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Water Pollution in the Tigris and Euphrates Rivers: A Comparative Review (2019-2024)

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ABSTRACT

Background: Iraqs main fresh water resources, which provide the country with drinking water, agricultural and industrial needs, are the Tigris and Euphrates rivers. However, over the last decade, they have clearly become more polluted largely because urbanization, industry, and agriculture have all expanded at an alarming rate.
Objective: This review compares the water pollutioin of Tigris river at Baghdad and Euphrates river (Al Gharaf). It covers the chemical and microbial contaminants and their public health related consequences.
Method:We performed a systematic review of studies published from 2019 to 2024. Extracted data on physicochemical parameters (pH, dissolved oxygen, total dissolved solids, and electrical conductivity), heavy metals (cadmium, lead) and microbial indicators (coliform bacteria). The approaches Water Quality Index (WQI) and Health Risk Assessment (HRA) were used to evaluate the pollution status or the possible health risk.
Results: Both rivers have substantial pollution which exceeds WHO drinking water guidelines. Cadmium was 0.012–0.018 mg/L (WHO limit: 0.003 mg/L), and lead was 0.021–0.025 mg/L limit: 0.01 mg/L). The Coliform counts were 180–210 of feces contamination in CFU/100mL. These contaminants have a long-lasting effect as studies in 2025-2026 reported for example antibiotic-resistant Escherichia coli at Euphrates [38] and a peak of cadmium accumulation of 5.4 mg/kg of other heavy metals in soils surrounding Tigris [41]. Based on Water quality Index (WQI) values, the water quality was classified as medium (65) for the Tigris, and medium-low (58) for the Euphrates. Higher organic pollution (BOD: 6.1 mg/L) and salinity (EC: 1340–1560 µS/cm) were recorded in the Euphrates, while lower dissolved oxygen (2.4–3.1 mg/L) concentrations occurred in the Tigris downstream of industrial wastewater zones.
Conclusion: These two rivers are not only highly polluted but also under threat by various actors. Urban-industrial pollution poses a significant threat to the Tigris, agricultural pollution to the Euphrates. we suggested that high concentrations of toxic heavy metals as well as contamination by microbes could cause health problems, especially for children. There is an urgent need to implement continuous monitoring, enforce environmental regulations and laws, and upgrade sewage treatment.

Keywords- Water Pollution; Tigris River; Euphrates River; Heavy Metals; Water Quality Index; Health Risk Assessment; Iraq.

I. INTRODUCTION

Rivers constitute an important freshwater resource in Iraq for drinking, agricultural production and industrial development [1]–[5]. For thousands of years, the Tigris and Euphrates rivers have formed the backbone of Iraq's water resources and nourished civilizations alongside them[6], [7].

The Tigris River flows through Central Iraq, where it provides the major supply of freshwater for drinking, agricultural/farming, and industrial uses [8]. However, during the last four decades the river has been facing increasing environmental pressure due to fast urbanisation, industrial development and unsatisfactory sewage disposal system [9]. Recent spatial studies that employed GIS and remote sensing have suggested that there is a high concentration of heavy metals in the soil along the Tigris in Baghdad with cadmium levels reaching 5.4 mg/kg, which exceeds the permissible level due to irrigation with polluted water and application of cadmium containing fertilizer [41]. The input will be then into seasons, but also years and for different sources of pollution, as physicochemical properties of the river (i.e. temperature, pH, dissolved oxygen, electrical conductivity) differs affecting mobility and toxicity of pollutants [10].

Likewise, the Euphrates River has been reported as a polluted river with high levels of both nutrients([5]) and microbial pollution, especially in highly cultivated regions (like Al Gharaf due to agricultural return flows on top of seasonal waste water discharge ([2], [7], [11]).WQI values between 42.07 and 97.14 were calculated which range the water quality for the Euphrates between poor and very poor in the vicinity of 22 monitoring stations, also depicts increased concentrations of sulfate, chloride, calcium and magnesium[38],[40]. The isolation of antibiotic-resistance Escherichia coli and Staphylococcus aureus in 90% of Euphrates water samples, together with Pseudomonas aeruginosa [38], [39], indicates excessive fecal pollution and ineffectiveness in water treatment methods.

Industrial effluents and untreated domestic wastewater, and agricultural runoff lead to a complex mixture of heavy metals, nutrients, and pathogenic microorganisms in river systems. [3], [12], [13].

Among the most dangerous pollutants in aquatic systems are heavy metals, which enter rivers through untreated municipal discharges, industrial runoff and atmospheric deposition [14]. Heavy metals are sustainable in both water and sediment matrices incapable to biodegrade, unlike organic pollutants [15]. In particular, metals such as lead, cadmium, mercury, zinc and copper, when found in water and assimilated into human bodies, will likely lead to diarrhea, nausea, and/or chronic renal impairment, hepatic dysfunction, and neurological disorders [16],[17], and [18]. Environmental heavy metal exposure has been associated with chronic kidney disease (CKD), an increasing global public health problem[19], [20].

For microbiological contamination, high levels of coliform are a marker and indicator organism for microbiological contamination, which results from lack of sewage treatment facility and discharge of untreated or partially treated waste waters to river channels [6], [21], [22]. This promotes the spread of waterborne diseases (i.e. gastrointestinal infections), especially to communities that depend on untreated river water for domestic use [23], [24]. Furthermore, the isolation of resistant bacteria in rivers of Iraq [38], [39] adds another dimension to the subsequent public health problems and challenges to the treatment of waterborne disease.

Research conducted in Baghdad has indicated higher levels of chemical and biological contaminants in the Tigris River than reference sites upstream [1], [3], [4], [25]. Likewise, research carried out on the Euphrates River in Al Gharaf have shown rising occurrences of nutrient enrichment and microbial contamination due to agriculture and seasonal wastewater discharge patterns [2], [7], [11], [38]– [40].

This review aims to compare and contrast studies on water pollution in the Tigris River at Baghdad and the Euphrates River at Al Gharaf with regard to chemical and microbial contamination and their public health implications based on relevant peer-reviewed literature published between 2019 and 2024, along with incorporation of emerging evidence from 2025–2026 studies. The specific objectives are to: 1) compare key water quality parameters between the two river systems; 2) assess pollution levels using WQI and HRA; and 3) identify priority intervention and future research areas.

II. MATERIALS AND METHODS

2.1 Study Area

Review sites Two of Iraq's major rivers represent the two sites at our focus on Iraq.

- Tigris River field site: Baghdad site, an urban-industrial polluted setting with anthropogenic environmental settings of severe urbanization/industrial practices and wastewater discharges.
- Euphrates River (Al Gharaf region): an agricultural pollution context dominated by widespread agricultural practices, agricultural return flows, and seasonal inputs of wastewater.

2.2 Search Strategy and Study Selection

A systematic literature search was conducted in March 2025 using the following electronic databases:

- Google Scholar
- Scopus
- PubMed/MEDLINE
- Iraqi Academic Scientific Journals (IASJ)
- Web of Science
- bioRxiv (for preprints)
- F1000Research
- SpringerLink
- DOAJ (Directory of Open Access Journals)

The search used variations of the following terms: Tigris River, Euphrates River, water quality, water pollution, heavy metals, cadmium, lead, coliform bacteria, antibiotic resistance, Iraq, Baghdad, and Al Gharaf. The reference lists of included manuscripts were hand searched for further manuscripts of relevance.

Inclusion criteria:
- Published between January 2019 and March 2026.
- Original articles that are peer-reviewed (or preprints from established servers)
- Published quantitative data for at least one of the endpoints
- Performed among study sites in the defined regions
- Published either in English or in Arabs (with English abstracts having adequate information)

Exclusion criteria:
- Review articles, conference abstracts, and grey literature
- Studies lacking clear methodology or quality assurance procedures
- Studies with insufficient data for extraction (e.g., only graphical presentation without numerical values)

2.3 Data Extraction

Data were extracted in a standardized form from each included study regarding:

Now, regarding the Availability of Reference Choices:
- Author(s) and Date
- Randomization of study subjects, study time points, study site.
- Type of sample (water, sediment, soil) and individual assays
- Average concentrations (standard deviations posted where possible) of key parameters
- Water Quality Index and their values and classification
- Health risk assessment results (if applicable to your county)

Target parameters included:
- **Physicochemical:** pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), electrical conductivity (EC), nitrate (NO_3^-)
- **Heavy metals:** Cadmium (Cd), Lead (Pb)
- **Microbiological:** Total coliform bacteria, antibiotic-resistant bacteria

When multiple studies reported data for the same location, mean values were calculated to ensure comparability across studies.

2.4 Water Quality Index (WQI) Classification

Water Quality Index values reported in the included studies were interpreted according to the standard classification system widely applied in Iraqi water quality research [2], [26], [27]:

WQI Range	Classification
0–25	Excellent water quality
26–50	Good water quality
51–75	Medium (moderately polluted)
76–100	Poor (heavily polluted)
>100	Unsuitable for drinking

2.5 Health Risk Assessment

Non-carcinogenic health risks associated with heavy metal exposure through water ingestion were evaluated based on the Hazard Quotient (HQ) and Hazard Index (HI) approaches described in environmental health studies [14], [17], [28]. The HQ is calculated as:

$$\mathbf{HQ = CDI / RfD}$$

Where:
- CDI = Chronic Daily Intake (mg/kg/day)
- RfD = Reference Dose (mg/kg/day)

The Hazard Index (HI) represents the sum of HQs for multiple metals. An HQ or HI value <1 indicates no significant risk of non-carcinogenic effects, while values ≥1 suggest potential adverse health effects, with risk increasing as the value increases.

Exposure assessment considered ingestion as the primary route of concern for local populations consuming untreated or inadequately treated river water.

2.6 Comparative Analysis

Comparative interpretation was based on previously published multivariate statistical results and pollution index tables for Iraqi rivers [27], [29]. Any difference between locations that was statistically significant was noted where that information was available from the original study.

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III. RESULTS

3.1 Study Characteristics

This review included a total of 41 peer-reviewed studies (publications) with an acceptance period between 2019 and 2026 and selected according to predefined inclusion criteria. These were 23 Tigris River studies (mainly within the regions of Baghdad and Mosul) and 18 from the Euphrates River (including studies from Al Gharaf, Al Najaf, Al Hilla, and the western-southern regions). The studies used a variety of analytical techniques such as atomic absorption spectrometry(AAS), inductively coupled plasma mass spectrometry (ICP-MS), standard microbiological methods, and GIS-based spatial analysis.

3.2 Comparative Water Quality Parameters

Table 1 summarizes the key water quality parameters for the Tigris River (Baghdad region) and Euphrates River (Al Gharaf region) based on the reviewed studies.

Table 1. Comparative water quality parameters of Tigris River (Baghdad) and Euphrates River (Al Gharaf)

Parameter	Tigris River (Baghdad)	Euphrates River (Al Gharaf)	WHO Guideline [30]	Risk Level	References
Physical/Chemical					
pH	7.65–7.93	7.6–8.3	6.5–8.5	Safe range	[18], [19], [21]
Dissolved Oxygen (mg/L)	2.4–3.1	5.0–8.4	>5 (for aquatic life)	**Low in Tigris**	[1], [2]
BOD (mg/L)	4.5	6.1	<3 (unpolluted)	Moderate–High	[21], [25], [12]
TDS (mg/L)	455–770	600–1100	1000	Moderate–High	[1], [2]
EC (µS/cm)	877–1192	1340–1560	1200 (salinity indicator)	**High in Euphrates**	[1], [2]
Nitrate (mg/L)	1.2–4.8	3.5–6.0	50 (drinking); >3 (pollution indicator)	Moderate	[2], [6], [11]
Heavy Metals					
Cadmium (mg/L)	0.012	0.018	0.003	**High (both rivers)**	[18], [23], [31]
Lead (mg/L)	0.021	0.025	0.01	**High (both rivers)**	[18], [23], [14]
Microbiological					
Coliform (CFU/100mL)	180	210	0 (for drinking)	**High (both rivers)**	[24], [9], [20]
Antibiotic-resistant bacteria	Not systematically reported	Detected (E. coli, S. aureus, P. aeruginosa)	—	**Emerging concern**	[38], [39]
Water Quality Index	65 (Medium)	58 (Medium-Low)	—	Moderate Pollution	[19], [17], [26]

BOD: Biochemical Oxygen Demand; TDS: Total Dissolved Solids; EC: Electrical Conductivity; CFU: Colony Forming Units; WQI: Water Quality Index

3.3 Heavy Metal Contamination

Cadmium and lead concentrations of both rivers exceeded WHO drinking water guideline more than about 3–38 times of WHO drinking water guideline (0.003 mg/L for Cd; 0.01 mg/L, Pb) throughout the studies reviewed. Concentrations of both metals (Cd: 0.018 mg/L; Pb: 0.025 mg/L) were somewhat higher on the Euphrates at Al Gharaf than on the Tigris at Baghdad (Cd: 0.012 mg/L; Pb: 0.021 mg/L).

Recent studies have shown that the contamination levels are spatially varied depending on their distance from the urban discharge sites [13] and industrial sites [17], [24], [25]. The comparatively high concentrations of heavy metals that were found in sediments at the lower reaches of Tigris River in Baghdad based on a study of 2023 were discussed to be a result of the continuous accumulation of pollutants as it is observed to be 8–139 times higher than the upper reaches [13], [19]. In the same manner, seasonal monitoring in the Euphrates basin detected high metal concentrations in low-flow seasons, especially in summer months when dilution capacity decreases, resulting in pollutants being concentrated [8], [11], [32].

Important recent spatial analysis based on GIS and remote sensing methods showed that cadmium accumulates in and around Iraqi soils and soil near the Tigris river in Baghdad ranged from a concentration of 3.55 to 5.4 mg/kg [41] which are levels far exceeded permissible limits. The soil contamination is due to the perennial irrigation with polluted river water and use of fertilizers containing cadmium, this partial pollution source can be remobilized into the river during floods or irrigation return flows.

3.4 Organic and Microbial Pollution

The two rivers had BOD values that ranged from moderate to high in organic pollution, with a higher level of pollution in the Euphrates (6.1 mg/L) than the Tigris (4.5 mg/L). Both of these values are higher than the 3 mg/L that is associated with unpolluted waters.

The fecal coliform (FC) concentrations were 180 CFU/100mL in the Tigris and 210 CFU/100mL in the Euphrates which indicated high fecal contaminations. WHO guidelines reported that any isolation of coliforms from drinking water is unsafe, which indicates a public health risk for any community that uses river water without treatment.

There are more recent studies from 2025–2026 that have also reported river water contamination with antibiotic resistant bacteria in the Euphrates River. Altameemi et al. In hydrological enrichment, workers such as [38] reported the detection of antibiotic-resistant Escherichia coli strains in water samples from the Euphrates, indicating both severe fecal contamination and the dissemination of antimicrobial resistance in the aquatic environment. Kenoosh et al. Results from [39] showed the presence of E. coli and Staphylococcus aureus in 90% of Euphrates samples tested, as well as Pseudomonas aeruginosa, leading when combined with their own interpretation of the results to the conclusion that current water treatment approaches are not capable of removing such pathogens effectively. These results, echoing others to date, suggest another route for transmission of antibiotic resistant infections — that of the water supply.

3.5 Physicochemical Parameters

Dissolved oxygen concentrations on the Tigris River (2.4–3.1 mg/L) were alarmingly low in the Baghdad area, and particularly so adjacent to industrial outflow areas. Stress aquatic organisms and indicate low water quality when under 5 mg/L In comparison, DO concentrations in the Euphrates at Al Gharaf were always above the critical threshold (5.0–8.4 mg/L). The electrical conductivity measured for salinities was higher values of the Euphrates (1340–1560 µS/cm) than that of the Tigris (877–1192 µS/cm) the values of Euphartes has exceeded 1200 µS/cm level salinity threshold. It probably relates to agricultural return flows and lower evaporation upstream in the Euphrates basin.

These trends were corroborated from a detailed hydrochemical survey of the Euphrates River at 22 monitoring stations from western to southern Iraq [40] where the WQI ranged from 42.07 (poor) to 97.14 (very poor), with high concentrations of sulfates, chlorides, calcium, and magnesium over the entire river system.

3.6 Water Quality Index Classification

From the combined studies, the average Water Quality Index for the Tigris River at Baghdad was 65—in the "Medium" (moderately polluted) class. For example, the WQI at Al Gharaf was slightly less (58) from the Euphrates River and it found in "Medium-Low" classification. These categories corroborated, as expected, with the high contaminant concentrations detected previously (Jiang et al., 2023) confirming that both river systems are moderately polluted. the final Euphrates assessment, Ahmed et al. Contrasted with other studies which found the lowest WQI (i.e., 42.07–97.14) at other locations on the river [40], the urban location of the Al Gharaf is suggestive of somewhat intermediate polluted water compared with less affected sites downstream.

3.7 Health Risk Assessment

The review of some studies that reported health risk modeling [14], [17], [28] identified that no-carcinogenic health risk due to consumption of river water by resident populations was associated with cadmium and lead. Children (greater intake-to-body-weight ratios) were more vulnerable. For individual metals in some studies, hazard quotient (HQ) values were approximately equal to or >1, including cadmium, suggesting potential adverse public health effects following continuous exposure over time.

This also poses an additional health risk as compared to pathogens from other non-contaminated reservoirs, the pathogens can be resistant to common antibiotics used to treat water contact or ingestion related infections, resulting in protracted illness, higher treatment costs, and greater risk of death during illness [38], [39].

IV. DISCUSSION

4.1 Pollution Sources and Patterns

Results confirm that both rivers are highly anthropogenically affected, but the primary sources of pollution differ between the two systems. Industrial discharge, urban runoff and untreated municipal wastewater are the main pollutants entering the Tigris river in Baghdad [3], [13], [24], [28]. Baghdad, the largest city in Iraq, contributes large quantities of untreated industrial and household effluents that are discharged to the river. Heavy metals, among other industrial pollutants, are found widely in water and sediments, increasing environmental and human health risks [13], [19], [28]. Low dissolved oxygen concentrations in the Tigris (2.4–3.1 mg/L) correspond to organic enrichment from municipal wastewater and industrial effluents that utilizing oxygen during decomposition. Another pathway of pollution is illustrated by the recent record of soils polluted by cadmium in the adjacent area to the Tigris [41] — water polluted with metals has been used for irrigation transferring metals from the river to agricultural soils that can hold them and migrate back to the river by surface runoff or leaching.

On the other hand, water quality may be impaired in the Euphrates River at Al Gharaf due to the discharges associated with agricultural return flows and seasonal wastewater [7], [8], [11], [22], [32]. Al Gharaf is in an area under intensive cultivation including fertilizer and pesticide applications. The runoff associated with these nutrient loading and pesticides residues reduce water quality and enhance microbial growth [11], [22]. The greater salinity (specific electrical conductivity) of the Euphrates indicates the net impact of irrigation return flows that concentrate dissolved salts. As Ahmed et al. The increase in salinity and concentrations of major ions found along the Euphrates' course indicates cumulative effects of agricultural input and restricted dilution [40].

4.2 Heavy Metal Contamination: Sources and Health Implications

The observed levels of Cadmium and lead in all studies have consistently exceeded WHO guideline limits for drinking [15], [17], thereby rearing major concerns on chronic exposure of riparian communities [11], [19]; 3 out of the reviewed studies. According to its toxicity, persistence and bioaccumulation, these two metals are classified as a priority hazardous substance [15], [33].

Cadmium: Enters aquatic systems due to industrial disposal (electroplating, battery manufacturing, pigment production), phosphate fertilizers ornamentation, atmospheric deposition [14], [34]. Iraq was identified as one of the most polluted countries in the world, due to the two main sources of cadmium pollution in the country, namely the poor treatment of industrial effluent on one side, and the historical improper use of phosphate fertilizers in agriculture on the other side. Sultan and Al-Obaidi [41] reported values between 3.55 and 5.4 mg Cd/kg soil in the soil and to a large extent, the transferred metallic cadmium from the industrial and urban discharges via Tigris towards agricultural land in which these land feed through irrigation from Tigris river; thus, all the contamination above remain existent in the long term [41]. Renal tubular dysfunction, bone demineralization, and increased risk of cancer death are associated with chronic cadmium exposure [16], [35].

Lead: Major sources of lead include industrial emissions, as well as urban runoff, particularly from cities with older plumbing infrastructure containing lead pipe and solder, and atmospheric deposition from motor vehicle exhaust (in recent decades) [14], [34]. Lead exposure in Baghdad's densely populated, dry atmosphere could be from aging municipal water distribution infrastructure and other industrial processes. Lead is a systemic toxin [16], and children are especially susceptible to neurodevelopmental effects, such as decreased IQ and behavioral problems [16], [35].

Higher concentrations of metals in the Euphrates are attributed to cumulative effects of agriculture (cadmium from fertilizers) and reduced dilution capacity during low-flow periods. From the perspective that children are the population group most at risk [11], [19], [28], this leads to the conclusion that interventions to protect the health of children are warranted.

4.3 Microbial Contamination and Antibiotic Resistance: An Emerging Crisis

The elevated coliform counts reported for both rivers (180–210CFU/100mL) are consistent with poor sewage treatment infrastructure, and the direct discharge of raw or partly treated sewage [6], [12], [16], [23]. These bacteria indicate the presence of fecal contamination and the risk of enteric pathogens (bacteria [Salmonella, Shigella, pathogenic E. coli], viruses [hepatitis A, noravirus], and protozoa [Giardia, Cryptosporidium]) in water.

Bacterial pathogens like Escherichia coli, Staphylococcus aureus, and Pseudomonas aeruginosa in Euphrates River water [38], [39] possess an important multiplication of an increased public health threat [39]. Antibiotic resistance, especially emerging in environmental waters, represents one of the greatest global health threats because of its establishment of routes for community-acquired resistant infections [2,3]. Our data show that 90% of all samples tested positive for these pathogens and that the conventional water treatment methods did not remove [39], implying that communities using Euphrates water for drinking, domestic or irrigation, may be exposed to antibiotic-resistant bacteria.

Antibiotic resistance in Iraqi rivers is probably influenced by a combination of reasons:

- Release of untreated hospital wastewater containing antibiotics and resistant bacteria
- Inadequate treatment of municipal wastewater, which accumulates resistant bacteria from community sources
- Agricultural runoff containing antibiotics used in livestock production
- Environmental selection pressure resulted from heavy metals (such as cadmium and lead), which may co-select for antibiotic resistance through cross-resistance mechanisms

The co-occurrence of heavy metal contamination and antibiotic-resistant bacteria is particularly concerning, as metal exposure can maintain antibiotic resistance genes in bacterial populations even in the absence of antibiotic selective pressure [38].

4.4 Implications for Water Quality Index Classification

The WQI values (Tigris: 65, Medium; Euphrates: 58, Medium-Low) calculated in this study were associated with a summary-based assessment of overall water quality capable of conveying the adding together multiple dimensions could be depicted through this variable [1]. Of course, both rivers are in the moderate pollution band, albeit just, and require action to get them into the "Good" or "Excellent" category for real. The detailed WQI assessment of Euphrates [40] reveals that

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locations all the way downstream from Al Gharaf up to 42.07 (Poor) represents low WQI values which suggests the further water quality degradation.

The recent studies on the evaluation of water quality index for Iraqi rivers using multivariate statistical analyses responsible for WQI classification, also confirm the significance of Cadmium and Lead factors on WQI [5]. Jing et al. [17], Shamsudin et al. [21], Zhao et al. [27] among others demonstrated that these metals should be considered as a priority for pollution control action. However, antibiotic resistance is not considered in WQI approaches and therefore solves the emerging microbial threat in river water which is largely overlooked by conventional WQIs. This is a critical limitation future monitoring effort need to avoid.

4.5 Seasonal and Spatial Variability

Results: We summarized key seasonal and spatial trends from the reviewed studies. Both chemical and biological contaminants in freshwater sources exist at high concentrations during low-flow periods (typically summer months), as there is inadequate dilution of such contaminants [8], [11], [32]. This seasonal effect intensifies health risks during periods of peak demand for potable water. Particulate metals are essentially transported downstream to releasable sediment zones beyond industrial and urban areas, with distance downstream of hotspots being scaled by contaminants [13], [19]. Nevertheless, sediments may also function like a sinks and/or secondary sources of pollutants like, in unconsolidated environmental condition like pH business meetings or floods [36], that these pollutants can re-enter the aquatic phase throughout disturbance events, to be in a position to free historic contaminated components per this accretion approach.

The transboundary footprint of the pollution and associated alteration of water quality due to Tigris basin urban expansion [41] does not stop at the channel edges, but with subsequent irrigation of bordering farmland creates a river-soil continuum that has the potential for prolonging contaminant lifetime within the environmental system and human pathways of exposure.

4.6 Study Limitations

Limitations of this Review The following limitations should also be noted with respect to this review. This relies on the availability of earlier studies that differ in sampling locations, analytical methods, seasonal coverage or quality assurance procedures, making direct comparison difficult [17], [21], [27]. Secondly, the majority of the studies are oriented towards conventional pollutants (Cd, Pb, coliforms), while other emerging contaminants such as pharmaceuticals, personal care products, pesticides and microplastics were rarely addressed even though their significance for environment and health is high accuracy. It will be limited to Baghdad and Al Gharaf regions due to geographic scope of study; conditions at other locations along both rivers may differ. Fourth, studies assessed at different intervals could not measure temporal trends rigorously. Fifth, although antibiotic-resistant bacteria have been observed [38, 39], we still lack quantitative data on how abundant) and diverse are resistance genes.

4.7 Future Research Directions

Based on the findings and limitations of this review three themes will guide future research such as Priority areas for future research are:

1. Expanded monitoring programs that include emerging contaminants (penicillin, antipseudomonal penicillins, quinolones and quinolone antibiotics everywhere, glycopeptides and tetracycline residues) in both river systems, with standardized protocols to enable temporal and spatial comparisons;
2. The three issues lead naturally to a long, hard road up the slope ahead of us, long-term longitudinal studies embodied link climate variability with hydrological modeling and the use of advanced statistical techniques in order to better unravel the dynamics of pollution and anticipate future trends [27],[32],[37].
3. -Integrated risk assessment frameworks combining ecological risk assessmentwith human health risk modeling to offer a comprehensive guidance for sustainable water resource management
4. Source apportionment studies using advanced analytical and statistical equipment (e.g., positive matrix factorization, principal component analysis with absolute principal component scores) can identify the sources of pollution and their quantities
5. Health impact studies that directly determine contaminant levels in exposed populations (e.g., biomarker data) and that would provide a basis for some personal exposure levels for statistically significant changes in health events, including medicine-resistant infections.
6. Antibiotic resistance surveillance in the aquatic environment, characterization of resistance genes, mobile genetic elements, and pathogenic bacteria
7. Soil-river interaction research to understand how between river water, sediments, and irrigated soils various contaminants circulate, as well as look at long-term trends in accumulation rates
8. Effectiveness evaluation of water treatmenttechnologies and pollution control measures applicable to Iraqi conditions, incorporating assessments of their abilityto remove antibiotic-resistant bacteria

V. CONCLUSION

From 2019 to 2026, based on research published, this comparative report of water pollution in the Tigris River at Baghdad and the Euphrates River at Al Gharaf leads us to the following conclusions:

1. Both rivers are strongly affected by chemical and biological pollution. They have distinct pollution source profiles as well: in the Tigris (Baghdad) urban-industrial sources preponderate, while in the Euphrates (Al Gharaf) agricultural sources are primary [3], [7], [24], [25], [38]–[41].
2. The two rivers show consistent levels of heavy metals pollution (cadmium and lead), above the WHO freshwater concentrations standards, but with the Euphrates express slightly greater concentrations. [11], [14], [18], [19], [28] There is an clear risk of health hazards, in particular with children who are exposed continuously. Recent evidence corroborates that some cadmium present in river water is transferred to the adjacent agrosystems and establishes permanent reservoirs of contamination [41].
3. Microbial pollution as indicated by coliform bacteria denotes insufficient infrastructure for wastewater treatment and represents a significant public health hazard in terms of transmission of waterborne disease. [6], [12], [16], [23] The emergence of antibiotic-resistant bacteria (E. coli, S. aureus, P. aeruginosa) in the Euphrates River [38], [39] is thus an increasing danger with which current water treatment methods seem hopeless to cope adequately.
4. Water Quality Index classification indicates that Tigris and Euphrates rivers are classified as moderately polluted (Tigris: 65 Medium; Euphrates: 58 Medium-Low), and heavy metals are the main drivers affecting the overall quality grades [2], [17], [21], [26]. At some locations on the Euphrates, even lower water quality Standards (WQI as low as 42.07) are still accessible (WQI) [40].
5. Oxygen levels drop as an indicator of organic pollution stress on the Tigris (2.4–3.1 mg/L), while high salinity feed into Euphrates River complex water systems where it is farmed (EC >1200 µS/cm) [1], [2], [40].
6. The policy objectives of this report include strengthening wastewater treatment facilities, enforcing environmental regulations, and launching a continuing monitoring program for water quality. Evaluations would be needed to determine the efficiency of antibiotic resistance in removing compounds from sewage treatment systems.
7. Future research must address emerging contaminants including antibiotic resistance, develop standardised monitoring protocols and investigate the role that soil-surface water interactions play in spreading contamination. This will increase inter-study comparability and provide a basis for evidence-based policies [38]–[41].

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Faisal H. G. Q. Al-Amier: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing.

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DATA AVAILABILITY STATEMENT

All data analyzed in this review are available in the published articles cited in the references section.

CONFLICTS OF INTEREST

The author declares no conflicts of interest.

DECLARATION OF GENERATIVE AI USE

During the preparation of this manuscript, Chat-GPT (OpenAI) was used by the author to help with language editing, formatting, and organization of content according to journal guidelines. When you use this tool, then the author has reviewed and changed content as necessary to make sure it is fine for publication.

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