Article

Study of the Heavy Elements of the Al-Kharazi Water Course Inside the University of Mosul

Sura Salim Hamid1\*, Alaa Taha Aziz1

1. College of Agriculture and Forestry, University of Mosul, Department of Basic Science, Mosul, Iraq

**\*** Correspondence: [surasalimhamid74@uomosul.edu.iq](mailto:surasalimhamid74@uomosul.edu.iq)

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**Abstract:** This study investigated the levels of heavy metal contaminants (copper, zinc, cadmium, and lead) in water samples collected from the Al-Kharazi watercourse traversing the University of Mosul campus over four seasons in 2022 and 2023. Water samples were taken from five stations along the watercourse and analyzed for dissolved and particulate phases of the heavy metals. The heavy metals have been extracted using a standard method and their concentrations in river water and sediments have been estimated using Atomic Absorption Spectrophotometer. The results showed mean concentrations of 0.0527 ± 0.0131 mg/L for cadmium, 0.0178 ± 0.0051 mg/L for lead, 0.0145 ± 0.002 mg/L for dissolved copper, and 3.232 ± 0.635 mg/L for zinc across all seasons. Substantial discrepancies were noted among seasons and across various sampling sites. At specific sites and during certain seasons, the levels of cadmium and lead were discovered to surpass the drinking water guidelines set by the World Health Organization (WHO). The research shows that there is a significant amount of heavy metal pollution, particularly cadmium, in the Al-Kharazi watercourse. This contamination is most likely caused by human activities in the university area. It is advisable to regularly assess and apply solutions to mitigate the risks of heavy metal contamination to both the aquatic environment and human health.

**Keywords:** World Health Organization (WHO), watercourse, aquatic environment, human health

1. Introduction

One of the defining features of Mosul, the capital of Nineveh Governorate in northern Iraq, and its water identity is the Al-Khosur River. Due to the lack of drainage water, the river is seasonal [1]. The Al-Khosur River flows from Jabal Maqlub on the edge of Nineveh Governorate through the Komel River, Wadi Al-Maleh, Bashiqa and Al-Shekhan before joining the Tigris on the left bank in the centre of the city of Mosul [2]. The Al-Khosur River is classified as a seasonal river because it relies on runoff from smaller sources and rainfall. This means that, despite its catchment area of approx. 1000 km2, the river sometimes has abundant water in winter and drought in summer [3].

The Iraqi river environment is severely affected by water pollution caused by human activities. The main problem in Iraq is water pollution in rivers caused by human activities, oil spills from ships and fishing chemicals. As a result, heavy metal concentrations have increased in both the water and sediment in the river basin [4].

Heavy metals are substances with a high density of more than 6 g/cm3. Even in extremely low concentrations, these substances can be toxic. Due to their harmful nature, heavy metals are widely considered to be one of the most dangerous environmental pollutants [5]. Heavy metals occur naturally in the environment in very small quantities and are introduced into water bodies from two main sources. A source of these elements is found naturally in the earth's crust. Weathering, erosion and volcanic activity transfer these elements into the water [6]. Although heavy metals occur only in low concentrations, they pose a significant threat due to their ability to persist in living environments and accumulate in organisms. This accumulation, which increases through the food chain, makes them particularly dangerous [7].

In a study conducted by Ansam in 2019, it was found that the Al-Khosur River has concentrations of physical and chemical characteristics that exceed the maximum permissible limits globally. This is primarily due to the disposal of untreated waste and sewage water into the river. The water of Al-Khosur River is heavily impacted by the large amounts of civil, industrial, and agricultural waste that is dumped into it, resulting in water that is significantly harder compared to the water of the Tigris river [2]. In a study conducted by Agha in 2019, the concentrations of heavy elements (Pb and Fe) in the Al-Khosur river water were examined. The study revealed that during the autumn season, the concentrations of these elements ranged from 0.022 to 0.85 mg/l and 0.75 to 95 mg/l, respectively. Interestingly, the Atomic Absorption Spectrophotometry did not detect any values of copper [8].

As a result of the river Al-Khosur's significance to Mosul, the purpose of this research is to estimate the concentration of heavy metals in water course inside the University of Mosul.

1. Materials and Methods

*2.1. Study area*

The study was conducted on the Al-Kharazi water course, which traverses the University of Mosul campus. The investigation focused on several key points along the watercourse, beginning from its source, extending under the stone bridge near the iron bridge, past Prophet Yunus's vicinity near the Suez bridge, and continuing downstream every 100 meters or more until the mouth of the watercourse. Additional sampling was performed near the Muthanna bridge and the Khosr bridge, encompassing a diverse range of urban aquatic environments within the university's vicinity.

*2.2. Sample collection*

Water samples were gathered from five stations in the study area during the four seasons of 2022 and 2023. Plastic bottles (polyethylene) with a capacity of 3 liters per sample were used to collect water samples. Prior to sampling, the bottles underwent a thorough cleaning process using a nitric acid dilution cleaning solution. They were then rinsed twice with deionized water and carefully dried to ensure no sample contamination.

*2.3. Extraction of heavy metals from water*

Water samples were collected at each station, with a volume of 5 liters. Filter paper with a pore size of 0.45µm was used to filter the samples. The filtered water was classified as dissolved, while the retained water was categorized as particulate. The extraction of heavy metals in the dissolved phase was carried out using the method described in [9]. The method involved extracting heavy metals from the particulate phase in water. To determine the total particulate matter (PM), the filter paper was dried in an oven at 60°C for 6 hours until completely dry and then weighed. A certain weight of particulate matter (PM) weighing 0.5 gm is used for digestion. It is digested using a mixture of concentrated HCl and HNOз acids in a 1:1 ratio. After undergoing evaporation until almost completely dry, the digestion process continued with a concentrated mixture of HClO4 and HF acids in a 1:1 ratio, which were once again evaporated until nearly dry. The remaining substance was dissolved in a solution of 0.5 N HCl, and then the volume was adjusted to 25 ml using deionized water. The samples were carefully placed in 25 ml Nalgene screw cap bottles and securely sealed for analysis.

*2.4. Measuring of heavy metals*

Analysis for heavy elements which are Cu, Zn, Cd, and Pb were conducted in the laboratory. Cu and Zn were analyzed using Atomic Absorption Spectrophotometry (AAS) while Cd and Pb were analyzed with the same method at higher temperatures and all these procedures were according to the Standard Methods for Examination of Water and Wastewater. The levels of Cu, Zn, Cd and Pb were used as indicators to the types of heavy elements pollution in the watercourse. The data collection was done by evaluating the difference of the color of the water sample with the standard chart color and taking readings from instruments.

*2.5. Limits of selected heavy metals and major sources*

Heavy metals enter the body through food and cutaneous absorption from water. The average daily dose of contaminants from identified routes is used to determine exposure. Reference doses (RfD) are calculated for no carcinogens, and slope factors (SF) are derived by the USEPA Integrated Risk Information System (IRIS) database for carcinogens. Using the above facts, a study evaluated the Subarnarekha River's metal water quality, including its temporal classification, source of identification, and human health risk when ingested or absorbed through the skin. This helps determine contamination levels and prepare strategies (Table 1) [10]. The majority of heavy metals in the water come from human and natural activity. Wet and dry deposition of atmospheric salts, water-rock contact, and soil-water interaction are further natural sources of heavy metal contamination. Anthropogenic sources of water contamination include rapid urbanization and industry (Table 1) [11].

Table 1. Limits of selected heavy metals as recommended by WHO and major sources in drinking water

|  |  |  |
| --- | --- | --- |
| Heavy metal ions | WHO’s permissible limit (mg L−1) [10] | Common sources [11] |
| **Cadmium (Cd)** | 0.05 | Paints, pigments, electroplated parts, batteries, plastics, synthetic rubber, photographic and engraving process, photoconductors, and photovoltaic cells |
| **Lead (Pb)** | 0.01 | PVC pipes in sanitation, agriculture, recycled PVC lead paints, jewelry, lead batteries, lunch boxes, etc. |
| **Zinc (Zn)** | 3.00 | Soldering, cosmetics, and pigments |
| **Copper (Cu)** | 0.02 | Fertilizers, tanning, and photovoltaic cells |

*2.6. Statistical analysis*

Data was managed and analyzed using SPSS 27.0. The quantitative variables were tested for normalcy (Kolmogorov-Smirnov). Continuous variables were presented using mean ± standard deviation throughout the study.

1. Results and Discussion

*3.1. Copper (Cu)*

Our results in Table 2 revealed that varied throughout the year at the locations. During autumn sites 1, 3 and 5 showed values ranging from 0.018, to 0.021 while winter consistently had the lowest values ranging from 0.011 to 0.018 across all sites. Spring displayed values between 0.011 and 0.019 except for sites 1 and 4, which had readings. Summer recorded the least values across all sites between 0.010 and 0.014. The mean values ranged from 0.0125±0.002 at site 4 to 0.018±0.003 at site 3 indicating variations at each location studied. The differences observed in seasons and locations suggest that environmental factors, like temperature and precipitation could be influencing the recorded values.

Available evidence by Aljanabi et al. (2021) [12] observed that the levels of dissolved and particulate metals, in the Al Garaf river throughout different seasons. In autumn, the concentration of dissolved Copper varied between 0.032 ±0.06 μg/L in water. In winter, the average amount of dissolved Copper was around 0.023±0.008 μg/L in water.

In agreement with our results Al-Sarraj et al. (2019) [7], the concentration rates and sites of water in the river during the study year show that Cu concentrations from the three studied sites (0.288, 0.220, 0.061 mg/l) increase as they approach the sites, possibly due to rainwater runoff pollutants. The content drops to 0.040 mg/l in winter and spring, possibly due to rainwater entering the river and spreading water purification. The center of the site's concentration decrease may be due to river water dilution. Despite the increase in concentration, for all seasons in the city, the increase caused by treatment and without direct river discharge interacts with pollutants naturally within WHO limits before reaching 0.468 mg/l in the Bosif area in summer. According to the World Health Organization, drinking water concentrations can reach 3 mg/l and agricultural water 12 mg/l.

Table 2. Concentration of Copper (Cu) (mg/l) in water samples of Al-Khosur river

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Season | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
| **Autumn** | 0.019 | 0.015 | 0.021 | 0.015 | 0.018 |
| **Winter** | 0.011 | 0.013 | 0.018 | 0.013 | 0.017 |
| **Spring** | 0.013 | 0.014 | 0.019 | 0.011 | 0.013 |
| **Summer** | 0.010 | 0.012 | 0.014 | 0.011 | 0.013 |
| **Mean ±SD** | 0.0133 ±0.004 | 0.0135 ±0.001 | 0.0180 ± 0.003 | 0.0125 ± 0.002 | 0.0153 ± 0.003 |

SD; standard deviation

*3.2. Zinc (Zn)*

Our study revealed a range of zinc element concentrations, varying from 1.98 to 2.98 mg/l, as displayed in Table 3. The lowest value was observed during the summer at the first site, likely due to the absence of estuaries that typically contribute to higher levels of heavy metals in water. During the winter season, the three site experienced the highest value. This can be attributed to the presence of estuaries and the runoff of agricultural, industrial, and domestic waste that gets washed away by rainwater. These estuaries flow into the Al-Khosur catchment area and eventually reach the river bed [7]. The Al-Khosur River remains free from zinc pollution and falls within the acceptable range of factors that contribute to river conservation. The concentration of zinc reached its peak at 0.5 mg/L [13]. A study by Agha et al. (2022) [8] found that indicated that the zinc element concentrations varied from 0.08 to 0.49 mg/l, with the minimum value being documented during the summer at the initial location. As well as, Iwar et al. (2021) [14] reported that the zinc concentration in the waters of the Benue River was 3.628 mg/l, which falls within the limitation set by the World Health Organization (WHO). It was discovered that the Tigris River had a zinc concentration of 2.528 mg/L, which was the highest recorded. Al-Sarraj et al. (2019) [7], found that rainfall and runoff increase Zinc content, especially in winter. This shows that city, south, and middle concentrations improve river water concentration, treating non-pollutants from discharges. The annual average concentration of Zinc in river water at the studied sites ranged from 0.469 mg/l in a supervised area due to rainfall in spring to 1.961 mg/l in the Bosif area during summer and 2.528 mg/l in another area due to water evaporation due to rising temperatures. This meets World Health Organization and Iraqi natural limits.

Table 3. Concentration of Zinc (Zn) (mg/l) in water samples of Al-Khosur river

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Season | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
| **Autumn** | 2.64 | 3.54 | 2.98 | 2.25 | 2.87 |
| **Winter** | 2.32 | 2.54 | 2.54 | 2.11 | 2.21 |
| **Spring** | 2.34 | 2.87 | 2.54 | 2.32 | 2.65 |
| **Summer** | 1.98 | 1.98 | 2.87 | 2.54 | 2.87 |
| **Mean ±SD** | 2.405 ± 0.417 | 2.7325 ± 0.652 | 2.8175 ± 0.787 | 2.805 ± 0.446 | 3.424 ± 0.447 |

SD; standard deviation

*3.3. Cadmium (Cd)*

The study findings revealed that the levels of cadmium varied between (0.24-0.71) mg/l. interestingly, the lowest concentration of cadmium was observed during the summer at the first site, whereas the highest concentration was recorded during the autumn at the third site (Table 4). An explanation of the cadmium values across various sites and seasons. One possible explanation is the existence of effluent estuaries and the noticeable increase in traffic density. This increase in friction between tires and the ground may contribute to the rise in cadmium levels. The recorded values exceed the Iraqi standards for river conservation and pollution prevention, as stated in No. 25 of 1967. This regulation sets the maximum allowable concentration of cadmium in rivers at 0.1 mg/L [13].

According to a study by Abed and Jabar (2023) [13], it was found that the concentration of cadmium in Garraf River water was measured at 0.0091 μg/l.

The findings is in accordance with Agha et al. (2022) [8] revealed that the concentrations of cadmium ranged from 0.12 to 0.62 mg/l. It was observed that the lowest cadmium value occurred during the summer at the first site, while the maximum value was recorded during the autumn at the fourth site.

Based on Al-Sarraj et al. (2019) [7] observed that cadmium values in Tigris River sites throughout the research year varied from 0.006-0.001 mg/l. Mushirfa had the lowest winter and spring value at 0.001 mg/l. In July, Bosif had the highest value at 0.006 mg/l.

Table 4. Concentration of Cadmium (Cd) (mg/l) in water samples of Al-Khosur river

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Season | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
| **Autumn** | 0.049 | 0.055 | 0.071 | 0.065 | 0.058 |
| **Winter** | 0.031 | 0.053 | 0.068 | 0.053 | 0.047 |
| **Spring** | 0.033 | 0.044 | 0.069 | 0.051 | 0.043 |
| **Summer** | 0.024 | 0.032 | 0.054 | 0.051 | 0.043 |
| **Mean ±SD** | 0.0343 ± 0.0106 | 0.046 ± 0.0105 | 0.0655 ± 0.0078 | 0.055 ± 0.0067 | 0.0478 ± 0.0071 |

SD; standard deviation

*3.4. Lead (Pd)*

In the current study, the findings indicated that the concentrations of lead in the water varied between 0.07 and 0.64 mg/l, as documented in Table 5. The lowest concentration was observed in the Winter at the first site, which is located far from pollution sources. In contrast, the highest concentration occurred in the autumn at the third site due to the significant amount of pollutants discharged into the river. These values surpass the Iraqi regulations for conserving rivers and preventing water pollution, as stated in Regulation No. 25 of 1967. According to this regulation, the permissible limit for lead concentration in rivers is 0.1 mg/L [15]. A study conducted by Abed and Jabar (2023) [13], the concentration of lead in the Al-Khosur River was measured to be 0.134 mg/l. The varying amounts of lead in different regions and at different times indicate that its presence is influenced by the sources of pollution and their disparities in terms of concentrations and volumes. Our results were in line with Agha et al. (2022) [8] revealed a range of lead values in the water, varying from 0.07 to 0.64 mg/l. The findings deviated with the data reported by Al-Sarraj et al. (2019) [7], as the levels of lead in the Al-Khosur River during the autumn season varied between 0.75 and 0.95 mg/l.

Table 5. Concentration of Lead (Pb) (mg/l) in water samples of Al-Khosur river

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Season | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 |
| **Autumn** | 0.019 | 0.021 | 0.029 | 0.022 | 0.018 |
| **Winter** | 0.011 | 0.021 | 0.024 | 0.021 | 0.016 |
| **Spring** | 0.013 | 0.019 | 0.021 | 0.020 | 0.017 |
| **Summer** | 0.012 | 0.012 | 0.018 | 0.015 | 0.008 |
| **Mean ±SD** | 0.0135 ± 0.0038 | 0.0183 ± 0.0043 | 0.0230 ± 0.0047 | 0.0195 ± 0.0031 | 0.0148 ± 0.0046 |

SD; standard deviation

*3.5. Concentration of heavy metals (mg/l) in all seasons*

We described the results of the concentration of heavy elements in the water of Al-kharazi river was measured over the course of the study. The findings found the variability in seasonal fluctuations of heavy elements in both the dissolved and particulate phase. The order in which heavy water elements were found to be concentrated is as follows: Pb, > Cd, > Cu, > Zn. In autumn, there was a noticeable increase in the concentration of heavy metals compared to winter.

The study by Aljanabi et al. (2021) [12] examined the concentration of heavy elements in the water of the Al-Garraf river throughout time. The outcome demonstrated the standard deviation of the seasonal fluctuations in heavy elements in both the dissolved and particulate phases. The heavy water elements were determined to have the highest concentration in the following order: Ni, Pb, Cu, Cd. The winter season witnessed a greater elevation in the content of heavy metals compared to fall.

Table 6. Concentration of heavy metals (mg/l) in all season water samples of Al-Khosur river

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Season | Cu | ZN | Cd | Pb |
| **Autumn** | 0.0176 ± 0.002 | 2.992 ± 0.525 | 0.0596 ± 0.0086 | 0.0218 ± 0.0043 |
| **Winter** | 0.0144 ± 0.002 | 2.944 ± 0.502 | 0.0504 ± 0.0133 | 0.0186 ± 0.0051 |
| **Spring** | 0.0140 ± 0.001 | 2.744 ± 0.553 | 0.0480 ± 0.0134 | 0.0180 ± 0.0032 |
| **Summer** | 0.0124 ± 0.001 | 2.448 ± 0.448 | 0.0408 ± 0.0127 | 0.0128 ± 0.0038 |
| **Overall**  **Mean ±SD** | **0.0145 ±0.002** | **3.232 ± 0.635** | **0.0527 ± 0.0131** | **0.0178 ± 0.0051** |

SD; standard deviation

1. Conclusion

The concentrations of heavy elements in river water followed the sequence: Pb, > Cd, > Cu, > Zn., indicating that the concentrations of Lead and Cadmium in water was higher than those of. Zinc, Copper. Nonetheless, the concentrations of heavy elements in the water remain below local and global standards.

1. Recommendation
2. Ongoing qualitative monitoring of the Al-kharazi River's waters, maintaining their quality and cleanliness, is everyone's responsibility. All necessary precautions must be taken to prevent pollution in the river and protect it from all sources of pollution.
3. Coordination with the management of the Mosul Dam to release sufficient discharges to maintain good water quality.
4. Treatment at the source or centralized treatment of wastewater efficiently to allow its discharge into the river after meeting Iraqi environmental standards.
5. Large industries and commercial activities must be mandated to treat their waste at the production site before discharging it into the river.

[16], [17], [18], [19], [20]

REFERENCES

[1] T. A. Al-Tayyar and F. A. Mandel, “Limnological Study of Al-Khosur River in Mosul city,” *Journal of Resrarch of the Basic Education*, 2019.

[2] B. Ansam, A. S. Al-Hamdany, and ..., “Studying Some Physical and Chemical Properties of Al-Khosur River in Mosul city,” …, 2022, [Online]. Available: https://search.proquest.com/openview/4b34e8642f7da1f622b763b14164cc4f/1?pq-origsite=gscholar&cbl=2035897

[3] M. H. Al-Sultan and K. T. Al-Yuzbeki, “Sustainability of Al-Khosar River Water–Ninavah Governarate/Iraq,” *International Journal of Environment and Water*, 2021.

[4] N. J. A. Alrikaby, A. A. Maktoof, and ..., “Bioaccumulation of some heavy elements in different tissue of Cotugnia polycantha and two parasites (Raillietina tetragona and Streptopellia senegalensis) …,” *EurAsian Journal of …*, 2020, [Online]. Available: https://www.researchgate.net/profile/Nuha-Abed/publication/343430776\_Bioaccumulation\_of\_some\_heavy\_elements\_in\_different\_tissue\_of\_Cotugnia\_polycantha\_and\_two\_parasites\_Raillietina\_tetragona\_and\_Streptopellia\_senegalensis\_infected\_with\_birds/links/5f91b2e5299bf1b53e3d6d56/Bioaccumulation-of-some-heavy-elements-in-different-tissue-of-Cotugnia-polycantha-and-two-parasites-Raillietina-tetragona-and-Streptopellia-senegalensis-infected-with-birds.pdf

[5] M. N. Fadhel, M. F. Khattab, and H. J. Nuaimy, “Adverse impact of Al-Khoser river upon Tigris river at outfall area,” *Iraqi. J. for Earth Sci*, 2008.

[6] A. S. Oleiwi and M. Al-Dabbas, “Assessment of contamination along the Tigris River from Tharthar-Tigris canal to Azizziyah, middle of Iraq,” *Water (Basel)*, 2022, [Online]. Available: https://www.mdpi.com/2073-4441/14/8/1194

[7] E. S. Al-Sarraj, M. H. Jankeer, and S. M. Al-Rawi, “Estimation of the concentrations of some heavy metals in water and sediments of Tigris River in Mosul City,” *مجلة دراسات موصلیة, 2019‎*, [Online]. Available: https://www.mosuljournals.com/article\_159015\_0.html

[8] B. Z. K. Agha, A. A. S. Al-Hamdany, and ..., “Assessment of Pollution by Heavy Metals in the Water and Sediment of Al-Khosur River Bed,” *Pakistan Journal of …*, 2022, [Online]. Available: https://mail.pjmhsonline.com/index.php/pjmhs/article/view/2716

[9] E. W. Rice, L. Bridgewater, and ..., *Standard methods for the examination of water and wastewater*. yabesh.ir, 2012. [Online]. Available: https://yabesh.ir/wp-content/uploads/2018/02/Standard-Methods-23rd-Perv.pdf

[10] World Health Organization, *Guidelines for drinking-water quality: first addendum to the fourth edition*. apps.who.int, 2017. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/254636/9789241550017-eng.pdf

[11] P. Priti and B. Paul, “Assessment of heavy metal pollution in water resources and their impacts: A review,” *Journal of Basic and Applied Engineering Research*, 2016, [Online]. Available: https://www.academia.edu/download/104157987/JBAER\_3\_8\_671-675\_2016.pdf

[12] Z. Z. Aljanabi, A. A. Maktoof, R. J. Al-Khairalla, and ..., “Levels of some heavy elements in water, sediments and two aquatic plants in Al-Garraf river at Shatra district/southern Iraq,” *… Series: Earth and …*, 2021, doi: 10.1088/1755-1315/779/1/012055.

[13] M. M. Abed and R. A. A. Jabar, “Evaluation of some Physical and Chemical Properties of Ground Water in Alshirqat District, Salaheddin province, Iraq,” *Tikrit Journal for Agricultural Sciences*, 2023, [Online]. Available: https://www.tjas.org/index.php/tjas/article/view/378

[14] R. T. Iwar, J. T. Utsev, and M. Hassan, “Assessment of heavy metal and physico-chemical pollution loadings of River Benue water at Makurdi using water quality index (WQI) and multivariate …,” *Appl Water Sci*, 2021, doi: 10.1007/s13201-021-01456-8.

[15] S. Abdul-Kareem, “Environmental Study of Drinking Water to Some Areas of Baghdad–Side Al Karkh,” *Current Research in Microbiology and …*, 2018, [Online]. Available: https://www.researchgate.net/profile/Shaimaa-Abdul-Kareem/publication/325130863\_Environmental\_Study\_of\_Drinking\_Water\_to\_Some\_Areas\_of\_Baghdad-Side\_Al\_Karkh/links/5af9ef7b458515c00b6b52d5/Environmental-Study-of-Drinking-Water-to-Some-Areas-of-Baghdad-Side-Al-Karkh.pdf

[16] M. Rincon-Sandoval, “Evolutionary determinism and convergence associated with water-column transitions in marine fishes,” *Proc Natl Acad Sci U S A*, vol. 117, no. 52, pp. 33396–33403, 2020, doi: 10.1073/PNAS.2006511117.

[17] S. J. van de Velde, “Bistability in the redox chemistry of sediments and oceans,” *Proc Natl Acad Sci U S A*, vol. 117, no. 52, pp. 33043–33050, 2020, doi: 10.1073/PNAS.2008235117.

[18] R. Wilda, “A review: The use of mangrove for biomonitoring on aquatic environment,” *IOP Conf Ser Mater Sci Eng*, vol. 980, no. 1, 2020, doi: 10.1088/1757-899X/980/1/012083.

[19] M. Ilie, “Detection of emerging pollutants oxytetracycline and paracetamol and the potential aquatic ecological risk associated with their presence in surface waters of the Arges-Vedea, Buzau-Ialomita, Dobrogea-Litoral River Basins in Romania,” *IOP Conf Ser Earth Environ Sci*, vol. 616, no. 1, 2020, doi: 10.1088/1755-1315/616/1/012016.

[20] Z. Qiu, “Theoretical Study of Ozonation of Methylparaben and Ethylparaben in Aqueous Solution,” *Journal of Physical Chemistry A*, vol. 124, no. 52, pp. 10967–10976, 2020, doi: 10.1021/acs.jpca.0c09207.