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Measurements of Magnetic Susceptibility and Its Application in Pollution Detection- A Case Study in the Tigris River in Baghdad City, Iraq

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Abstract

The Tigris River is considered the largest river that crosses Baghdad City, the capital of Iraq. It is regarded as one of the main water suppliers to the city.
River sediments can be used to detect the pollution in rivers; thirty sediment samples were collected one to two meters away from the riverside to assess the level pollution in sediments. The area is situated not so far from an industrial area, the Dura oil refinery, factories, and other facilities.
A series of magnetic measurements has been performed, including magnetic susceptibility (χ), anhysteretic remanent magnetisation (ARM), saturation isothermal remanent magnetisation (SIRM) and thermomagnetic analyses (κ-T).
Very high values of χ, χ_{ARM} and SIRM were detected; the mean values were 2962 $\times 10^{-8}$ (m^3/kg), 569$\times 10^{-8}$ (m^3/kg) and 2721$\times 10^{-5}$ (Am^2/kg), respectively.
The high correlations between χ and χ_{ARM}, χ and SIRM are (R^2=0.78) and (R^2=0.82), respectively.
Thermomagnetic analyses at high and low temperatures show that the curves of high temperatures (0 to 700 ºC) decrease around 580 ºC, which is the Curie temperature of magnetite; the low-temperature curve (0 to -200ºC) shows a typical curve of magnetite, and the Verwey transition is clearly detected. These results indicate the presence of Single-Domain (SD) to Multi-Domain (MD) grains of magnetite (Fe_3O_4) in high concentrations and the absence of superparamagnetic (SP) grains in the sediments. The results indicate that the river sediments are highly polluted, which could be due to anthropogenic activities, including oil refineries, industrial activities, and atmospheric particle pollution.

Keywords: Tigris River, Magnetic susceptibility, Baghdad city, Magnetite, polluted sediments.

قياس الحساسية المغناطيسية وتطبيقاتها في تحديد التلوث

نورس ناهض امين
قسم الفيزياء, كلية العلوم, جامعة المثنى, السماوه, العراق

الخلاصة

يعتبر نهر دجلة أكبر الأنهار التي تعبر مدينة بغداد، عاصمة العراق. ويعتبر المورد الرئيسي للمياه لمدينة بغداد .
يمكن استخدام الرواسب النهرية للكشف عن التلوث في الأنهار؛ حيث تم جمع ثلاثين عينة من الرواسب على بعد متر إلى مترين من ضفة النهر للكشف عن التلوث في الرواسب. تعتبر المنطقة ليست بعيدة جداً عن منطقة صناعية ومصفى الدورة لتكرير النفط والمصانع والمرافق الأخرى .

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اجريت سلسلة من القياسات المغناطيسية؛ الحساسية المغناطيسية، والمغناطيسية المتبقية اللاهستيرية، والمغنطة المتساوية التشبع والتحليلات المغناطيسية الحرارية.

وجدت عن قيم عالية جدًا للحساسية المغناطيسية والمغناطيسية المتبقية اللاهستيرية، والمغنطة المتساوية التشبع ؛ كانت القيم المتوسطة 2962×10^{-8} (م^3/كغم)، 569×10^{-8} (م^3/كغم) و 2721×10^{-5} (اي ام^2/كغم)، على التوالي.

الارتباط العالي بين الحساسية المغناطيسية والمغناطيسية المتبقية اللاهستيرية والحساسية المغناطيسية والمغنطة المتساوية التشبع هي (R^2=0.78) و(R^2= 0.82) على التوالي.

تعكس هذه النتائج وجود حبيبات أحادية المجال (SD) ومتعدد المجال (MD) من المغنتايت (Fe_3O_4) وعدم وجود حبيبات فائقة المغناطيسية (SP) في الرواسب .

يظهر منحنى درجات الحرارة المنخفضة (0 إلى −200 درجة مئوية) منحنى نموذجيًا للمغنتايت ويتم الكشف عن تحول فيروي بوضوح. تعكس هذه النتائج وجود حبيبات من المجال الفردي (SD) والمجال المتعدد (MD) من المغنتايت (Fe3O4) بتركيزات عالية وغياب حبيبات فائقة المغناطيسية (SP) في الرواسب. نتائج الدراسة اثبتت ان رواسب النهر ملوثة بشكل كبير بسبب النشاطات البشرية والتي تتضمن مصافي النفط، والنشاطات الصناعية والجسيمات الجوية الملوثة.

1. Introduction

In the last few decades, magnetic susceptibility techniques have been widely used in pollution detection. Sediment particles can carry different types of minerals, including iron oxides. Magnetic mineralogy techniques were employed in several studies as a means of identifying areas contaminated with magnetic minerals. Magnetic susceptibility analysis of low frequency (χ_{lf}) and high frequency (χ_{hf}) was used to compare the magnetic properties of river sediments before and after exposure to gold processing waste in a polluted area of gold mining in Indonesia. The findings showed that lithogenic and anthropogenic minerals are the source of magnetic minerals in the environment [1].

The Moldau river sediments and neighbouring soils in the Czech Republic have been studied to investigate the anthropogenic impact using the magnetic susceptibility method. The major geogenic magnetic anomaly in the region of the Slapy dam has made it impossible to firmly interpret the magnetic signal in terms of anthropogenic impact in the last downstream [2]. The sediment pollution of a typical reservoir in northwest China has been assessed using magnetic susceptibility. Significant positive relationships were found between the magnetic susceptibility values and natural radionuclides (232Th and 40K) and trace metals (Co, Cu, Mn, Ni, and V). Statistical analysis revealed that magnetic particles and trace metals had similar deposition properties and shared sources. Magnetic susceptibility has been confirmed as a useful indicator for locating industrial sources of trace metals [3].

A geochemical, mineralogical and sedimentological study of the Tigris River floodplain has been conducted in Tikrit Governorate, northern Iraq, to identify the properties of the sediment. The XRD technique was applied. The results revealed that the concentration of major oxides, as determined by geochemical analysis, indicates a high content of SiO_2 and CaO in the floodplain of the Tigris River [4].

The Tigris River in the Baghdad Governorate has undergone a geochemical investigation, and sediments were examined close to the Baghdad Medical City hospital. To initiate immediate remediation actions, the goal is to assess the water and soil conditions in the area next to the Tigris River. Chemical indicators have revealed a similar trend for all tested samples, indicating a potential direct threat to the local environment and residents/benefits, with the medical complex being the primary location [5].

The objective of this study is to investigate the trends of magnetic susceptibility to assess the contamination situation in the Tigris River sediments in Baghdad city, where the river crosses a residential neighbourhood. The Tigris River transports sediments to central Iraq, including sand that contains a variety of light and heavy minerals as well as rock fragments. The high magnetic susceptibility trends will have an impact on pollution levels.

2. Study Area and Sampling

The study area is situated in Baghdad City, Iraq, and is designated as Station One (SP1) (33°17'41" N, 44°23'51" E) and Station Thirteen (SP30) with coordinates (33°17'7" N, 44°22'36" E) as shown in Figure 1. The study area lies between the Suspension Bridge and Al-Jadriya Bridge. The region's geological setting includes the Tigris River's location on the Mesopotamian alluvial plain, which is primarily composed of river sediments including sand, silt, and clay [6]. Thirty sediment samples (with an average interval distance of about 75 m) were collected using a manual shovel; the samples were kept in plastic bags and labelled.

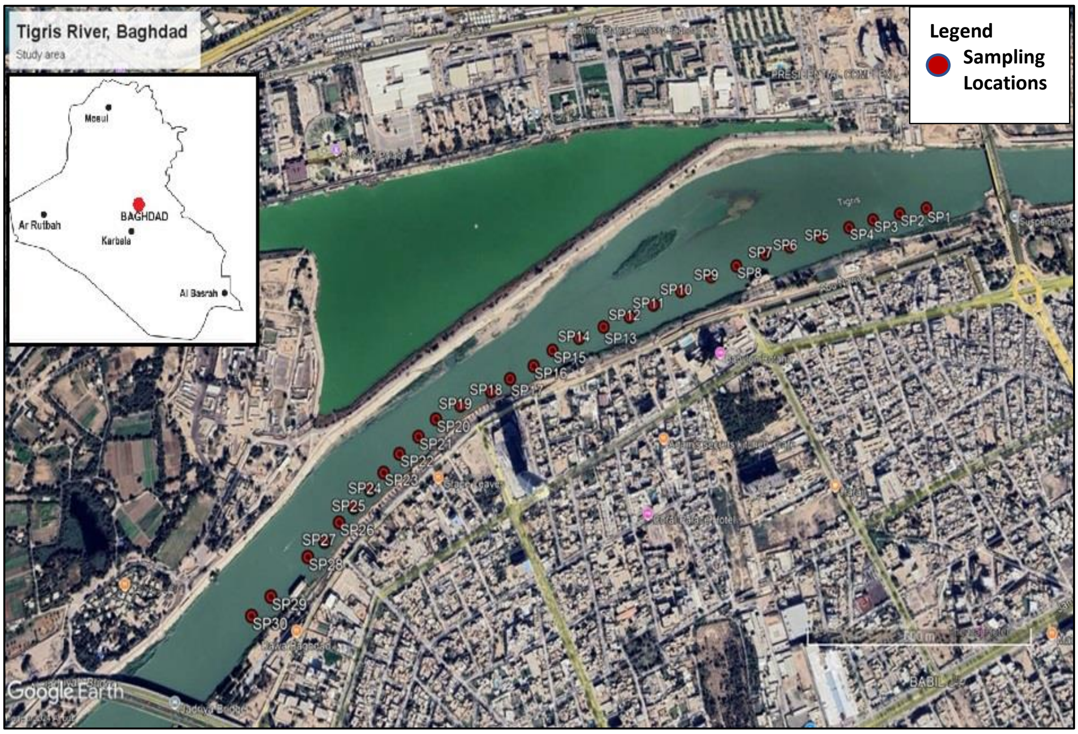

Figure 1: Location map of the study area (*taken from Google Earth*). The red points show the sampling locations.

3. Materials and Methods

The samples were air-dried at room temperature, stored in small plastic bags, and then transported to the magnetic laboratory at Potsdam, the German Research Centre for Geosciences (GFZ) in Germany. The sample preparation involved sieving the sediment samples to remove organic matter and then sealing them tightly in small 6 cm^3 cubic, non-magnetic plastic boxes to conduct several magnetic experiments.

The magnetic susceptibility was measured using an AGICO Multi-function Kappabridge MFK1A and converted into mass-specific χ (m^3/kg) [7]. An AGICO MFK1 Kappabridge was used to measure frequency-dependent susceptibility (κ_{fd}%) at five frequencies (475, 825, 1525, 2675, and 4775) Hz to estimate the grain size distribution [8].

The anhysteretic remanent magnetisation (ARM) parameter was measured using a cryogenic 2G Enterprises 755 SRM long-core magnetometer, which features a sample holder for eight distinct samples. The ARM was applied along the z-axis of the samples using a static field of 0.05 mT and an AF field of 100 mT. The ARM susceptibility (χ_{ARM}) (m^3/kg) was then calculated.
Saturation isothermal remanent magnetisation (SIRM) was measured using a Molyneux spinning magnetometer at two intensities, back field of 300 mT and 1000 mT. Isothermal remanent magnetisation (IRM) was applied using a 2G Enterprises 660 pulse magnetizer.

The Bloemendal equation was applied to calculate the S-ratio, which is used to distinguish between hard magnetic phases, such as hematite and soft magnetic phases like magnetite [9].
High-temperature thermomagnetic measurements were performed on bulk samples (0-700 °C) and then cooled back to room temperature to determine the Curie temperature of magnetite (around 580 °C); this was done using a Bartington furnace. Low-temperature measurements (0 to -200 °C) were also performed in a liquid nitrogen environment with an AGICO Multi-function Kappabridge MFK1A.

4. Results and Discussions

Concentration-dependent magnetic parameters

High concentrations of magnetic susceptibility in lake sediments have been linked to fine-grained iron oxides from urban and industrial sources, as indicated by numerous magnetic studies [10]. Results of χ show very high values in all samples from the study area, which varied between (2822-3126)$\times10^{-8}$ (m^3/kg) with a mean value of 2962$\times10^{-8}$ (m^3/kg); χ_{ARM} results varied between (519-614.33)$\times10^{-8}$ (m^3/kg) with a mean value of 569$\times10^{-8}$ (m^3/kg), SIRM ranges between (2271-3077)$\times10^{-5}$ (Am^2/kg) with a mean value of 2721$\times10^{-5}$ (Am^2/kg).
Figure 2 shows the profiles of the concentration-dependent magnetic parameters versus the distance intervals between the sampling stations.
Concentration-dependent magnetic parameters increase in all sediment samples; Figure 2 displays the similar trends for χ, χ_{ARM}, and SIRM, suggesting that magnetite is more likely to be a major magnetic carrier. κ_{fd}% has been measured to investigate the grain sizes of magnetic minerals in the sediments; κ_{fd}% ranges from 0.40 to 0.49% (Figure 3A), with a mean value of 0.44%. According to Dearing et al. (1996) [8], Ultrafine superparamagnetic (SP) grains tend to cause lower κ_{fd}% in soils, while magnetite is found in the grain sizes of stable single (SSD) and multidomain (MD) ferrimagnetic grains.
According to the study of Heslop [11], the S-ratio (S-ratio=IRM/SIRM) is a rock magnetic characteristic used to give a relative indication of the contributions of low and high-coercivity minerals to a sample's saturation isothermal remanent magnetization (SIRM); the more value near 1 refers to high coercivity (like magnetite), and low coercivity may refer to hard coercive minerals (like hematite). In the present study, the S-ratio lies between (0.95-0.99) and the mean value is (0.97) (Figure 3B) (Figure 3), which implies that the sediment samples are rich in high-coercive minerals, like magnetite.

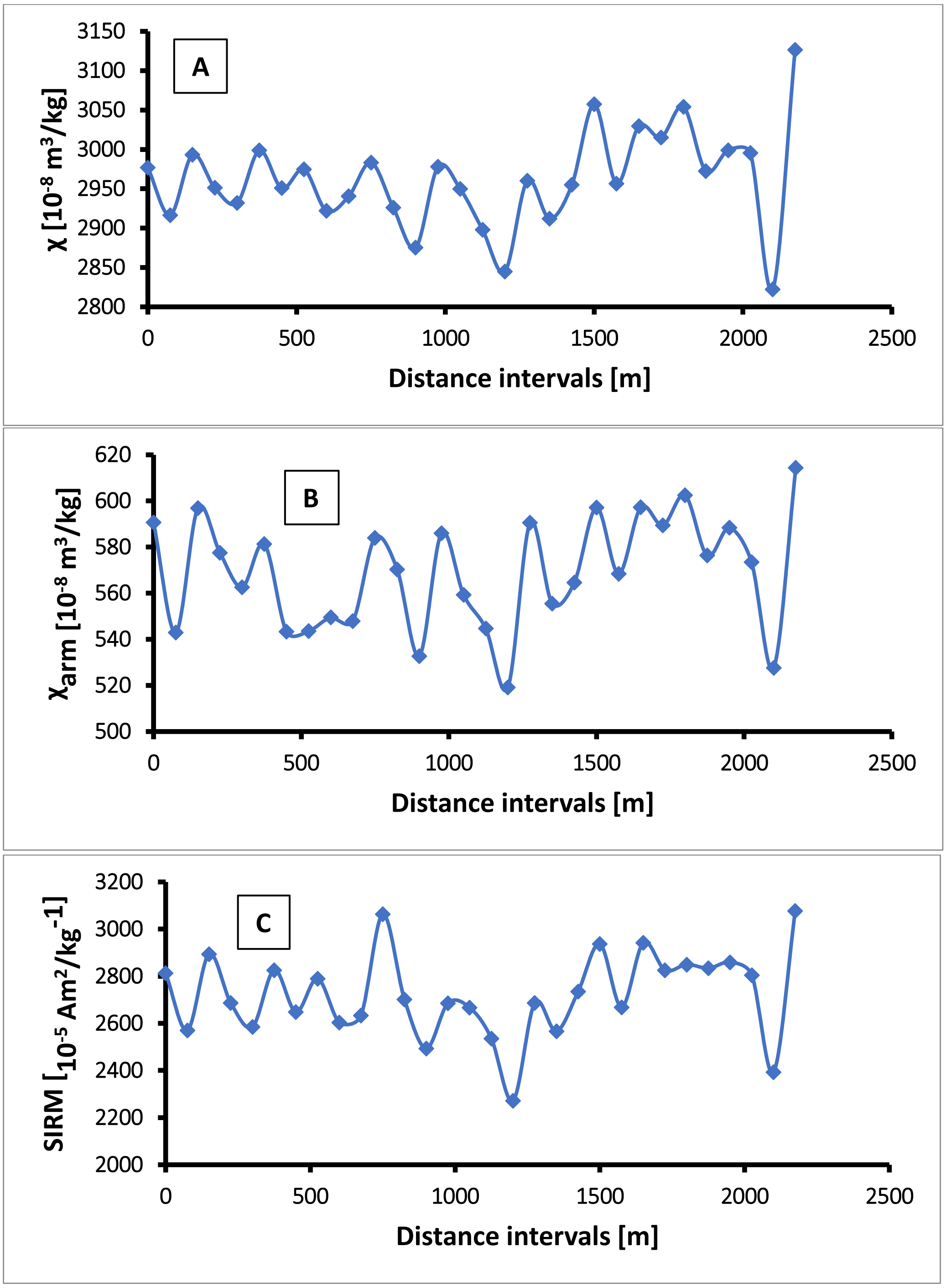

Figure 2: profiles of **A)** magnetic susceptibility (χ); **B)** Anhysteretic remanent magnetisation (χ_{ARM}); C) Saturation isothermal remanent magnetisation (SIRM) versus distance intervals of sediment samples collected from the Tigris River, Baghdad City.

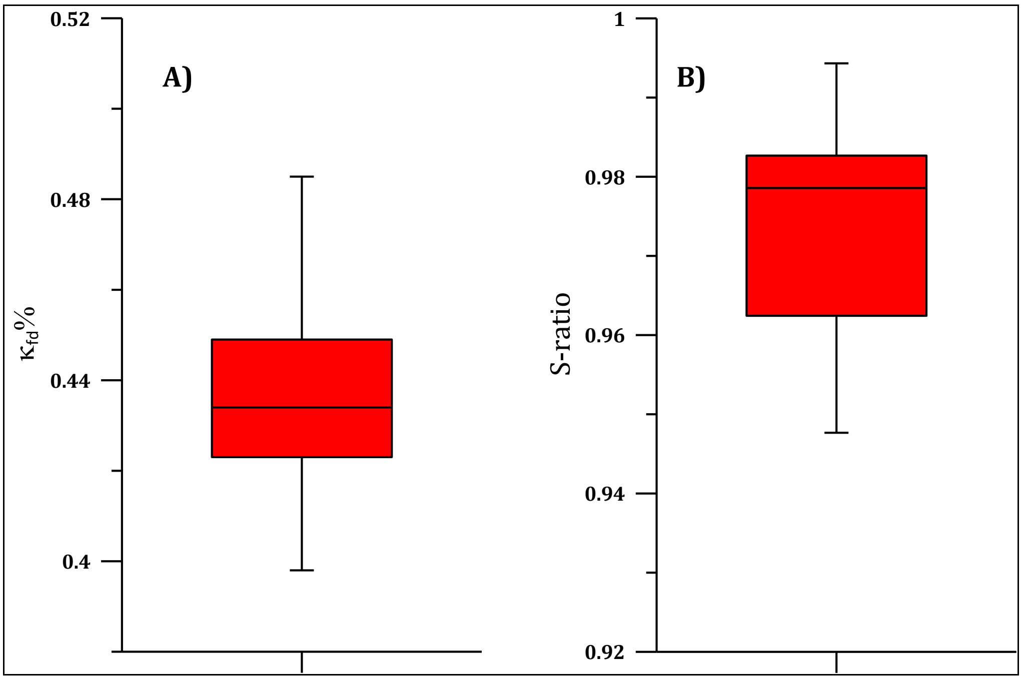

Figure 3: Box-Whisker plots; **A)** Frequency-dependent susceptibility (κ_{fd}%), **B)** S-ratio of sediment samples collected from Tigris River, Baghdad City.

Magnetic phase identification

To support the study findings, χ versus χ_{ARM} were plotted; as shown in Figure 4 below, χ is positively correlated with χ_{ARM} with a correlation coefficient (R^2=0.78), and χ versus SIRM were also positively associated with a correlation coefficient (R^2=0.82). Ferro(i)magnetic phases, such as magnetite control χ, as indicated by the linear positive correlation between χ and χ_{ARM}, χ and SIRM [12].

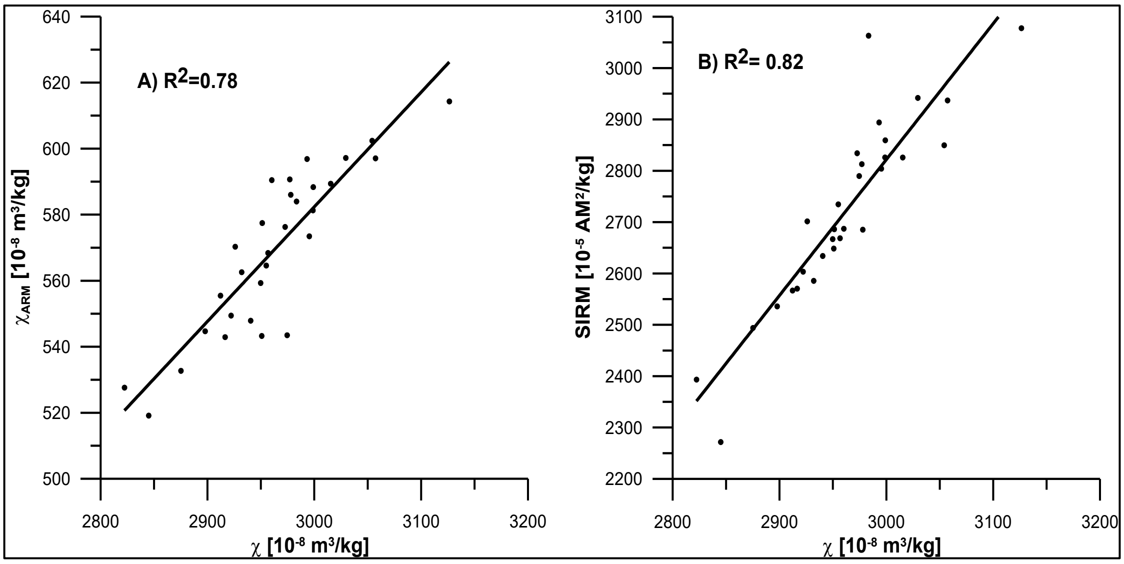

Figure 4: Relationship between: **A)** magnetic susceptibility (χ) and susceptibility of anhysteretic remanent magnetisation (χ_{ARM}), and **B)** magnetic susceptibility (χ) and saturation isothermal remanent magnetisation (SIRM). The correlation coefficients (R^2) are listed.

High and low-susceptibility (κ-T) curves were measured for a selected sediment sample (A02) from 0 to 700 ºC, taken from the first study location as shown in Figure 5. High temperature curves clearly show strong drop in the heating curve (red curve) around 580 ºC which is the Curie temperature of magnetite [13], when the temperature drops below 500°C, the susceptibility of cooling curves appears to be stronger than that of heating curves, suggesting that more magnetic mineral may occur during heating [14]. Meanwhile, a strong increase in the cooling curve (blue curve) indicates that the Low-temperature magnetic method offers efficient tools for identifying the low-temperature transition of magnetite in sediments, thereby determining the amount of ultrafine-grained (superparamagnetic) minerals in sediments [15].

The low-temperature curve (0 to -200 ºC) in the selected sample (A02) shows a typical curve of magnetite; the presence of magnetite is indicated by the distinctive characteristics of the low-temperature stage known as the "Verwey transition" [16], where an apparent transfer of susceptibility appears near the temperature of -150°C.

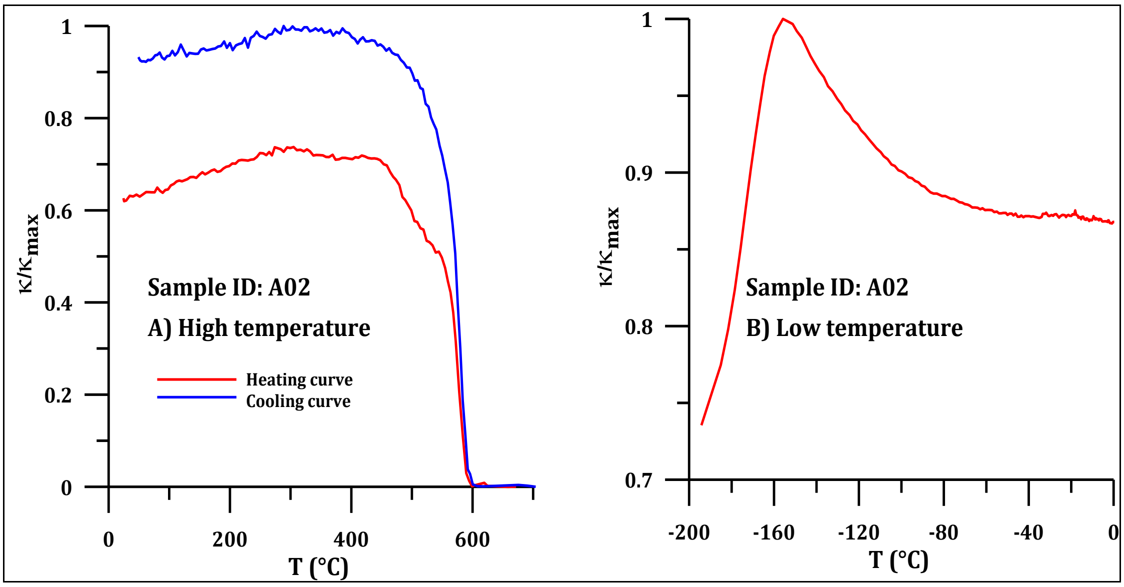

Figure 5: A) high temperature curves; **B)** Low temperature curve of selected sediment sample (ID: A02)

5. Conclusions

The results of the study on sediments from the Tigris River in Baghdad City indicate that:

1. The dominance of magnetic as the main magnetic carrier in all sediments, the type of magnetite is in the Single-Domain (SD) to Multi-Domain (MD) states, with grain sizes lying between 1 µm and 5µm, which is hazardous to health and is easily absorbed.
2. Concentration-dependent magnetic parameters (χ, χ_{ARM}, and SIRM) in all sediment samples show very high concentrations, and no decrease in the concentrations was detected, implying that the river sediments are highly polluted, which could be due to anthropogenic activities, including oil refineries, industrial activities, and atmospheric particle pollution.
3. The magnetic susceptibility method improved the capability to detect the pollution and the ability of this method in pollution monitoring.

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