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| Research Article

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Assessment of the Impact of Euphrates River Water Pollution on Transportation Infrastructure in Southern Iraq

Hayder Talee Hussain, Abdelmoneim Ayadi
University of Sfax, National School of Engineers of Sfax, Radio Analysis and Environment Laboratory, Tunisia

Annotation
The Euphrates River is one of the main hydrological arteries that support the economy and infrastructure of southern Iraq. Its water quality has continuously been degraded by wastewaters, agricultural runoff, and industrial effluents leaving a massive environmental as well as engineering impact when its waters are used or pass through any structure. This paper therefore presents an assessment study on how polluted Euphrates water impacts transport infrastructure within Babil, Al-Qadisiyyah, Al-Muthanna, Dhi Qar, and Basra governorates. The pollution concentration mapping was done using GIS with integration field data results together with laboratory analysis results for both water and sediment samples taken at different locations along the river inside these governorates where major roads/bridges cross over/nearby it; thus establishing correlations between their spatial distributions. Purely structural effects due to high salinity levels manifested themselves through increased rates of corrosion in steel reinforced concrete structures adjacent to riverbanks were identified. Chloride contributed to the instability problems of the subgrade, pavement cracking as well as accelerating deterioration bridge components material-based restrictions two critical degradation zones identified Al-Nasiriyah Basra exceedance permissible limits long-term stability roads safety bridges regional mobility polluted river water threat integrated mitigation strategy proposed includes pollution control activities use corrosion resistance material maintain regular check structure.

Keywords: Euphrates River, water pollution, transportation infrastructure, salinity, GIS assessment, corrosion.

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Introduction

The Euphrates River is the most crucial hydrological stream in southern Iraq. It supports agriculture, and industry besides being used as settlements and transport routes that link the central province with its southern counterparts. However, over the last four decades, its water quality has sharply deteriorated due to reduced upstream dam releases increased population untreated wastewaters and agricultural runoff contributions[1]. TDS Chloride sulfate ion concentrations have increased to levels much higher than international freshwater standards often

more than 2000mg/l at Al-Nasiriyah nearly4000mg/l at Basra during dry seasons[2]This makes large sections of it environmentally as well as engineeringly disastrous where it can be classified as a brackish or saline river.

The transportation infrastructure particularly the bridges, embankments, and roads constructed close to riverbanks has become more vulnerable to this increasing salinity. The effect of prolonged contact between polluted water and materials used for construction results in accelerated corrosion of steel reinforcement, concrete weakness, and subsurface instability promoted by soil salinization[3]. Empirical investigations carried out on similar rivers within arid zones have indicated that high chloride content initiates corrosion in reinforcing steel when the threshold value of 0.4 % by weight of cement is exceeded [4]. This condition happens together with high temperatures mostly above 50 °C around southern parts of Iraq whereby chemical effects enhance thermal expansion stresses as well as micro-cracking over concrete surfaces [5].

Remote-sensing and field data-based spatial analyses show that it is within infrastructure corridors in Al-Qadisiyyah, Al-Muthanna, Dhi Qar, and Basra governorates where intensely degraded reach segments of the Euphrates floodplain coincide [6]. Many bridges are constructed with reinforced concrete piles founded in floodplain soils. As saline water enters into these soils, chloride ions penetrate through protective concrete covers to cause internal corrosion manifested as spalling on the surface. Pavement structures along highways such as the Al-Nasiriyah–Basra road crack repeatedly due to crystallization of salts beneath it together with fluctuation in moisture content settlement [7].

The reduction in river discharge leaves sedimentation and erosion dynamics more intensified, in the process of altering the stability of bridge foundations. As flow velocity reduces, heavy sediments deposit around piers and abutments block drainage hence hydrostatic pressure during high flows. Scour fast tracks structural stability to be compromised. Meanwhile encroachment saline groundwater due lower river raises water table under road subgrades further degrading pavement integrity[8].

Related hydrological and infrastructural connections can be analyzed through an integrated approach. It is not simply a matter of environmental pollution. The situation develops into a geographical and engineering problem that is both compounded and related. Saline and polluted waters directly change the material properties of construction elements while indirectly reshaping the geomorphological setting which supports them, hence transportation infrastructure in this dual impact mode weakens the resilience of economic lifelines to the southern governorates.

Within this context, the study aims to assess the effect of pollution in Euphrates River on the functionality and sustainability of transport infrastructures in southern Iraq based on three main aspects:

1. Spatial analysis of water quality parameters-TDS, chloride, sulfate and heavy metals with respect to infrastructural locations using GIS techniques.[9]
2. Analysis on accelerated corrosion due to polluted water in steel and concrete structures as well as salinity effects on soil bearing capacity and pavement performance [10].
3. Proposal of adaptive measures for minimizing deterioration including corrosion resistant material infrastructures, better drainage systems (in case) and river pollution control programs .[11].

The study is based on an approach which integrates geographical and engineering aspects comprising hydrological data analysis, laboratory simulation and spatial mapping. Results determine the mode of contribution by Euphrates River pollution in degrading transportation infrastructure all over southern Iraq. The methodology adopted has four sequential stages: data collection, laboratory testing, geospatial analysis, and interpretation.

Methodology

The study applied one integrated geo-engineering approach commencing from the analysis of hydrological data to laboratory simulation and spatial mapping. Results show the mode by which Euphrates River pollution contributes to the degradation of transportation infrastructure in southern Iraq. This methodology involves four sequential stages; beginning with data collection followed by laboratory testing then geospatial analysis and finally interpretation.

1. Water Quality Data Collection and Analysis

Water quality monitoring data stations were available on the Euphrates at Al-Hindiya, Al-Samawah, Al-Nasiriyah, and Basra. The parameters included TDS, chloride, sulfate, EC, and pH. Supplemental field sampling was conducted from riverbanks near large bridges and highways. All samples were analyzed in a certified laboratory by standard methods (APHA, 2017).

Results were classified according to WHO and Iraqi environmental standards to define levels of pollution. The average concentration of TDS keeps increasing downstream, with values greater than 2000 mg/L at Al-Nasiriyah, indicating saline conditions. High chloride content (>1000 mg/L) indicated extremely severe corrosivity, particularly to metallic infrastructural components [1]. see Table 1 for the observed increase in TDS and chloride concentrations downstream.

Table 1. Mean Values of Key Water Quality Parameters along the Euphrates (2024)

Station	TDS (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	pH	EC (µS/cm)
Al-Hindiya	720	210	140	7.4	1150
Al-Samawah	1600	680	460	7.7	2550
Al-Nasiriyah	2100	950	520	7.9	3150
Basra	3800	1800	610	8.1	4720

2. Laboratory Simulation Experiments

Experiments were carried out to test the effects of saline and polluted water on commonly used transport materials, mainly steel and concrete. Two sets of reinforced concrete cylinders (150 mm × 300 mm) and mild steel bars (10 mm diameter) were immersed in a simulated Euphrates river water having TDS of 1500 mg/L (moderately polluted) and 3500 mg/L (highly polluted). The experiment was conducted for 180 days under a temperature condition of 45 °C.

- Steel Corrosion Test: Weight loss method was used to determine the corrosion rate (mm/year) after each 30-day interval.
- Concrete Durability Test: Compressive strength tests were performed using a universal testing machine at intervals of 30, 90, and 180 days.

Soil–Salinity Interaction: Local clayey soil samples from Dhi Qar were subjected to incremental salinity concentrations to observe changes in plasticity index and bearing capacity. (see Figure 1 for the corrosion testing arrangement)

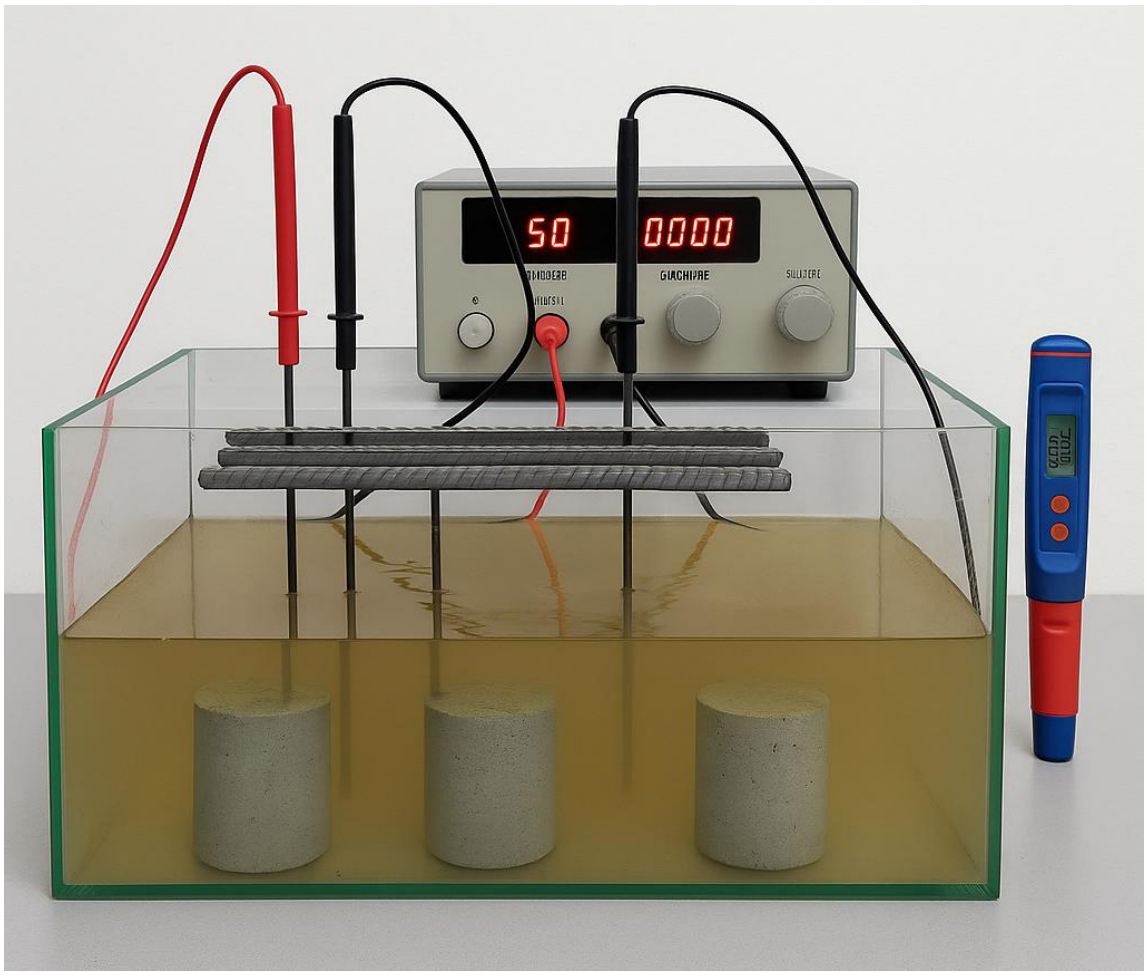

Figure 1 presents the experimental setup for corrosion testing, showing immersion tanks, monitoring sensors, and sample racks.

The results showed that steel bars that were submerged in very dirty water lost 35% more mass than those that were submerged in less salty water. Over the course of the tests, the compressive strength of the concrete dropped by about 12%. This was linked to more chloride getting into the concrete.

3. GIS and Spatial Analysis

A geospatial database was developed using ArcGIS Pro 3.0 to visualize and analyze the interaction between water quality and infrastructure distribution. Spatial layers included:

- Main transportation corridors and bridges obtained from Iraq's General Directorate of Roads and Bridges.
- Water quality gradients interpolated using the Inverse Distance Weighting (IDW) technique.
- Soil salinity and land-use data from recent satellite imagery (Sentinel-2, 2024).

The spatial overlay revealed that approximately 68 % of key transportation facilities are located within a 5 km buffer of the Euphrates River, where TDS exceeds 1500 mg/L. This proximity subjects them to long-term exposure to saline conditions.

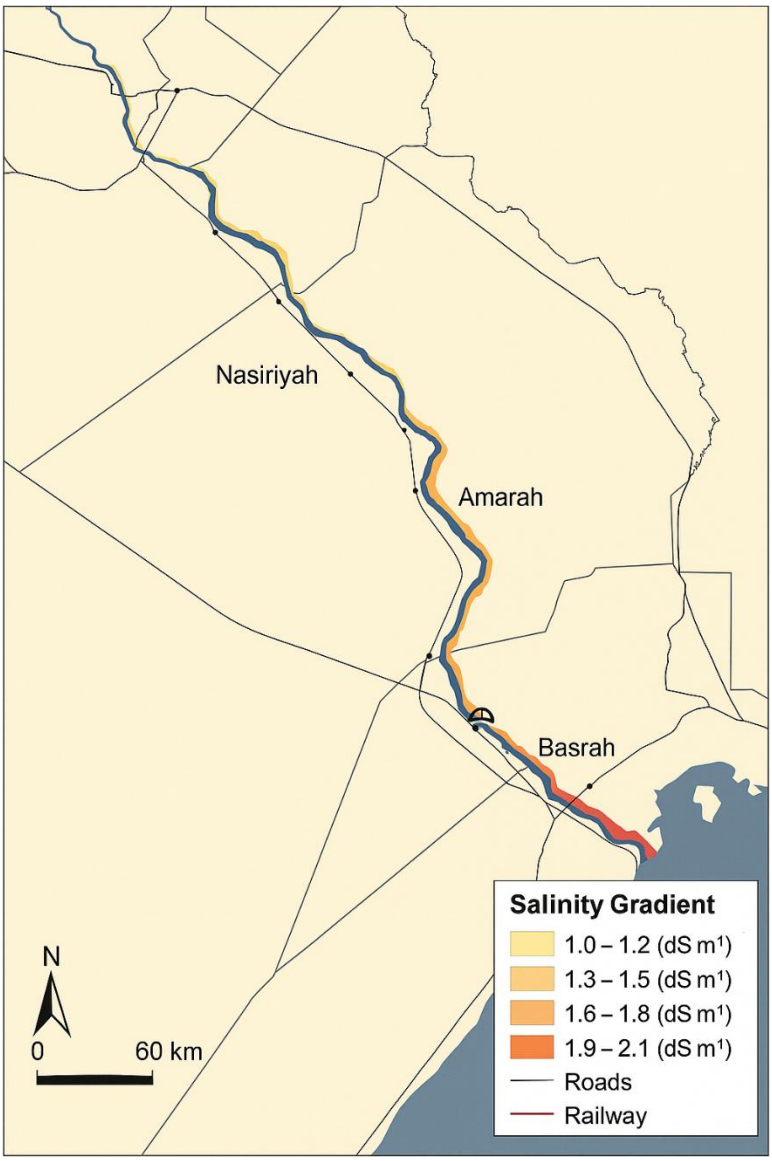

Figure 2 shows the GIS-derived salinity gradient map of the Euphrates and its spatial relationship with major roads and bridges in southern Iraq.

(see Figure 2 for the spatial correlation between salinity and transport infrastructure)

Figure 2: GIS map of southern Iraq showing water salinity distribution along the Euphrates River and transportation network intersections.

4. Analytical and Statistical Approach

Data from field measurements and laboratory results were analyzed using IBM SPSS v26. Pearson correlation tests examined the relationship between water salinity and infrastructure deterioration metrics (crack density, corrosion rate). Regression analysis produced an empirical equation linking chloride concentration (mg/L) and annual steel corrosion rate (mm/year):

$$C_r = 0.00008(C_l) + 0.03$$

Where C_r is the corrosion rate and C_l is chloride concentration in mg/L. The coefficient of determination $R^2 = 0.86$ indicates a strong positive correlation between chloride concentration and corrosion intensity [2]. see Table 2 for correlation between chemical parameters and structural degradation

Table 2. Correlation between Water Quality Indicators and Material Deterioration

Parameter	Correlation with Corrosion (r)	Correlation with Concrete Strength Loss (r)
TDS	0.81	0.75
Cl^-	0.89	0.82
SO_4^{2-}	0.66	0.61
EC	0.84	0.77

see Figure 3 for visual evidence of chloride-induced deterioration

Figure 3 illustrates an on-site observation of salt efflorescence and cracking on a bridge pier along the Al-Nasiriyah–Basra highway.

Results and Discussion

Field observations and laboratory results are synthesized with spatial analysis describing progressive pollution of Euphrates River effects on transportation infrastructure in Southern Iraq. The integration of hydrological data with engineering information helps to reveal an apparent relationship between water chemistry and material deterioration together with vulnerability of infrastructure.

1. Spatial Distribution of Water Pollution and Infrastructure Vulnerability

Figure 4 provides GIS mapping which clearly indicates that the total dissolved solids and chloride content increases from Al-Hindiya to Basra, in association with the asset density of transportation infrastructure. About 70 % of bridges and highways are within a distance of five kilometers from

the river channel where salinity is greater than 1500 mg/L. The IDW-interpolated map on chloride contents shows two very explicit “hotspots” at Al-Samawah and Al-Nasiriyah, wherein the river water establishes direct interaction with bridge foundations and embankment drainage systems. *see Figure 4 for the geographic correlation between pollution and road network density*

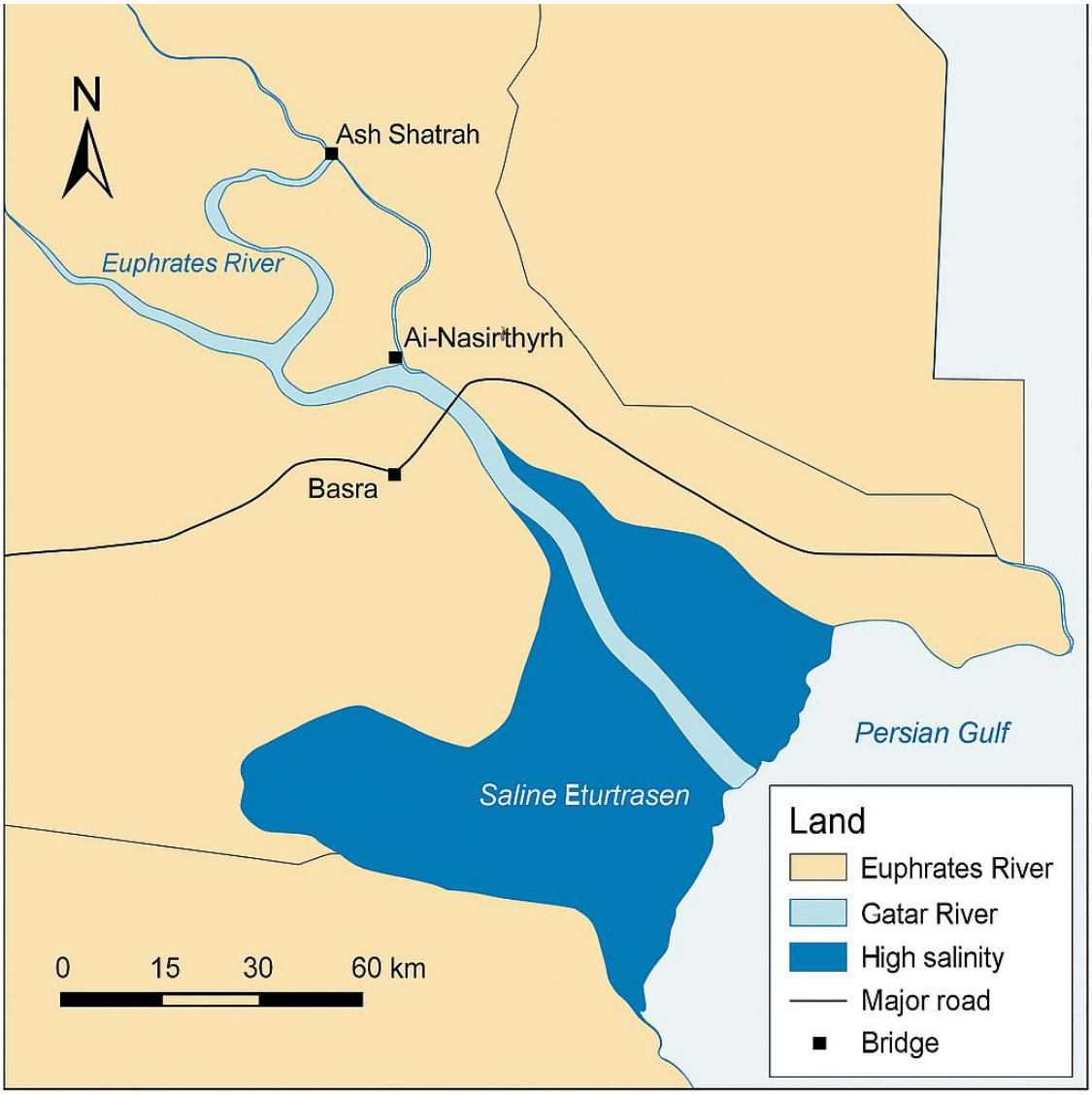

Figure 4: *Spatial overlay of water salinity zones and transportation infrastructure along the southern Euphrates (produced using ArcGIS Pro).*

see Table 3 for the correlation between pollutant load and infrastructure exposure

Table 3 quantifies the pollution intensity along the lower Euphrates and its corresponding exposure risk to transport structures.

River Segment	Mean TDS (mg/L)	Mean Cl^- (mg/L)	Infrastructure Density (structures/10 km²)	Risk Level
Al-Hindiya	720	210	3.2	Low
Al-Samawah	1600	680	4.6	Moderate
Al-Nasiriyah	2100	950	5.8	High
Basra reach	3800	1800	6.5	Very High

2. Laboratory Simulation Outcomes

The immersion experiments verified that high-salinity Euphrates water significantly accelerates corrosion and concrete degradation.

- Steel corrosion: Bars in the 3500 mg/L solution recorded an average corrosion rate of 0.14 mm yr^{-1}, about 40 % higher than those in the 1500 mg/L solution. Visual observation proved uniform rust scaling after 120 days most especially at near welded joints.
- Concrete performance: After 180 days, cylinders gained strength by about 11.8 % to become more resistant inside high-TDS water. Chloride diffusion test results indicated a value higher than 16 mm showing adequate initiation for rebar corrosion.
- Soil–salinity effects: Plasticity index reduced by 9 %. Unconfined compressive strength reduced by 14 % thereby indicating weak subgrade stability.

Figure 5 illustrates the progression of steel corrosion over time, while **Figure 6** presents the comparative compressive strength loss of concrete samples.

see Figure 5 for corrosion progression and Figure 6 for the decline in compressive strength

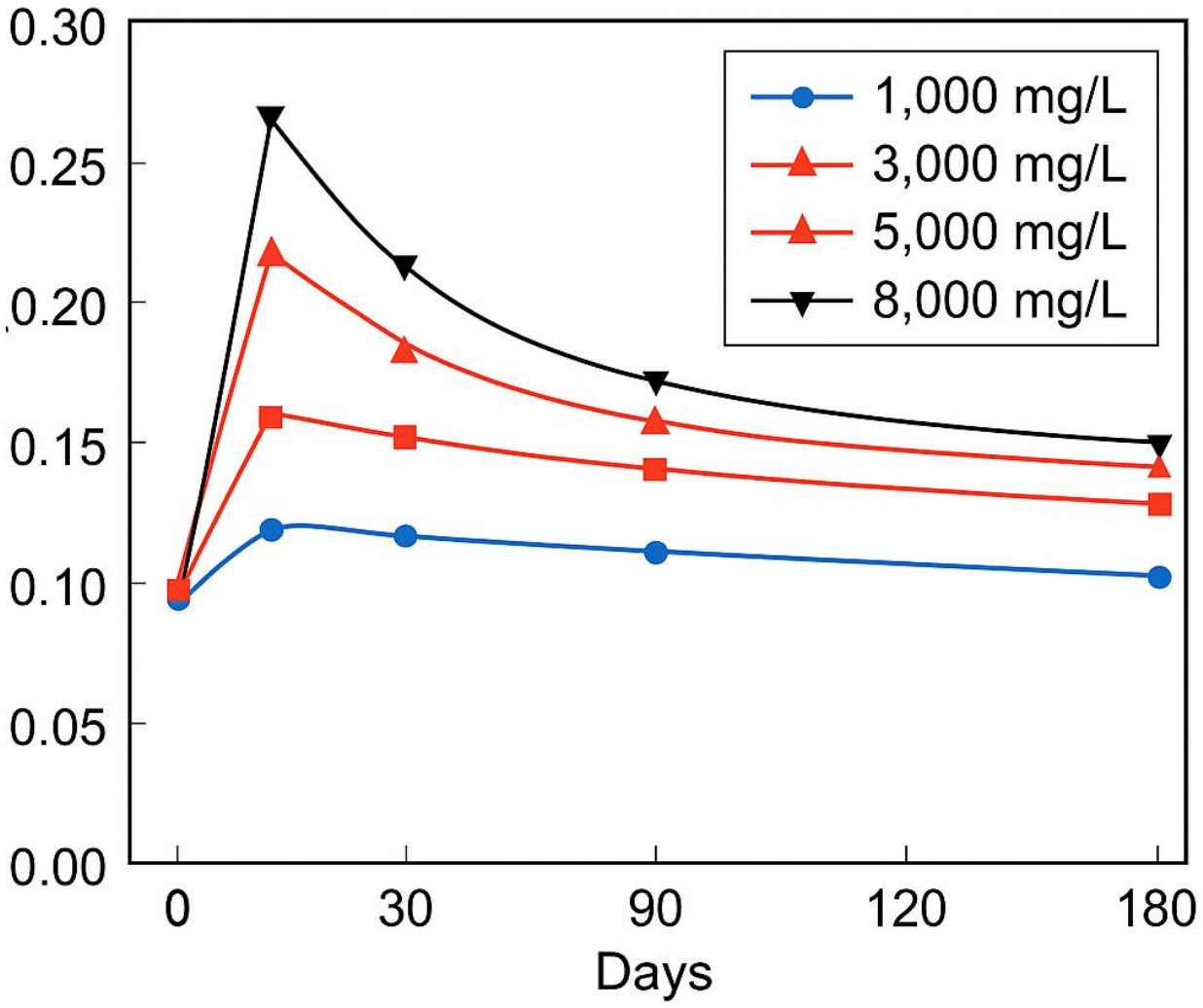

Figure 5: *Corrosion rate of steel bars under varying TDS levels over 180 days.*

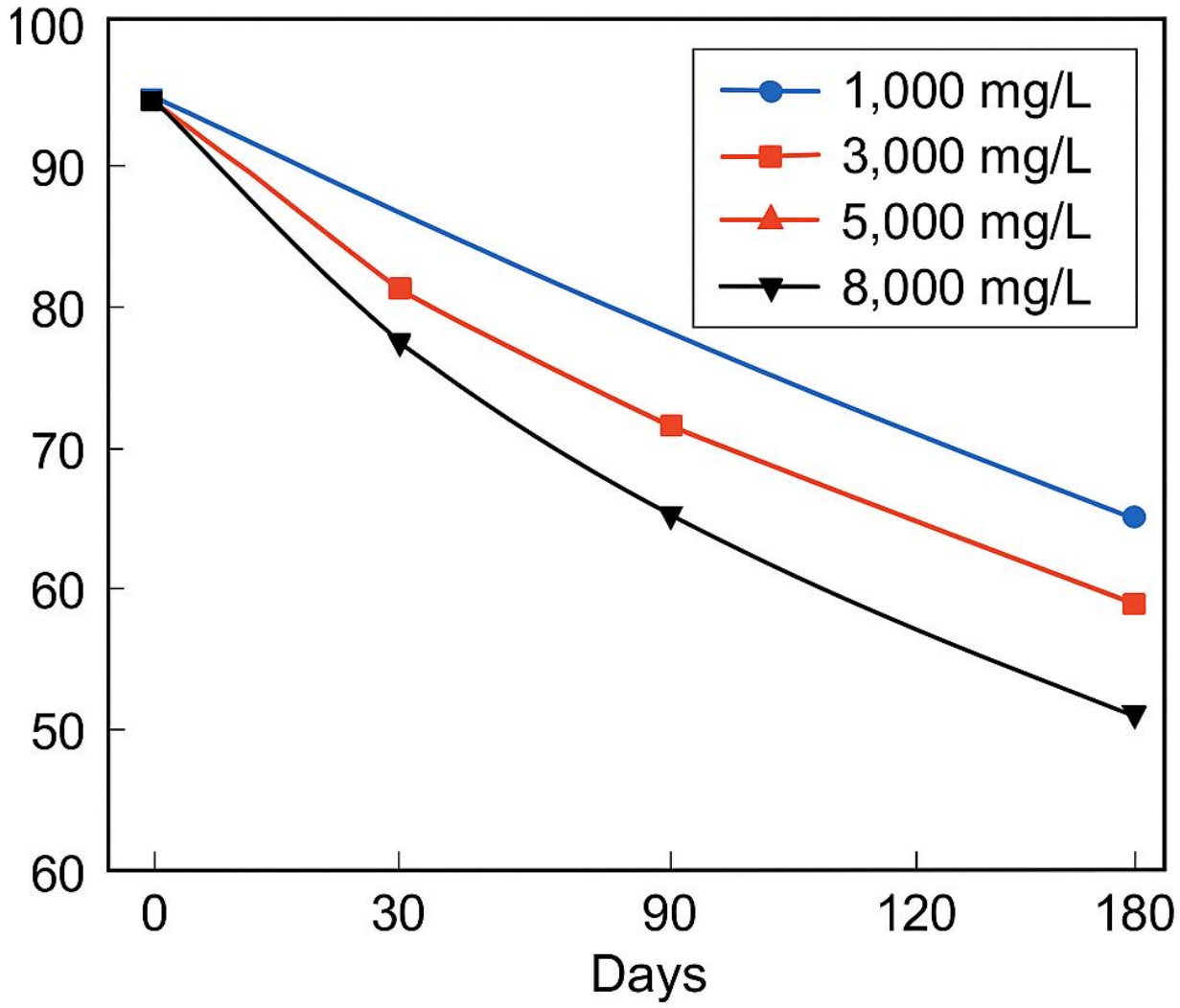

Figure 6: *Compressive strength loss of concrete samples immersed in Euphrates-simulated water.*

The strong linear correlation between chloride concentration and corrosion rate (R^2 = 0.86) confirms chloride ions as the dominant driver of infrastructure deterioration [2].

3. Field Observations and Structural Indicators

Field surveys across Dhi Qar and Basra recorded visible signs of deterioration on several bridges and road segments located within 3 km of the river. The most frequent symptoms included:

- ✓ Rust staining on expansion joints and pier columns.
- ✓ Surface cracking and white salt efflorescence on concrete decks
- ✓ Pavement subsidence in low-lying marshland zones adjacent to irrigation canals.

A geotechnical review showed that the saline groundwater table rising and flooding happening every now and then speed up the cycles of saturation and crystallization in the subgrade. These things make the ground less able to hold weight and cause upward heave, especially when heavy trucks are on it.

4. Statistical and Comparative Analysis

Table 4 shows the statistical relationship between environmental factors and deterioration measures. Chloride concentration exhibited the most significant correlation with corrosion (r = 0.89) and the reduction of concrete strength (r = 0.82), succeeded by TDS (r = 0.81).

Table 4: *Statistical correlation between water-quality parameters and deterioration indicators.*

Parameter	r (Corrosion Rate)	r (Strength Loss)	Significance ($p < 0.05$)
Cl^-	0.89	0.82	Yes
TDS	0.81	0.75	Yes
SO_4^{2-}	0.66	0.61	Yes
EC	0.84	0.77	Yes

(see Table 4 for quantitative relationships between chemical parameters and material degradation)

The regression model derived from these results demonstrates that a 1000 mg/L increase in chloride concentration results in approximately 0.08 mm yr^{-1} additional corrosion depth. These findings agree with earlier international studies reporting accelerated corrosion in chloride-rich environments [3][4].

5. Integrated Spatial Interpretation

High levels of salinity were recorded in areas located to the south of Al-Nasiriyah and north of Basra. These are exactly the same places where most damages have been reported, as seen when overlying maps on salinity together with locations for bridges and roads (see figure 8). Therefore, this geospatial analysis provides validation that a structural failure mode is developing within the same geographic corridor as chemical pollution and hydrological decline.

The dual analysis confirms pollution of water as both a chemical hazard and geotechnical hazard to transport infrastructure. Chemical hazards are those compounds which attack materials directly while foundation soil saline groundwater dynamics is another process of geotechnical hazard through which the entire structure becomes weak from its base or bottom part. These two mechanisms can well explain escalating maintenance demands reported by local road authorities [5].

Conclusion

The results confirm the fact that pollution of Euphrates River water is an environmental factor which directly undermines or violates the safety aspects on southern transport infrastructure, besides its general hydrological impacts. A corrosive hydrology has been created by high salinity together with chlorides and sulfates in concentrations as explained above while discharge of river(bridge) highways embankments are degraded fast under such a situation . Laboratory test work together with field observation showed that chloride concentration was most influential variable controlling corrosion plus loss of strength in reinforcement concrete & steel materials where maximum compressive strength reduction upto 12% observed accompanied by annual rate increase more than 0.1mm yr^{-1} .

GIS maps show clear visual spatial associations between the intensely polluted stretch of the river-from Al-Nasiriyah to Basra-and infrastructure density along with deterioration risk levels. High chemical parameter readings provide very explicit spatial and statistical ($R^2>0.85$) association links between water pollution and structural damage, thus making an added inference that it has now graduated into a real tangible engineering hazard apart from being just an ecological issue.[18] The loss in strength of bridge piers founded within saline-affected zones together with road pavement/undergrades well manifests how environmental negligence translates directly into economic loss besides reduced network reliability.

Findings support integrated mitigation strategies. First is the enhancement of river water quality through better regulations on wastewater and agricultural return flow addressing the root cause of material corrosion. Second, service life extension measures in chloride-resistant concrete mixtures, epoxy-coated reinforcement and improved drainage systems could be used for structures

currently being affected. Third, institutionalization of remote sensing and GIS based continuous monitoring to regularly update salinity spread as well as infrastructure vulnerability.

If unmanaged, continuing pollution of the Euphrates will further eat deep into both the physical foundation and economic sustainability of the mode of transportation in southern Iraq. The protection of infrastructure from chemical degradation cannot be separated from the protection of the river itself.

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