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# Towards a Sustainable Planning and Design Framework for Urban Riverfronts: Application of the Leopold Matrix to the Euphrates River in Al-Siniyah City

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## Abstract

Environmental pollution is among the most critical contemporary challenges facing human societies due to its direct and indirect impacts on human health and the sustainability of urban ecosystems, particularly riverine environments, which constitute a fundamental element in shaping cities and their functional and spatial structures. This study addresses the problem of declining environmental and urban performance of riverfronts as a result of increasing urban pressures and the insufficient integration of environmental assessment tools into planning and architectural design processes.

The study adopts a comprehensive analytical methodology, whereby the study area was divided into six environmental zones, each characterized by one or more environmental problems directly related to watercourses and their surrounding urban fabrics. These issues were subjected to integrated analysis within the framework of Strategic Environmental Assessment (SEA). The research examined the causes and impacts of environmental problems, the locations of pollution sources, their spatial extent, and the shared environmental interactions among different zones, in addition to identifying pollution levels and their effects on the environmental and urban performance of riverfronts. To achieve these objectives,


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a set of environmental assessment tools was employed, including the direct method, checklists, the Leopold Matrix, interaction matrices, and the Safir Matrix, alongside the use of Geographic Information Systems (GIS) and Google Maps to accurately identify problem locations and spatial extents. Integrating the outcomes of these analytical tools enabled the identification of the most influential environmental issues affecting the river system and adjacent urban riverfronts, particularly water pollution, water scarcity, and air quality deterioration in river-adjacent areas.

Accordingly, the study proposes a set of sustainable planning and design solutions and alternatives to mitigate these problems or reduce their impacts, thereby supporting the effective integration of environmental considerations into urban planning and architectural riverfront design in Al-Siniyah City.

**Keywords:** Leopold Matrix, Environmental Impact Assessmentand Sustainable Urban Planning, Environmental Architecture, Environmental Impacts of the Euphrates River, Direct Impacts, Water Quality, Al-Siniyah City.

## Introduction

The Euphrates River, particularly its urban reach within Al-Siniyah City, represents one of the principal water resources upon which the city depends for domestic, agricultural, and industrial uses, in addition to its pivotal role in shaping the urban environment and riverfront landscapes. However, recent years have witnessed a significant decline in water levels due to increasing water scarcity across Iraq, which has contributed to higher concentrations of pollutants within the river channel and reduced its functional efficiency, particularly in areas not served by formal drinking water networks.

Field surveys indicate the presence of approximately twenty pollution sources along the urban stretch of the river, extending from the northern to the central and southern parts of the city, especially near the wastewater treatment plant in the Khairy area, where pollution levels reach critical thresholds that adversely affect water quality and the surrounding urban environment. Consequently, residents have experienced the impacts of industrial, domestic, and medical effluents, as well as sewage discharges, resulting in significant health, environmental, and urban consequences. Within this context, environmental assessment emerges as a fundamental scientific tool for identifying the negative impacts of human activities on river systems and for guiding planning and design decisions toward the protection and sustainability of environmental resources. Accordingly, this study seeks to apply the Leopold Matrix to analyze the environmental impacts on the Euphrates River and to link its outcomes to the development of a sustainable planning and design framework for riverfronts in Al-Siniyah City, thereby enhancing integration between environmental considerations and the requirements of urban planning and architectural design.

## Research Problem

Riverfronts in Al-Siniyah City suffer from environmental and functional degradation due to unregulated urban growth, declining water quality, and weak integration between environmental considerations and the requirements of urban planning and architectural design. The research problem lies in the absence of a systematic scientific framework that links environmental impact assessment results for the river corridor to the design requirements of sustainable riverfronts.

## Research Hypothesis

Applying the Leopold Matrix to assess the environmental impacts of the Euphrates River contributes to the development of a sustainable planning and design framework that enhances the environmental and urban performance of riverfronts and strengthens their integration with the surrounding urban fabric.

## Research Aims

1. To apply the Leopold Matrix in assessing the environmental impacts of the Euphrates River in Al-Siniyah City.
2. To analyze the implications of environmental impacts on urban structure and riverfront treatments.
3. To derive sustainable planning and design determinants for riverine urban environments.
4. To develop a guiding framework for riverfront development in Iraqi cities.

## The Important of Research

- Integrating environmental assessment tools with urban planning and architectural design.
- Supporting sustainable riverfront development projects.

- Providing an applied model that can be generalized to Iraqi river cities.

## Theoretical Framework

**Environmental Impact:** is defined as the positive and negative outcomes resulting from changes in ecosystem characteristics caused by natural or anthropogenic activities. Such impacts may be harmful to humans and their settlements—particularly in urban environments—or, in some cases, beneficial to both society and nature. Environmental impacts may be immediate and direct or indirect and cumulative, requiring extended periods to manifest and influence environmental systems. While direct impacts are generally easier to measure, indirect and cumulative impacts are more difficult to quantify and are often more severe than primary impacts. Environmental impact is also defined as the degree of change occurring in an environmental component as a result of human activities over a specified period, compared to pre-activity conditions. Identifying such changes requires forecasting and prediction using appropriate environmental assessment methods to evaluate future impacts on natural and urban environmental systems (Abed, Abdul Qader et al., 2003, p. 289).

Environmental impact is further understood as actual or potential environmental changes resulting from the implementation of a specific human activity or proposal affecting both natural and human environments, including biophysical, social, and economic dimensions. Environmental Impact Assessment (EIA) aims to identify these impacts prior to final decision-making on projects or plans, estimate their magnitude, and determine measures and alternatives that reduce adverse effects or enhance positive outcomes, within the broader context of sustainable development and environmental decision-making (Environmental Impact Assessment [EIA], 2024).

**Assessment of Environmental Impacts:** is a tool for integrating environmental considerations into decision-making processes and for providing a legal and informational framework for decisions related to environmentally influential activities (Trivedi, 2009). The EIA process comprises interconnected research steps, including:

- Identifying baseline environmental conditions prior to development or change.

- Determining the scale and nature of changes and associated activities.
- Identifying potential impacts and their causes.
- Measuring these impacts and predicting future trends using appropriate methods.
- Analyzing and interpreting environmental impacts.
- Evaluating impacts and determining their spatial and temporal magnitude.
- Proposing preventive and mitigation measures to avoid or minimize adverse impacts.

The evaluation phase is considered one of the most challenging stages of environmental impact studies due to the extensive data requirements and the high level of expertise required, which are often difficult to secure in many contexts (Moushiet, 2002, p. 93).

**Leopold Matrix:**

The Leopold Matrix is one of the pioneering methods in environmental impact assessment for development and industrial projects. It was developed by Dr. Luna Leopold and colleagues to evaluate the environmental impacts of various types of development projects. The matrix's principal strength lies in its structured cause-and-effect framework, which systematically links project actions to environmental consequences. It is an open-cell matrix comprising 100 actions along the horizontal axis and 88 environmental factors along the vertical axis (Gharaibeh & Al-Farhan, 1987, pp. 441–445).

Environmental impact assessment using the Leopold Matrix requires quantifying two dimensions of impact: magnitude and importance, each measured on a numerical scale ranging from 1 to 10. In the evaluation process, the cell representing the intersection between a specific action and an environmental factor is divided diagonally, with the upper-left corner indicating magnitude and the lower-right corner indicating importance. Among the key advantages of the Leopold Matrix are:

1. Its applicability to a single environmental component against multiple activities or projects to determine their cumulative impacts on that component.

2. The ability to develop multiple matrices for different temporal stages, facilitating the prediction of future environmental degradation resulting from proposed projects.

The Leopold Matrix is also defined as a quantitative environmental impact assessment methodology that employs a two-dimensional grid linking proposed project activities with potentially affected environmental factors. It systematically identifies the severity and significance of each potential impact, enabling comprehensive characterization of both positive and negative project effects. The matrix is widely used in project evaluation and environmental planning to visualize and rank impacts by importance and can be adapted to suit project characteristics and local environmental contexts (Environmental Impact Assessment Techniques, 2024).

**Sustainable Urban Planning:** is a strategic approach aimed at developing cities and communities in a balanced manner that integrates environmental, social, and economic dimensions, thereby meeting the needs of present populations without compromising the ability of future generations to meet their own needs. It also seeks to enhance quality of life, promote efficient resource management, and reduce the negative environmental impacts of urban growth (Ajirotutu et al., 2024).

Within this context, Environmental Impact Assessment (EIA) emerges as a fundamental tool for identifying the positive and negative effects of human activities on natural and urban environments and for establishing measures to mitigate adverse impacts or enhance beneficial outcomes. The Leopold Matrix is employed in this framework to evaluate the environmental impacts of riverfront development projects, ensuring sustainable design that balances urban environments with water resources and improves residents' quality of life.

**Environmental Architecture:**

Environmental architecture concerns the design of buildings and urban communities in ways that respect natural ecosystems and minimize the negative impacts of human activities while enhancing user well-being. It aims to achieve environmental sustainability through the use of eco-friendly materials, improved energy and water efficiency, indoor climate control, enhanced air quality, and the integration of natural elements such as daylight, ventilation, and green spaces into architectural design (Kibert, 2016).

**Environmental Impacts on River Systems:**

River water is often diverted for irrigation within the river basin, while drainage return flows and excess irrigation water frequently re-enter groundwater systems or the river itself in various forms. Such return flows typically exhibit degraded chemical, organic, and biological water quality, carrying dissolved salts and agricultural residues such as fertilizers and pesticides, which contribute to river pollution and may lead to increased salinity levels within the river channel.

From a quantitative perspective, diverting water away from the natural river course affects discharge rates and flow variability, thereby altering natural flow regimes and the ecological requirements of aquatic life. When river water is diverted outside the basin, environmental impacts tend to be even more severe, as surface waters are inherently more vulnerable to pollution from solid and liquid wastes discharged into watercourses, along riverbanks, or within watersheds (Rao, 2009).

Surface water pollution has substantial adverse effects on the sustainability and density of aquatic life. Thermal pollution, in particular, negatively affects aquatic species—especially cold-blooded organisms that are unable to adapt to sudden temperature fluctuations. Thermal pollution originates from power generation plants, nuclear reactors, steel industries, oil refineries, and other facilities that discharge heated effluents into surface waters, causing significant harm to aquatic ecosystems, especially fish populations. Nevertheless, surface water utilization also plays an important positive role in supporting economic and social development in cities worldwide (Rao, 2009).

**Water Quality:**

Proper water use and management yield significant benefits to human societies. Conversely, excessive exploitation, wastage, and inadequate protection of natural water characteristics contribute to varying degrees of water quality degradation, depending on the volume used, patterns of use, treatment methods, and levels of conservation (Al-Zouka, 2000, p. 401). Water quality is assessed through its physical, chemical, and biological characteristics. Naturally, water is colorless, tasteless, and odorless; any alteration in these properties renders it unsuitable for drinking. Elevated turbidity levels in flowing waters, caused by sediment transport, also influence treatment requirements depending on seasonal variations and climatic conditions (Al-Samawi & Meti, 2003, p. 98).

Deterioration in water quality threatens global achievements in expanding access to safe drinking water. Between 1990 and 2006, more than 1.6 billion people gained access to improved water sources; however, not all of these sources are necessarily safe (UNDP, 2006, p. 72).

**Monitoring of Water Quality:**

The decline in physical, chemical, and biological water characteristics across many regions of the world, along with increasing incidences of waterborne diseases and mortality rates associated with contaminated water, has necessitated the establishment of standards for potable water quality. Table (1) presents the acceptable physical and chemical parameters for drinking water as defined by the World Health Organization (Duggal, 2000, p. 103).

Table (1): WHO Acceptable Physical and Chemical Standards for Drinking Water (mg/L) (Source: Duggal, K. N. (2000). Elements of Environmental Engineering. Chand, New Delhi, p. 103)

| No. | Parameter | Desirable Level | Maximum Permissible Level | No. | Parameter | Desirable Level | Maximum Permissible Level |
|---|---|---|---|---|---|---|---|
| 1 | Turbidity (NTU) | 5 | 10 | 14 | Copper (Cu) | 0.05 | 0.5 |
| 2 | Chloride (Cl) | 5 | 50 | 15 | Zinc (Zn) | 5 | 15 |
| 3 | Taste | Not specified | Not specified | 16 | Calcium (Ca) | 75 | 200 |
| 4 | pH | 7.0–8.5 | 6.5–9.2 | 17 | Magnesium (Mg) | 30 | 150 |
| 5 | Total Dissolved Solids (TDS) | 500 | 1500 | 18 | Phenol (Ph) | 0.001 | 0.002 |
| 6 | Chloride ($Cl^-$) | 200 | 600 | 19 | Anionic detergents | 0.02 | 1.0 |
| 7 | Sulfate ($SO_4^{2-}$) | 200 | 400 | 20 | Arsenic (As) | 0.05 | 0.05 |
| 8 | Chromium (Cr) | 0.1 | 0.1 | 21 | Cadmium (Cd) | 0.01 | 0.01 |
| 9 | Hardness (as $CaCO_3$) | 200 | 600 | 22 | Cyanide ($CN^-$) | 0.05 | 0.05 |
| 10 | Nitrate ($NO_3^-$) | 45 | 45 | 23 | Lead (Pb) | 0.1 | 0.1 |
| 11 | Fluoride ($F^-$) | 1.0 | 1.5 | 24 | Selenium (Se) | 0.01 | 0.01 |
| 12 | Iron (Fe) | 0.1 | 1.0 | 25 | Mercury (Hg) | 0.001 | 0.001 |
| 13 | Manganese (Mn) | 0.05 | 0.5 | 26 | Total pesticides | 3 | 3 |

## Previous Studies (General and Specific)

Recent years have witnessed growing scholarly interest in riverfronts and their relationship with urban environmental sustainability, as well as in the assessment of environmental impacts resulting from urban interventions from integrated perspectives combining urban planning, architectural design, and environmental analysis.

1. **Zhang, Li, & Huang (2024), "Environmental Sustainability Study of Urban Waterfront Landscapes":**

   This study focused on evaluating the sustainability of urban riverfronts using multiple methodologies, including Life Cycle Assessment (LCA), emergy analysis, carbon footprint assessment, and artificial neural networks to predict environmental performance. The research aimed to examine the capacity of riverfronts to improve air quality, mitigate urban heat island effects, and enhance integration between environmental dimensions and urban functions. The study area comprised riverfront zones in Nanjing, China, particularly newly developed urban districts adjacent to the river with mixed residential and commercial uses. The findings revealed that sustainable riverfronts could reduce urban heat island impacts by approximately 15–20% compared to conventional waterfronts, confirming that integrating environmental sustainability assessment into riverfront design represents an effective tool for supporting sustainable urban planning and improving the environmental, social, and economic performance of riverfront areas.

2. **Dewi, Suartika, & Saputra (2021), "Riverfront Development – A Public Realm, Its Adaptations, and Environmental Impacts":**

   This study provided an empirical analysis of the impacts of riverfront development as urban public realms, with particular emphasis on changes in land use and environmental conditions in waterfront areas. Using spatial mapping and GIS-based land-use analysis, the study traced land-use changes in the Sidemen area of Indonesia during a period of river-based tourism expansion. The results indicated that intensive tourism infrastructure development along the river led to significant transformations in land functions, including the decline of agricultural and ecological lands in favor of built and incompatible uses, contrary to planned development objectives. These findings underscore the importance of comprehensive environmental planning and the integration of environmental dimensions into riverfront development processes to ensure alignment with sustainable development goals and to avoid degrading land functions and natural ecosystems.

3. **Ali, Al-Kindy, & Nasar (2025), "Developing a Sustainable Urban Riverfront Landscape: Planning and Design Strategies for Al-Adhamiyah and Al-Kadhimiyah in Baghdad":**

   This study examined the riverfronts of the Tigris River in the Al-Adhamiyah and Al-Kadhimiyah districts of Baghdad through an integrated framework encompassing design, planning, and environmental strategies. The researchers employed comparative spatial analysis informed by international case studies, including the Sabarmati Riverfront Project in India and riverfront revitalization initiatives in Kansas, USA. The results revealed disparities in spatial integration and land-use performance between the two districts, with Al-Kadhimiyah demonstrating stronger integration with the urban fabric and more effective environmental and social connectivity. The study proposed the development of continuous green corridors, enhancement of river transport systems, and expansion of public open spaces as strategies to strengthen city–river integration, thereby confirming the importance of sustainable riverfront planning and design in improving urban environmental and social performance.

## Materials and Methods

The study adopts a descriptive–analytical approach to examine the environmental and urban conditions of the Euphrates River in Al-Siniyah City, alongside an applied approach through the development of a modified Leopold Matrix to analyze the environmental impacts of urban activities on the river system and to link the results to sustainable planning and design determinants for riverfronts.

### Al-Siniyah City:

Al-Siniyah City is located in Al-Diwaniyah Governorate along the banks of the Euphrates River and represents an important agricultural and economic center within the region. The city's population relies heavily on river water for drinking, irrigation, and industrial uses, rendering it highly vulnerable to the impacts of water pollution and resource scarcity. Given these environmental challenges, Al-Siniyah constitutes an appropriate case study for applying the Leopold Matrix to environmental impact assessment and for examining sustainable urban planning and environmentally responsive riverfront design. This approach seeks to achieve integration between natural and built environments while enhancing residents' quality of life.


Figure (1): Geographical Location of Al-Siniyah City, Source: Google Earth

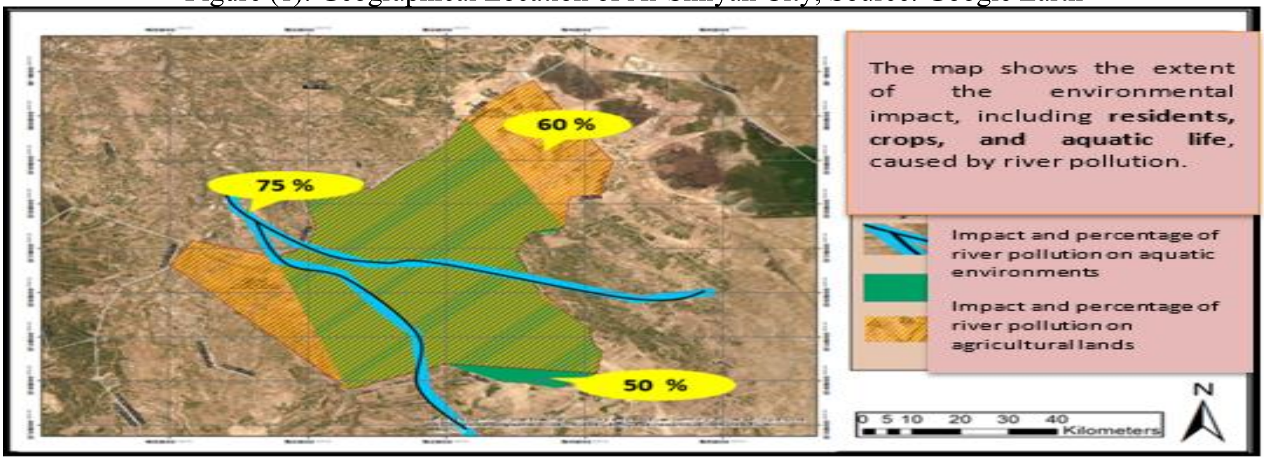


Figure (2): Relative Proportions of the Euphrates River Pollution Impact and Surrounding Areas ,Source: Prepared by the researchers

**Analysis:** As observed from the map and diagram, the greatest impact of river pollution on aquatic life is attributable to high concentrations of pollutants, which pose significant risks not only to the river itself but also to surrounding agricultural lands and local residents who utilize the water without adequate treatment.

Undoubtedly, the river and its pollutant load continue to flow toward downstream cities and regions, representing a substantial environmental hazard to the district itself as well as to adjacent areas. This highlights the urgent need for effective pollution control measures and sustainable management strategies to protect both ecological and human systems along the river corridor.

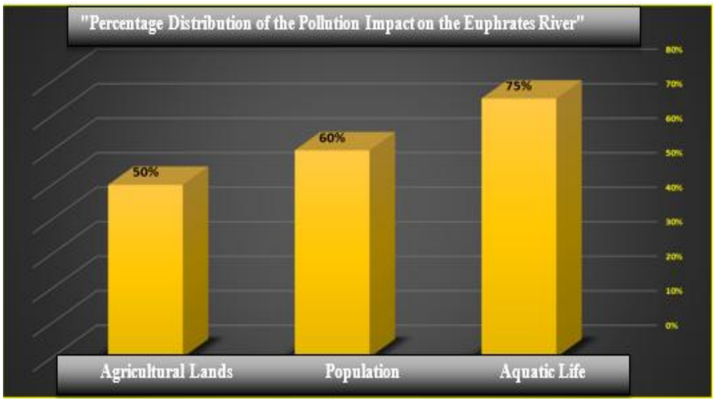


Figure (3): Percentage of the Euphrates River Pollution Impact on Aquatic Life, Local Residents, and Agricultural Lands ,Source: Prepared by the researchers

## Results

### Environmental impact Assessment of the Euphrates River Using Matrix Method (Leopold Matrix)

Table (2): Matrix Method (Leopold Matrix) Application (Source: Prepared by the researchers)

| Environmental Component | Increase in Heavy Metal Concentrations | Proliferation of Harmful Microorganisms & Insects | Acid Rain | Increase in Organic Matter | Dissolved Oxygen Decrease | Water Temperature Rise | Toxic Liquid Waste | Solid Waste | Odor & Color Changes |
|---|---|---|---|---|---|---|---|---|---|
| Water | 7<br>5 | 10<br>1 | 10<br>1 | 4<br>5 | 9<br>1 | 6<br>1 | 10<br>1 | 8<br>1 | 6<br>1 |
| Soil & Crops | 10<br>1 | – | 10<br>1 | – | – | – | 10<br>1 | 3<br>1 | 4<br>1 |
| Vegetation Cover | – | 10<br>1 | 10 | – | – | – | 7<br>1 | 8<br>1 | 10<br>1 |
| Groundwater | 10<br>1 | – | | | – | – | – | 10 | – |
| Public Health & Safety | 10<br>1 | 10 | – | | 9<br>1 | | 10<br>1 | 5<br>1 | 10<br>1 |
| Construction Noise & Scientific Techniques | 10<br>2 | 8<br>1 | – | 3<br>5 | 9<br>1 | 5<br>1 | 7<br>1 | 8<br>1 | – |
| Fishery Resources | 10<br>3 | 10<br>1 | 9<br>1 | 6<br>4 | 10<br>1 | 7<br>1 | 10<br>1 | 7<br>1 | 5<br>1 |
| Economic Activity | 7<br>1 | – | – | – | – | | 6<br>1 | 4<br>1 | 6<br>1 |
| Air Quality | | – | – | – | – | – | 8<br>1 | | 10<br>1 |
| Plants & Wildlife | 6<br>1 | – | – | – | – | – | 9<br>1 | 5<br>1 | 4<br>1 |

In order to identify the strongest interactions between environmental components and impact patterns, the magnitude of impact was multiplied by its importance for each parameter. This approach highlights the most significant environmental pressures and their relative effects on different ecological and social elements.

Table (3): Matrix Method (Leopold Matrix) – Multiplication of Magnitude and Importance
(Source: Prepared by the researchers)

| Environmental component | Increase in Heavy Metal Concentrations | Proliferation of Harmful Microorganisms & Insects | Acid Rain | Increase in Organic Matter | Dissolved Oxygen Decrease | Water Temperature Rise | Toxic Liquid Waste | Solid Waste | Odor & Color Changes |
|---|---|---|---|---|---|---|---|---|---|
| Water | 35 | 10 | 10 | 20 | 9 | 6 | 10 | 8 | 6 |
| Soil & Crops | 10 | – | 10 | – | – | – | – | 3 | 4 |
| Vegetation Cover | – | – | 10 | – | – | – | – | 8 | 10 |
| Air | – | – | 10 | 9 | – | – | – | 10 | – |
| Public Health & Safety | 10 | 10 | – | 9 | – | 10 | 5 | – | 10 |
| Construction Noise & Scientific Techniques | 20 | 8 | – | 15 | 9 | 5 | 7 | 8 | – |
| Fishery Resources | 30 | 10 | 9 | 24 | 10 | 7 | 10 | 7 | 5 |
| Economic Activity | 7 | – | – | – | – | 6 | – | 4 | 6 |
| Air Quality | – | – | – | – | – | – | – | 8 | 10 |
| Plants & Wildlife | 6 | – | – | – | – | – | – | 9 | 4 |

**Interpretation:**

From the table, it is evident that the correlation between increased heavy metal concentrations and water represents the highest intensity among all patterns. This indicates that heavy metal pollution in the river has the most significant environmental impact, particularly on aquatic ecosystems, and underscores the need for immediate mitigation measures.

Table (4): Leopold Matrix – Second Format (Environmental Impact Assessment of the Euphrates River)
(Source: Prepared by the researchers)

| No. | Parameter | Measurement | Standard Range |
|---|---|---|---|
| 1 | Turbidity (NTU) | 17 | 5–10 |
| 2 | Cadmium (Cd, mg/L) | 0.009 | 0.01–0.01 |
| 3 | Taste | Not determined | Not specified |
| 4 | pH | 7.47 | 6.5–9.2 |
| 5 | Phenol (mg/L) | 2.73 | 0.001–0.002 |
| 6 | Chloride ($Cl^-$, mg/L) | 182 | 200–600 |
| 7 | Sulfate ($SO_4^{2-}$, mg/L) | 280.17 | 200–400 |
| 8 | Dissolved Oxygen (DO, mg/L) | 4.5 | 6.5–8 (healthy) |
| 9 | Copper (Cu, mg/L) | 0.36 | 0.05–0.5 |

## Planning District Boundaries and the Euphrates River Course

| | |
|---|---|
|  |  |
| Figure (5): Turbidity, Water Color Changes, and Algal Bloom in the Euphrates RiverSource: Prepared by the researchers | Figure (4): Distribution of Solid and Liquid Pollutants Affecting Water QualitySource: Prepared by the researchers |

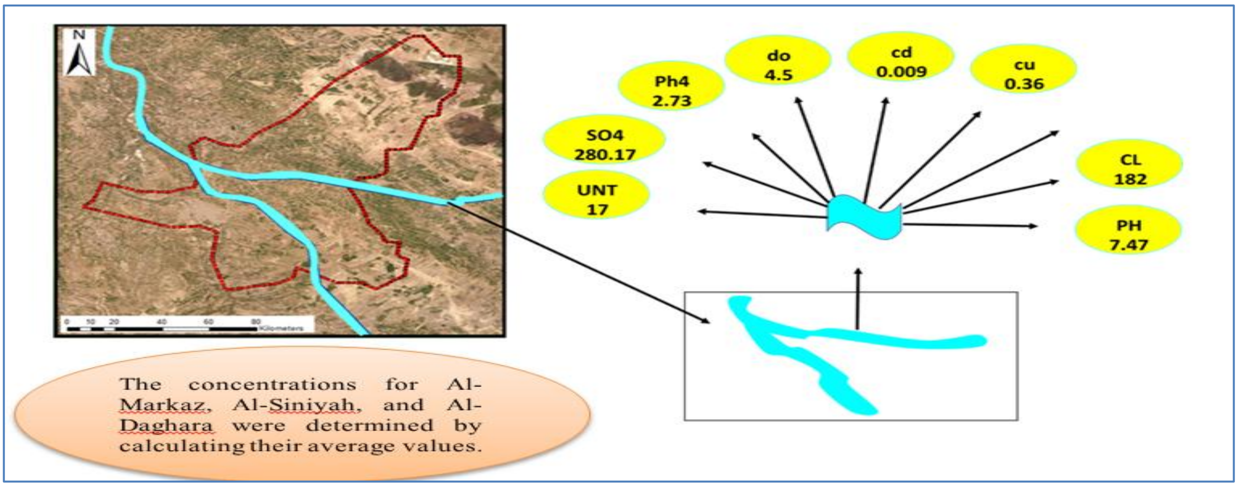


Figure (6): Boundaries of the Planning District and the Euphrates River Course, Source: Prepared by the researchers

# Discussion /Results

Table (5): Concentrations of Elements, Permissible Limits, and Impact Significance, Source: Prepared by the researchers

| Parameters<br>Parameters | Symbol<br>Symbol | Concentration<br>Symbol | Iraqi Standards<br>Iraqi Standards | Importance<br>Suggested |
|---|---|---|---|---|
| Lead | pb | 0.05 | 0.05 | - 10 |
| Copper | cu | 0.36 | 0.5 | - 6 |
| Cadmium | cd | 0.009 | 0.005 | - 10 |
| Dissolved Oxygen | do | 4.5 | 5 | + 8 |
| Chlorine | CL | 182 | 200 | - 6 |
| Hydrogen Ion (pH value) | PH | 7.47 | 8.5 | - 5 |
| Turbidity | UNT | 17 | 10 | - 4 |
| Phosphate | Ph4 | 2.73 | 1.976 | - 7 |
| Sulfates | SO4 | 280.17 | 200 | - 6 |
| Sulfates | SO4 | 280.17 | 200 | - 6 |

Table (6): Environmental Impact Assessment Using the Leopold Matrix, Source: Prepared by the researchers

| Contaminant / Environmental media | Lead (Pb) | Copper (Cu) | Calcium (Ca) | Dissolved Oxygen (DO) | Chlorine (Cl) | pH | Turbidity | Phosphate ($PO_4^{3-}$) | Sulfate ($SO_4^{2-}$) | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Water Quality | 1 / -10 | 0.72 / -6 | 1.8 / -10 | 0.9 / +8 | 0.91 / -6 | 0.88 / -5 | 1.7 / -4 | 1.4 / -7 | 1.4 / -6 | |
| | -10 | -4.32 | -18 | 7.2 | -5.46 | -4.4 | -6.8 | -9.8 | -8.4 | -59.98 |

Table (7): Classification of the Five Global Water Quality Categories

| Description | Category | Uses and Suitability |
|---|---|---|
| High Quality | 1 (0-20) | High quality water that can be used directly for drinking and for fish farming. |
| Good Quality | 2 (21-40) | Pure water of good quality but below category 1. It can be used for drinking after filtration or simple disinfection. Even lower quality waters may be used. |
| Moderate Quality | 3 (41-60) | Water containing pollutants that can be removed by advanced filtration, making it suitable for drinking (i.e., it does not contain toxic pollutants). |
| Poor Quality | 4 (61-80) | Water contaminated with one or more pollutants, such that no fish are seen at the source, or they are present in very small numbers. This water can be filtered to improve its quality for industrial use only. |
| Poor Quality | 5 (81-100) | Water clearly contaminated with several dangerous or toxic pollutants. It is impractical to utilize or filter it. It may be used for some industrial purposes after appropriate treatment. |

- After calculating the sum of the effects of each pollutant, it will be compared with the weighted average.
- We found a value of d =- 59.98
- and it falls within the category (41) - (60).
- We conclude that the water of the Euphrates River passing through the planning region has moderate quality.

Along the Euphrates Riverfront in Al-Siniyah city, derived directly from the study results. The findings indicated that the river water quality falls within the moderate category (41–60) and is affected by certain pollutants, necessitating the adoption of strategies for protecting the aquatic environment within the urban design. These strategies include:

1. **Water Quality Management:**

   The environmental protection buffer (comprising filter plants and a pollutant barrier zone) reflects the research findings regarding moderate water quality and the presence of some pollutants. This buffer reduces pollutants before they reach the river.

2. **Integration of Environmental Standards:**

   The natural water service area includes filtration ponds and water aeration systems, achieving the research recommendation to integrate aquatic environmental protection into the design.

3. **Balancing Social and Environmental Development:**

   The recreational and social area provides pathways, seating areas, and green spaces, allowing the river to be utilized for tourism and social purposes without compromising water quality.

4. **Environmental Impact Assessment:**

   Tools such as the Leopold Matrix can be applied to evaluate each element in the plan prior to implementation, ensuring that the design aligns with environmental standards and maintains river sustainability.

5. **Achieving Environmental Sustainability:**

   - Using the design framework as a tool for pre-implementation environmental impact assessment to ensure the project complies with sustainability criteria.
   - Linking urban development, social services, and aquatic environmental protection to maximize the benefits of river resources.

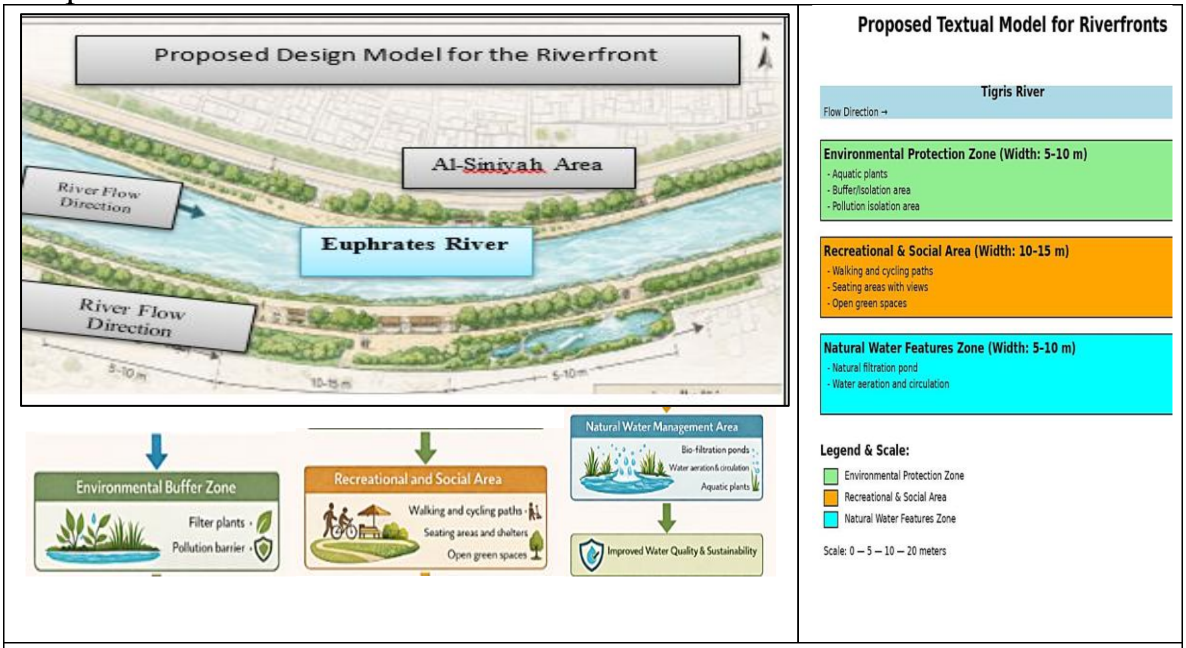


Figure (7): Proposed Design Model for the Euphrates Riverfront in Al-Siniyah Area Based on Research Findings , Source: Prepared by the researchers

## Conclusion

1. The results indicate that the total impact of pollutants on the Euphrates River in Al-Siniyah city reached d = -59.98, placing the water quality within the moderate category (41–60).
2. This moderate category reflects that the water maintains an acceptable level of environmental safety but is still affected by certain pollutants, necessitating environmental management measures in the area.
3. From the perspective of urban planning and riverfront design, these findings highlight the importance of integrating aquatic environmental protection standards into the riverfront design, such as establishing vegetated buffer zones along the riverbanks, water aeration areas, and natural filtration systems to reduce pollution impact.
4. The Leopold Matrix can be employed to assess the environmental impacts of each element within the urban design, ensuring a sustainable planning framework that balances river use for tourism and social activities with the preservation of water quality.
5. Therefore, the analysis indicates that any future riverfront design should achieve a balanced approach between urban development and aquatic environmental protection to ensure river sustainability and community benefit from water resources without increasing environmental pressure.

## Recommendations

1. Integrate water quality management into riverfront design through natural filtration systems and water aeration zones.
2. Develop vegetative buffer belts along the riverbanks as natural filters while providing recreational spaces for residents.
3. Apply environmental impact assessment tools, such as the Leopold Matrix, to evaluate urban design elements before implementation.
4. Establish regulatory policies to limit polluting activities and encourage environmentally friendly and sustainable tourism projects.
5. Conduct regular monitoring of water quality post-implementation to ensure the effectiveness of environmental measures.
6. Enhance community awareness about river protection and promote public participation in the preservation of water resources.

## References

1. Zhang, Y., Li, X., & Huang, L. (2024). Environmental sustainability study of urban waterfront landscapes based on LCA–Emergy–Carbon footprint and artificial neural network methods. Buildings, 14(2), 386. https://doi.org/10.3390/buildings14020386.
2. Dewi, L. M. R. R., Suartika, G. A. M., & Saputra, K. E. (2021). Riverfront development – A public realm, its adaptations, and environmental impacts. IOP Conference Series: Earth and Environmental Science, 903(1), 012013. https://doi.org/10.1088/1755-1315/903/1/012013.
3. Ali, N. H., Al-Kindy, S. K., & Nasar, Z. A. (2025). Developing a sustainable urban riverfront landscape: Planning and design strategies for Al-Adhamiyah and Al-Kadhimiyah in Baghdad. Acta Scientiarum Polonorum Administratio Locorum, 24(3), 335–354. https://doi.org/10.31648/aspal.11418.
4. Environmental impact assessment (EIA). (2024). In Dictionary of Toxicology. Springer. https://doi.org/10.1007/978-981-99-9283-6_861.
5. Trivedi, A. (2009). Management of environment through ages. Lucknow: International Book Distributing Co.
6. Environmental Impact Assessment Impact Assessment Techniques: From Checklists to Matrices. (2024, June 15). EVS Institute. Retrieved from https://evs.institute/environmental-impact-assessment/eia-impact-assessment-techniques-checklists-matrices/.
7. Ajirotutu, R. O., Lawoyin, J. O., Erinjogunola, F. L., & Adio, S. A. (2024). Sustainable urban planning: Principles and strategies. International Journal of Modern City Development, 5(2), 50–58. https://doi.org/10.54660/IJMFD.2024.5.2.50-58.
8. Kibert, C. J. (2016). Sustainable construction: Green building design and delivery (4th ed.). Hoboken, NJ: John Wiley & Sons.
9. Rao, P. V. (2009). Principles of environmental science and engineering (4th printing). New Delhi: PHI Learning Private Limited.
10. United Nations Development Programme (UNDP). (2006). Human development report 2006 (p. 72). Cairo: MERIC.
11. K. N. Duggal, 2000, Elements of Environmental Engineering Chand, Newdelhi, p103.
12. Al-Zouka, M. K. (2000). Environment, its degradation axes, and impacts on human health (p. 401). Alexandria: Dar Al-Maarefah Al-Jamiaiyah.
13. Al-Samawi, A. A., & Meti, L. Y. (2003). Assessment of the Tigris River water quality at water intake stations in Baghdad. Journal of Environmental Research and Sustainable Development, 6(1), 98.
14. Gharaibeh, S., & Al-Farhan, Y. (1987). Introduction to Environmental Sciences (1st ed.). Amman: Dar Al-Shorouk for Publishing and Distribution.
15. Abed, A. Q., et al. (2003). Fundamentals of Ecology (p. 289). Amman: Dar Wael for Printing and Publishing.