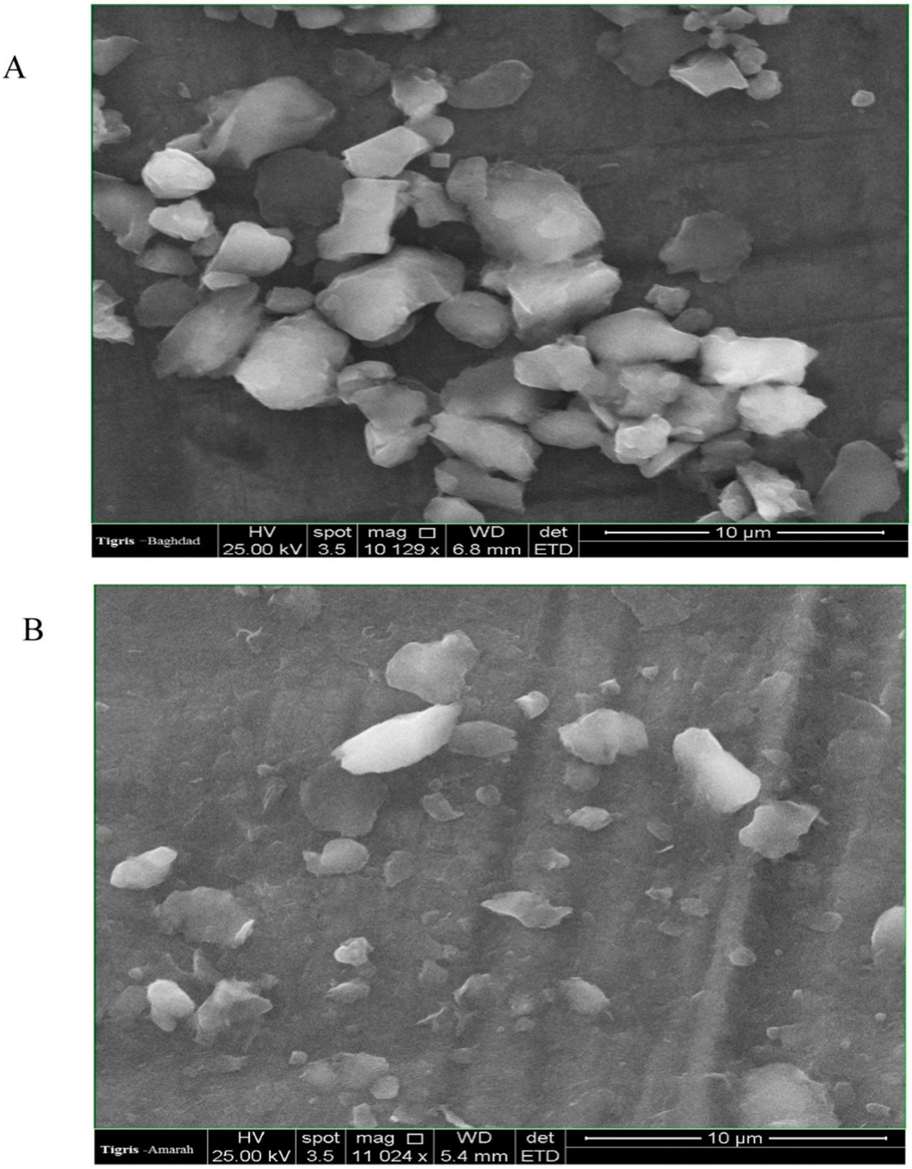

Fig. 2. Scanning electron microscope of sediment particles of the Tigris River at Baghdad (A) and Amarah (B).

both locations. The edges of clay mineral particles at the Amarah site are more rounded than the edges of clay mineral particles at the Baghdad site, clearly indicating the role of physical weathering as a result of abrasion and grinding processes (Bleam, 2012). The variation of particle size with the distance is primarily due to mechanical sorting, with no significant effect of physical or chemical weathering.

When examining the samples with a scanning electron microscope, the mica mineral was identified. It appeared when examining the sediment samples of the Baghdad site, as in shown Fig. 3A, which is exposed to the weathering of layers. When examining the sediment samples of the Amarah site, as shown in Fig. 3B, it appeared that they were exposed to the weathering of edges and layers. It is clear from Fig. 3 that there is a difference in the morphological features of minerals and size. We have previously indicated the effect of sorting is the highest, followed by physical weathering to a lesser extent in its effect on minerals in the river load with distance, and chemical weathering is almost non-existent.

4. Limitations of the current study, and future investigations

The paper concedes its limitations and proposes potential directions for future investigations in study field as outlined below:

1. The study collected samples from January 2020 and January 2021. However, the properties of sediment can vary seasonally and yearly due to factors such as rainfall patterns, land management, and human activities. Future studies must consider long-term monitoring to capture temporal variations and develop thorough sediment profiles.

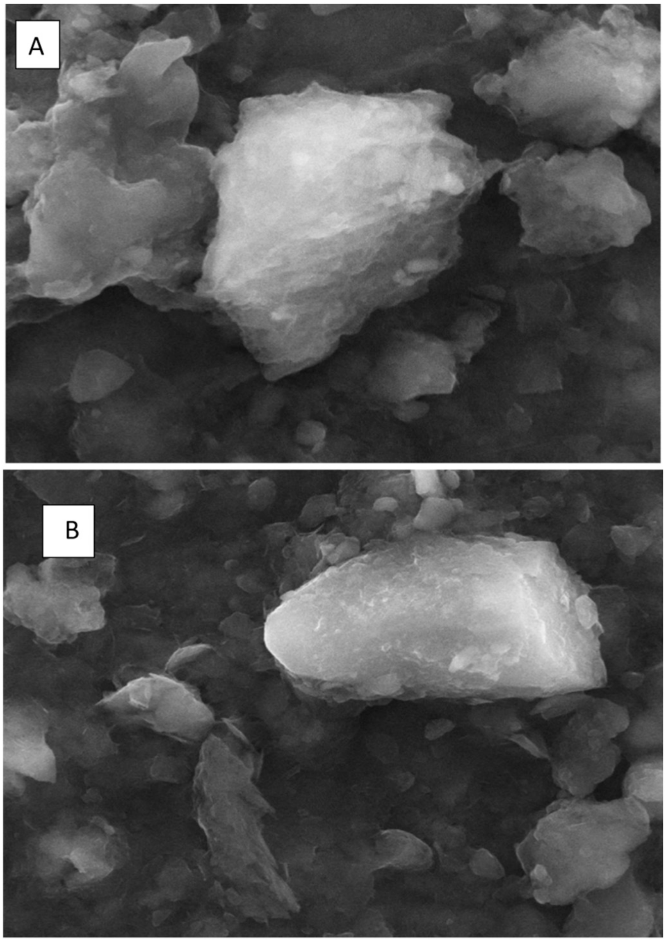

Fig. 3. Scanning electron microscope of sediment particles of the Tigris River at Baghdad (A) and Amarah (B).

2. The research focused on specific regions, including the governorates of Baghdad, Kut, Amarah, Karbala, and Diwaniyah. While these areas offer valuable insights, it would be beneficial to extend the research to encompass a wider geographical scope that contains places along the Tigris and Euphrates rivers.
3. The study utilized a submersible pump to collect samples of sediments occur. Although this method is widely used, it has introduced potential biases related to depth and placement of the samples. Future studies should investigate alternative sampling techniques or consider additional sampling points to address these limitations.
4. The mineralogical investigation was showed using X-ray diffraction and scanning electron microscopy. While these methods give useful insights about mineral composition, complementary analytical techniques, such as spectroscopy or elemental analysis, might provide a greater understanding of the mineralogical features of the sediments.
5. Additional research should be performed to find out the concentrations of pollutants elements in the sediments carried by the suspended river load. This will allow scientists to find the content of the source rocks that contain pollutants and evaluate the extent to that human activities contribute to the gain of sediments with pollutants.

5. Conclusions

Water shortages have reduced inputs in the Tigris and Euphrates rivers in recent years, lowering the amount and quality of sediments in the suspended river load. Silt particles were dominant in the sediment load, followed by clay and sand. The sediment pH was slightly alkaline and the electrical conductivity and the active and total calcium carbonate minerals increased more in the sediments of the Euphrates river than in the Tigris river. They presented higher differences with increasing distance. The mineral content of the river load sediment of clay and non-clay minerals varied in both rivers, and with the distance traveled by the rivers. The difference in the sizes of the sediment particles with the distance is mainly due to the mechanical sorting of the particles based on their specific weight, shape, and size. Although the effect of mechanical sorting prevailed on the distribution of sediment particles with distance, there are clear effects of physical weathering on the surfaces of sediment particles transported over long distances, especially those that are less resistant to weathering. There was no clear effect of chemical weathering on the surfaces of the sediment particles, as they are newly formed. This study recommends analyzing the suspended river load content of pollutants and nutrients, and expanding current mineral investigations to include the areas through which the Tigris and Euphrates rivers flow because of the changes in the water quantity and quality with time.

CRediT authorship contribution statement

Layth Saleem Salman Al-Shihmani: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft. **Ahmed Abed Gatea Al-Shammary:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft. **Jesús Fernández-Gálvez:** Data curation, Formal analysis, Methodology, Validation, Writing – review & editing. **Andrés Caballero-Calvo:** Conceptualization, Data curation, Formal analysis, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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